Modelling familiarity : towards age-friendly exergame design

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MODELLING FAMILIARITY: TOWARDS AGE-FRIENDLY EXERGAME DESIGN

HAO ZHANG

Interdisciplinary Graduate School

A thesis submitted to the Nanyang Technological University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy

2020

Statement of Originality

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution.

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I have reviewed the content and presentation style of this thesis and declare it is free of plagiarism and of sufficient grammatical clarity to be examined. To the best of my knowledge, the research and writing are those of the candidate except as acknowledged in the Author Attribution Statement. I confirm that the investigations were conducted in accord with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

13 Jan 2020

Date

Chng Eng Siong

Authorship Attribution Statement

This thesis contains material from 2 papers published in the following peer-reviewed journals and 1 paper accepted at conference in which I am listed as an author.

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The contributions of the co-authors are as follows:

- Prof Chunyan Miao suggested the direction of this research.
- I wrote the drafts of the manuscript. The manuscript was revised together with Dr. Qiong Wu and Prof Cyril Leung.
- I co-designed the study and applied for IRB approval with Dr Qiong Wu and Dr Zhiqi Shen. I conducted the experiment at LILY research centre. I also analyzed the data.

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The contributions of the co-authors are as follows:

- Prof Chunyan Miao provided the initial project direction.
- I prepared the manuscript drafts. The manuscript was revised by Dr Qiong Wu and Dr Xuehong Tao.
- I designed the experiment, and Dr Zhiqi Shen provided his suggestion on the experiment design.
- I conducted the study, including IRB application and participants recruiting, at LILY research centre. I also analyzed the data.

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The contributions of the co-authors are as follows:

- Dr Zhiqi Shen and Prof Yiqiang Chen suggested the direction of the project.
- I wrote the drafts of the manuscript. The manuscript was revised together with Dr Jun Lin and Prof Yuan Miao.

- I conducted the study, including IRB application and participants recruiting, at LILY research centre. I also analyzed the data.

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Abstract

Older adults are suggested to take regular exercises to prevent themselves from serious health problems and complications. Although the benefits of taking physical exercises has been highly publicized, the majority of older adults do not achieve the minimum physical activity level. For alternative methods to deliver physical activities for older adults, literature has shown that exergames, with entertaining game graphics and tasks, can make the exercise more efficient and effective. However, due to the perceived complexity and difficulty of new technologies, referred to as the digital divide, it is sometimes difficult for older adults to voluntarily take up exergames or be engaged in exergame playing. Therefore, bridging such a digital divide is necessary for improving older adults' game experience and encouraging them to take regular exercise.

In this thesis, I propose to bridge this divide by infusing familiarity design into exergames. Familiarity characterizes the relationship between a person and something that the person has had considerable experience with. It plays an important role in reducing the perceived difficulty and complexity in handling the environment, and in creating a feeling of harmony and comfort. Thus, familiarity can influence older adults' functional capability and motivation and improve the person-environment fit between older adults and exergames. To better understand familiarity, I identify five sub-constructs of familiarity, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, to shed light on multiple dimensions of familiarity. Two salient stimuli, namely *Interface* and *Task*, are identified to influence the overall familiarity levels of the exergames. Based on this familiarity model, I propose a set of familiarity design guidelines to help game designers incorporate familiarity into the exergame design for older adults. Lastly, an applicable familiarity instrument is proposed to easily evaluate the familiarity levels of exergames to each individual. Older adults and their family members can apply this instrument in selecting and playing exergames that are familiar to them. Meanwhile, game designers can use this instrument to assess whether their designed exergames are familiar to their target users.

Four studies were conducted in this thesis. Study I aims to evaluate the effectiveness of familiarity on improving older adults' ability and motivation to exergames. 44 Singaporean older adults were involved in this study to play *Ping Pong* exergame, which is infused with table tennis activities. The results show that the participants who are more familiar with table tennis exhibit higher motivation and ability in playing *Ping Pong* exergame, which indicates that familiarity can improve person-environment fit between older adults and exergames. Following the proposed familiarity design guidelines, we designed the *Escape Room* exergame. The objective of Study II is to qualitatively evaluate the familiarity design of *Escape Room* exergame. The interview results show that *Escape Room* exergame is highly familiar to the participants and all the five sub-constructs were involved in the exergame design. Study III was conducted to evaluate the proposed familiarity model. Four exergames designed with different interfaces and tasks were sequentially played by 59 participants in this study. Questionnaire and interview data about the participants' assessment of the five sub-constructs and the overall familiarity on different exergames were collected. The analysis results show a good fit of the proposed familiarity model and significant correlations between the five sub-constructs and familiarity. Moreover, there is a high positive correlation between the participants' perceived familiarity with the exergame and their satisfaction with the exergame. Study IV aims to evaluate the validity and reliability of the proposed familiarity instrument. 20 participants joined this study to play three exergames. The objective electroencephalographic data were collected in this study to evaluate the criterion-related validity of the instrument. The study results indicate satisfactory validity and reliability of the familiarity instrument. Based on all the research findings, familiarity can contribute to age-friendly exergame design and older adults' game experience can be enhanced with the help of this research.

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Acronyms

3H	Hyperglycemia, Hypertension, and Hyperlipidemia
P-E	Person-Environment
EEG	Electroencephalography
VR	Virtual Reality
HCI	Human Computer Interaction
WIMP	Window, Icons, Menus, and Pointing
HDB	Housing Development Board
fMRI	functional Magnetic Resonance Imaging
ERP	Event-Related Potentials
ERD	Event-Related Desynchronization
aMCI	amnesic Mild Cognitive Impairment
IADLs	Instrumental Activities of Daily Living
ANOVA	Analysis of Variance
SD	Standard Deviation
ANCOVA	Analysis of Covariance
KMO	Kaiser-Meyer-Olkin
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
SRMR	Standardized Root Mean Square Residual
ICA	Independent Component Analysis

Part I

Introduction and Background

Chapter 1

Introduction

1.1 Motivation and Background

The pace of aging is accelerating all over the world in the coming decades. The older adults aged 60 years and above numbered 962 million globally in 2017 and it is predicted to reach around 2.1 billion by 2050 [1]. Older adults may encounter various health-related issues as they age. Aging, a natural biological process, is related to both physically and cognitively physiological decline [2], and such decline will impair a person's life quality in normal aging. Serious health problems and complications brought about by hyperglycemia, hypertension, and hyperlipidemia (3H) have widely troubled many older adults and their families. For example, 29.1% of the adults in Singapore aged between 60 to 69 are suffered from diabetes and three-quarters of them reported having either hypertension or hyperlipidemia [3, 4]. The prevalence of 3H problems in Singapore is likely due to population aging [5]. It has been shown that regular physical exercises are effective at maintaining and enhancing the overall health of elderly individuals [6]. The World Health Organization suggests seniors aged 65 and above to take moderate-intensity physical activities at least 150 minutes per week, and they are recommended to increase the physical activities to 300 minutes per week for reducing the risk of 3H and other health benefits [7].

Despite the physical activity has been highly publicized, the majority of older adults do not achieve the minimum level of physical activities. For example, it is reported that only a quarter of seniors aged 65 and above in the UK meet the minimum

suggested physical activity level required to maintain health [6]. Moreover, older adults in Singapore are often unwilling to do regular physical activities considering their limited physical conditions [4]. Although older adults hold a positive attitude toward exercise, many of them experience physical activities as a burdensome task and lack the required knowledge and motivation [8].

Previous research has shown that rehabilitation exercises can effectively maintain and improve older adults' functional capabilities [9]. However, most rehabilitation exercises are often of little interest to older adults and the participation rate is usually quite low [10]. The alternative of traditional one-on-one nurse-guided rehabilitation treatment is very expensive and it is often inconvenient for older adults to travel to the clinics [10]. A prior study reported that only 31% of the prescribed exercises are completed, which severely affects the quality and effectiveness of such treatments [11]. It is challenging to maintain a rigorous exercise schedule for older adults and they are often reluctant to go outside due to their limited capabilities. Therefore, a potential demand is to design an indoor exercise for older adults.

For alternative modes to deliver physical activities for older adults, literature has shown that advances in technology make the exercises more efficient and effective [12]. New technology such as video games, virtual reality, and augmented reality can decrease the monotony of repeated exercises and provide instant feedback of older adults' motions, which is beneficial to both the quantity and quality of the exercises [13]. Meanwhile, indoor exercises are helpful for older adults who are either unwilling or unable to go outside [14]. Video games with motion detection devices, such as Microsoft Kinect, are able to attract older adults to follow the games by appealing and easy-to-understand interfaces and interesting tasks [15]. Therefore, a great variety of exergames (i.e., games for exercise purpose) with entertaining game graphics and tasks are proposed to deliver both physical and cognitive exercises for older adults, which are shown to be more satisfying than traditional rehabilitation exercises [12]. Various studies have shown that exergames are effective in helping older adults maintain their physical and mental capabilities [16–18].

However, exergames are not perfect yet. Despite expressing high initial enthusiasm, players tend to lose interest over time [19, 20]. Things could become less promising when coming to older adults. Due to the perceived complexity and difficulty of new technologies, referred to as the digital divide [21], it is sometimes difficult for older adults to voluntarily take up exergames or be engaged in exergame playing [22, 23].

FIGURE 1.1: P-E fit model.

One of the key reasons that make exergames unappealing is the lack of engagement and enjoyment [22]. Moreover, some of the new technologies and devices may be over-complex and difficult for older adults to use [22]. All these reasons lead to older adult's maladaptation to exergames.

To understand why maladaptation occurs, we refer to the Person-Environment (P-E) fit theory originated from the gerontology research [24]. P-E fit was first proposed by Lewin in a conceptual theory of "life space" [25]. In this theory, the effect of an object depends on a specific person in a specific time and environment. Lawton and Nahemow [24] applied Lewin's theory and proposed the P-E fit model to evaluate the adaptation of older adults to their surrounding environment. Their model indicates that the adaptation is determined by the interaction between the competence of an individual and the environment stimuli. The P-E fit model has been proven of its usefulness on adaptation assessment since Iwarsson and Isacsson applied it to home environment evaluations [26, 27]. According to this theory, a person's Behavior (B) reflects how well the Person's competence (P , personal abilities) matches the Environmental press (E , environmental stimuli and barriers): $B = f(P, E, P \times E)$ [24]. As shown in Fig. 1.1, optimal adaptation will occur only when older adults' personal competence can appropriately fit the

surrounding environment. Good adaptation will result in a feeling of comfort and enhance engagement and enjoyment [24]. However, maladaptation can occur in the following two cases: older adults with high competence in low press environments (low motivation) and older adults with low competence in high press environments (low ability).

To provide a better game experience, some exergame design guidelines for frail older players have been proposed to consider their low competence [28, 29], such as avoiding small objects and giving both visual and auditory feedback. Older adults' game motivation is relatively less considered in prior research. As older adults' maladaptation to exergames occurs when personal competence does not match the environmental press, we suggest that it can be mitigated by familiarity, which characterizes the relationship between a person and something (such as the environment) that the person has had considerable experience with [30]. Indeed, the feeling of familiarity can reduce older adults' perceived difficulty and complexity in handling the environment, and in creating a feeling of harmony and comfort [30]. Thus, considering familiarity in exergame design may help to bridge the digital divide and make exergames more attractive and engaging to older adults. On the one hand, exergame designs that can induce a feeling of familiarity with older adults may arouse positive emotions based on their past experiences and improve their motivation [31]. In a familiar environment, old adults may feel more comfortable and be more willing to improve their functional and social capabilities. On the other hand, familiarity with the exergame interfaces and tasks can help older adults recall approaches to deal with similar environments and improve their exergame playing capabilities [32]. Familiarity can evoke the older adults' past implicit and explicit memories [30], from which to recall the approaches to interact with the familiar environment [32]. Motivated by this, we propose to incorporate familiarity into exergame design to improve older adults' adaptation to exergames and improve their functional capabilities through indoor physical activities.

Familiarity is usually treated as a one-dimensional construct in previous research; it is often approximated by the frequency of encounter or evaluated using subjective assessment with a single metric [33–35]. However, viewing familiarity as a single-construct is hard to standardize. In addition, a one-dimensional approach is not insightful enough to understand familiarity or to provide meaningful design guidelines. In this thesis, we shall propose a multi-construct model to understand

familiarity. Based on this familiarity model, generalizable familiarity design guidelines should be proposed, which are helpful for game designers to design a familiar exergame for older adults and improve their engagement in exergames. A practical familiarity instrument is also needed to evaluate the familiarity levels of different exergames to older adults. The exergame designers may apply this instrument to evaluate the familiarity levels of their designed exergames to the target players, and the players can use the instrument to select and play their most familiar exergames from the game library and maximize the effectiveness of the exercises.

Finally, it's worth mentioning that the proposed familiarity model, design guidelines and instrument can also be applied to other games and intelligent interfaces designed for older adults although our studies mainly focus on exergames in this thesis.

1.2 Research Issues and Challenges

Major research issues and challenges tackled in this thesis include:

- **Older adults' game experience:** Exergames have been proved to be more attractive and effective to encourage older adults to take exercises than traditional physical activities [36, 37]. The multi-player exergames can also enhance friendships and foster social networking among the players without going outside [38]. However, due to the perceived complexity and difficulty of new technologies, it is sometimes difficult for older adults to voluntarily take up exergames or be engaged in exergame playing [23]. Meanwhile, current commercial exergames are primarily designed for younger populations for entertainment purposes without comprehensible interfaces for older adults, which make the exergames less feasible for many older adults [39, 40]. One of the main reasons as highlighted by Loos and Zonneveld [41, 42] is that such barriers are often caused by unfamiliar or even alien game interface and task designs. Hence, the first challenge in this thesis is to bridge the digital divide and design age-friendly exergames.
- **Familiarity model:** Indeed, research in gerontology has indicated that familiarity plays an important role in reducing the perceived difficulty and

complexity in navigating in the environment, and in creating a feeling of harmony and comfort [30]. Thus, understanding familiarity is important to suggest and design familiar exergames for elderly players. Familiarity has been recognized as one of the two independent memory processes (recollection and familiarity) in our brain [43]. It has been proved that the process of aging results in a negative influence on the recollection part of memory, but does not affect familiarity part [43]. Thus, the process of familiarity declines slowly with people aging compared to recollection. However, what factors have influences on familiarity and how to improve familiarity have not been discussed in the memory research. Previous research usually treats familiarity as a single-dimensional construct and the level of familiarity is often evaluated using subjective assessment with a single metric [34, 35, 44], which is not convenient to apply due to the instability and the difficulty of standardization. Therefore, a familiarity model is needed to understand familiarity and guide the development of familiarity design guidelines and instrument.

- **Familiarity design guidelines:** Since familiarity design can improve older adults' game experience, a set of applicable familiarity exergame design guidelines is helpful for exergame designers. As current familiarity research mainly focuses on the surrounding environment design for older adults, familiarity design guidelines in new technologies have seldom been proposed. Thus, a set of design guidelines based on the familiarity model should be proposed to help the game designers to develop familiar exergames for their target older adults and improve their game experience.
- **Familiarity instrument:** After designing an exergame for the target older adults, evaluating familiarity and adaptation of the designed exergame to the target users is needed. Meanwhile, because one exergame cannot be familiar to all the elderly players, evaluating various exergames' familiarity levels to an elderly individual is important to select an appropriate exergame for him/her. Familiarity is often approximated by the frequency of encounter or evaluated using subjective assessment in previous research [33, 35], which is hard to standardize. The next challenge is to provide a standardized familiarity instrument based on the familiarity model. The instrument may benefit both exergame designers and players. On the one hand, such an instrument can help game designers to evaluate whether familiarity design has been successfully incorporated into exergames. On the other hand, a

familiarity instrument can help exergame players to choose exergames that will induce a higher level of familiarity, which is especially desired for older players.

1.3 Research Scope and Contributions

Our research focuses on infusing familiarity design into exergames to improve older adults' game experience and engagement in physical activities. We summarized our research and contributions as follows.

1.3.1 Improving Older Adults' Game Experience with Familiarity

According to the P-E fit model mentioned above, an ideal design to improve older adults' adaptation should be able to expand the positive affect zone by increasing their both motivation and ability. Psychologically, familiarity represents "the relationship between an individual and something that the individual has had considerable experience with" [30]. On the one hand, familiarity will evoke older adults' past memories and make them recall the approaches to interact with the stimulus to enhance their abilities [32]. On the other hand, there will be an activating effect to arouse older adults' past feelings and enhance their motivations when encountering familiar stimuli [31].

To assess the effectiveness of familiarity design, we conducted a longitudinal study with 44 Singaporean older adults. During the experiment, the participants were invited to play *Ping Pong* exergame designed by our research centre for consecutive five weeks. The design of *Ping Pong* exergame is infused with activities in table tennis, which is one of the most common sports in Singapore¹. The participants were grouped into three categories of familiarity levels according to their prior table tennis experience. The experiment results showed a significant positive influence of familiarity on improving participants' ability and motivation in exergame play.

¹<https://www.channelnewsasia.com/news/singapore/table-tennis-gains-popularity-in-singapore-8127732>

Thus, our first study indicates that familiarity can improve older adults' game experience.

1.3.2 Modeling Familiarity with Five Sub-constructs

Familiarity is usually treated as a single-dimensional construct in previous research; it is often approximated by the frequency of encounter or evaluated using subjective assessment with a single metric [33–35]. However, viewing familiarity as a single-construct is hard to standardize. In addition, a single-dimensional approach is not insightful enough to understand familiarity or to provide meaningful design guidelines. Therefore, understanding and modeling familiarity is the second objective of our research.

In this thesis, we identified five sub-constructs of familiarity based on literature, including prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, to shed light on multiple dimensions of familiarity. We evaluated the correlations between the five sub-constructs and familiarity in a field study involving 59 Singaporean older adults. Four upper-limb exergames designed with different interfaces and tasks were played in a random sequence by each participant. Questionnaire and interview data about participants' feedback and their assessment of the five sub-constructs on different exergames were collected. The analysis results showed that the five sub-constructs can effectively model familiarity and significant correlations between the five sub-constructs and familiarity were found. Moreover, this study found a significant positive correlation between participants' perceived familiarity and their satisfaction with the exergames. The results deepen the understanding of familiarity and offer the support for an applicable familiarity evaluation instrument and design guidelines.

1.3.3 Familiarity Design Guidelines

As exergames with higher familiarity levels are more attractive to older adults, applicable familiarity design guidelines are helpful for game designers and developers. Therefore, based on the five sub-constructs and insights gained from our field studies, we proposed a set of familiarity design guidelines for developing and designing age-friendly exergames to improve older adults' game experience and satisfaction

with exergames. The design guidelines are: 1) Correspondence with the real world; 2) Evoking positive emotion; 3) Providing meaningful stimuli; 4) Selecting stimuli with high repeated exposure; 5) Considering recent experience. Based on these guidelines, we designed the *Escape Room* exergame to provide older adults familiar interfaces and tasks when playing the exergame. The qualitative study found that our participants felt familiar with the exergame and they gave positive feedback to *Escape Room* exergame.

1.3.4 Familiarity Instrument

The aforementioned studies indicate the positive influence of familiarity on older adults' adaptation and satisfaction with exergames. Thus, suggesting older adults with exergames which they are more familiar with should be more beneficial to their exercises. In this research, we propose a familiarity instrument for exergame players to evaluate their familiarity with two salient stimuli in exergames: *interface* and *task*. Interface refers to the virtual environment and context in the exergame display. Task refers to the control of objects in the virtual environment and context by the body motions of exergame players. To measure players' perceived familiarity with an exergame's interface and task, we evaluate the five sub-constructs of familiarity. The instrument consists of ten questions regarding the five sub-constructs of familiarity on exergame interfaces and tasks.

To evaluate the validity and reliability of our proposed instrument, we objectively measure users' familiarity through Electroencephalography (EEG) signal, which has been reported to be very sensitive to familiarity [45, 46]. The field study with 20 participants found a significantly positive correlation between the results of our proposed familiarity instrument and the EEG signals. These results indicate our proposed familiarity instrument is reliable and useful for evaluating the familiarity level of various exergames to different older adults.

1.4 Thesis Organization

The remainder of this thesis is organized as follows. In the rest of Part I, we provide a comprehensive literature review on the existing works that are related

to our research, including exergames for older adults (Chapter 2), P-E fit theory (Chapter 3) and research on familiarity (Chapter 4).

In Part II, we present the design and development of the familiarity model. Chapter 5 presents the framework of the P-E fit model with familiarity incorporated, identifies five sub-constructs of familiarity, and proposes two salient stimuli in exergames to influence familiarity. Chapter 6 presents the proposed familiarity design guidelines based on the five sub-constructs. Following these guidelines, we design the *Escape Room* exergame and the game is introduced in this Chapter. In Chapter 7, we further proposed an applicable familiarity instrument to assess individuals' familiarity feelings with different exergames.

Part III reports the validation studies to evaluate our proposed model. Chapter 9 presents the Study I to explore the effectiveness of familiarity design in exergames on improving older adults' game experience. Chapter 10 presents a qualitative case study to evaluate users' familiarity and satisfaction with our designed *Escape Room* exergame. Chapter 11 describes a large scale study to statistically evaluate the five sub-constructs familiarity model. Chapter 12 reports the Study IV to evaluate our proposed familiarity instrument via an EEG experiment.

Finally, we conclude the thesis in Chapter 13 and discuss several future directions.

Chapter 2

Exergames

Regular physical activities are needed for older adults to keep healthy and prevent them from health problems, including 3H [6]. In recent years, technology advances in virtual reality, augmented reality, and motion detection lead to the emerging of exergames. Exergames are “innovative and interactive digital games that combine exercises and video games” [47]. Studies on exergames indicate that technologies, such as video games, can enhance older adults’ motivation for repetitive exercises and decrease their health problems [48, 49]. These exergames aim to encourage older adults to take exercises in a relaxing and entertaining atmosphere without the feeling of monotony and isolated in traditional exercises. Compared with the traditional exercises, programmable systems, such as exergames, can provide attractive virtual game environments to encourage the users to be more engaged, immersed, and motivated in physical activities [50]. Next, we review prior exergame research for older adults on physical and cognitive training, rehabilitation and design suggestions.

2.1 Exergames and Physical Training

While the physical performance of frail and active older adults is limited by age-related impairments, exergames are shown to be a medium of physical exercises for older adults with different physical capability [51]. Exergames are considered as a catalyst for older adults to promote healthy lifestyle behaviors [52]. Active exergames provided light intensity physical exercises for community-dwelling older

adults and result in improved physical benefits whether played in a standing or seated position [53]. Outdoor exergames on mobile phones can also improve participants' engagement, interest and satisfaction with physical activities [54].

Exergames are usually implemented on wireless controllable platforms, including Nintendo Wiimote, Microsoft Kinect, and Xbox. These wireless devices require minimal operational support and allow older adults to play with few restrictions [55]. As such, they offer a sense of self-determination, independence, and improve the quality of older adults' daily lives [56]. The study conducted by Alison et al. applied Nintendo Wii to encourage older adults to take exercises and the results showed the feasibility and benefit of using it as a tool for physical exercise [57]. In addition, Wii appeared to be more entertaining for participants from different age groups (adolescents, young adults and older adults) in comparison to hand-held inactive video games [58]. The study of Loos and Zonneveld [41] using Kinect showed that playing exergames have a positive effect on older adults' physical well-being and can provide excitement and fun. The study of Chiang et al. [59] found that older adults' eye coordination and reaction times improved through using Xbox games as an intervention mode. This proved that exergames are beneficial for the sub-theme of physical training, such as enhancing visual acuity. Exergames on Wiimote were also reported to be a safe, acceptable, and effective medium to promote physical activities for older adults [60]. In addition, the study using Wiimote as an exercise intervention has shown that participants gradually developed a sense of accomplishment and empowerment after the initial reluctance and anxiety [61].

Augmenting physical exercises through virtual reality (VR) technology is another tool for exergame development. Research using VR technology to enhance physical exercises for retired home residents reported increased motivation of the participants to adhere to a regular exercise routine [62]. Rendon et al. [63] found a positive effect of exergames using VR technology on improving older adults' dynamic balance and confidence of balance. Wüest et al. also found VR game intervention improves older adults' physical performance on gait and balance and the participants positively evaluated the usability of the VR games [64]. The participants in the study of Jon et al. reported the VR content was interesting and beautiful and they desired to exercise longer [65]. However, the use of VR with older adults might

have some limitations. Older adults might be reluctant toward this technology and not used to handle it [66].

2.2 Exergames and Cognitive Training

Besides the impairment in motor capability, older adults may also suffer from memory loss and other mental problems, which can substantially affect their capability to interact with the real world [67]. Exergames can also serve as cognitive training for older adults. Study applying exergames on training older adults' cognitive function reported participants' significant improvements in executive control and processing speed through cognitive measures [68]. Previous studies have shown that cognitive training intervention can enhance healthy older adults' cognitive ability [69]. Therefore, there is a growing interest in exergame training as an effective method to enhance important aspects of cognition and neural plasticity in older adults.

In order to exercise both the elderly's physical and mental capabilities, various exergames should incorporate physical exercises together with cognitive challenges. For example, the *SilverBalance* exergame designed by Gerling et al. [28] aims to recover older adults' both bodily and cognitive impairments. The game's sensitivity can also be adjusted according to the level of reduction in an older adult's visual and cognitive capabilities. For example, most participants with mild cognitive impairment enjoyed the Wii Bowling exergame design by Hughes et al. [70] and the game was rated with high scores for cognitive training, physical, and social stimulation. Tai Chi training exergame with dual-task designed by Kayama et al. [71] was found effective in improving older adults' cognitive functions. The study of Rosenberg et al. [72] indicated that participation in exergames can significantly reduce the symptoms of depression, improve quality of life relevant to mental health, and improve cognitive performance. To sum up, most research focused on the advantages of exergames for older adults in cognitive training as a medium for physical training.

2.3 Exergames and Rehabilitation

Older adults may suffer from various impairments as they age, particularly the reduction of motor and cognitive capabilities. For elderly stroke patients, physical rehabilitation typically requires intensive treatments and hands-on physical and professional therapy for at least a few weeks after the initial injury, which is monotonous and time-consuming for both the patients and the therapists [11, 73]. Research shows that a sufficient amount of stimuli can be acquired through repetitive exercises to remodel the elderly's brain and hence regain better control of one's motor capability [74]. Exergames for health purposes can improve older adults' attitudes towards physical activities, which in turn will lead to positive behaviour changes and improve their life quality [75]. Furthermore, exergames' recreation and leisure value can encourage older adults to follow the exercise routines. This may also increase older adults' confidence in their capability to take repetitive exercises. Thus, exergames can enhance older adults' adherence rates and motivation for rehabilitation exercises [12].

Some exergames have been designed for stroke patients undergoing rehabilitation and to improve their motivation to proceed the rehabilitation [76]. Smith et al. [77] proposed a music video game, Dance Dance Revolution, to inspire the older adults and increase their adherence to rehabilitation. They also presented a mobile monitoring system to allow a health professional to monitor the patient's condition and progress. Alankus et al. [78] have evaluated the longer-term home-based use of therapeutic exergames on stroke rehabilitation. Their study found an increase in patient's basic motion through playing rehabilitation exergames one hour a day. Siegel and Smeddinck [79] designed the rehabilitation exergames for Parkinson's disease patients with dynamic difficulty adjustments to increase flexibility. Uzor and Baillie [80] suggested that older adults show better adherence to physical activities with exergames compared to traditional exercises. These programmes include tailored exercises for specific muscle groups to restore muscle strength and balance in older adults.

2.4 Design Exergames for Older Adults

Given the benefits of exergames for older adults, many research efforts have been devoted to improving exergame designs for better user experience. For example, Rizzo and Kim [12] emphasized that visibility, feedback, and identification of the target users are three important human factors for exergame design. Balaam et al. [23] suggested that entertainment-oriented exergames are effective in engaging older adults. Similarly, Alankus et al. [13] found that motion-based exergames, which combine motion detection with fun elements, can stimulate people to exercise voluntarily. Burke et al. [81] identified *meaningful play* and *challenge* as two principles of exergame design for older adults to improve their motivations. Moreover, they pointed out that positive feedback, such as high numerical scores, can incentivize older adults to continue playing exergames and reach a particular goal. On the other hand, the negative feedback, such as failure signs, should be used discretely in case of discouragement to the elderly [81]. Chang et al. undertook a test and found that the engagement created in the rehabilitation exergames can make the older adults feel more enjoyable [82]. The study of Velazquez et al. [83] described their insights into full-body exergame design for older adults with the emphasis on adapting to game play and spectator-centered design to monitor physical characteristics of older adults. John et al. [84] proposed to adapt exercise intensity in real-time based on the player's heart rate to avoid overexertion.

To provide a better game experience, some exergame design guidelines for frail older players have been proposed [28, 29]. The design guidelines mainly consider the decline of older adults' capabilities, such as "Avoid small objects", "Give visual and auditive feedback" and "Mind physical condition". Billis et al. [85] summarized from their study that adjusting dynamic game content based on one's emotional state will lead to better physical and cognitive training motivation and adherence for older adults. Uzor and Baillie provided some recommendations of rehabilitation exergame design [80], including "Model exergames on evidence-based Therapy", "Communicate rehabilitation progress to older adults", etc.

Another advantage of exergames is that the data performed by older adults' motions in-game playing can be non-intrusively captured and transmitted to a remote clinic for further analysis [86]. Game playing data, such as duration of exercise, failure rate, and even body posture are helpful to the therapists in analyzing the

patients' physical and mental recovery. In summary, we can identify from prior research that exergame is more acceptable for older adults in the home environment, which can encourage them to take regular physical activities in a relaxed and enjoyable atmosphere.

Chapter 3

P-E Fit Theory

Person–environment fit (P–E fit) is defined as the level of match between individual and environmental characteristics, which is widely used in different areas including person-job fit and person-organization fit [87]. Person characteristics include a person’s physical or psychological requirements, values, objectives, capabilities, and personalities, while the characteristics of environment may include the intrinsic and extrinsic rewards, needs of a role and a job, cultural values, characteristics of other individuals and collectives in the person’s social environment [88]. In this chapter, we are mainly reviewing the research of P-E fit theory in gerontology.

3.1 Introduction of P-E Fit

In the original P-E fit theory proposed by Lewin [25], the ecological equation $B = f(P, E)$ is used to characterize the common effect between the state of person P and the surrounding environment E , where P denotes the personal competence and E denotes the environment press (environmental stimuli and barriers). Based on Lewin’s theory, Lawton et al. [24, 89] added an interactive term $P \times E$ into the ecological equation: $B = f(P, E, P \times E)$, because they considered that behavior is also affected by the interaction between an individual’s competence and environment press. According to the model, the match between individual characteristics (i.e., physical and psychological demands, lifestyle, and other personal characteristics) and environmental characteristics is a predictor of multiple outcomes, such as physical and mental health, autonomy, satisfaction, and so on. This theory was

used to analyze older adults' well-being that they should cope with both the external environment change and the internal capability decline as they age. Therefore, Lawton et al. [24, 89] defined the P-E fit model to present the fit between the individual's competence and environment stimuli by using the degree of adaptive level.

From the point of view of P-E fit, *Fit* is specifically conceptualized in the environmental docility hypothesis [90], suggesting that people with fewer resources or lower competence are more likely to be influenced by environmental opportunities and constraints. According to this hypothesis, older adults who are socioeconomically vulnerable may be more positively influenced by the age-friendly environments. Furthermore, the concept of multidimensional environment suggests that the impact of age-friendly environments on older adults' experiences may vary by the aspects of environment [91]. Outcomes of *Fit* may be adjusted or regulated through "subjective" psychological patterns (e.g. a sense of personal competence, coping style, and health attitudes) and more "objective" dimensions (e.g. resources, social support, and life events).

As a multidimensional concept, an age-friendly environment includes the physical and social infrastructure to support daily activities of the older adults through local facilities; accessible and safe housing, neighborhoods, and communities; transportation; access to social support; and opportunities to participate in meaningful activities [92, 93]. These various characteristics should be well considered in the perspective of P-E fit covering the physical, psychological, social and cultural environment [94]. This model states that the maximum fit of P-E will be produced when the environment stimuli can appropriately fit an individual's competence (Figure 1.1). Both relatively high and low environment press are negative to an individual's adaptation to the environment [89].

3.2 Applications of P-E Fit in Gerontology

The application of the P-E fit theory in aging research emphasizes that behavioral and health outcomes vary with the function of individual's competence and the environmental press [95]. This has been proven to be particularly relevant in long-term care setting study, as design choices should necessarily consider the

complex interactions between physical setting, organization, staff, and the users' requirements [96].

Iwarsson et al. [26, 97] applied the P-E fit model to evaluate the adaptive level of the surrounding environment to older adults. They underlined the fit between the elderly's competence and environment conditions [98]. In demonstrating the finer aspects of how people interact with the environment, Iwarsson et al. [99] explained the importance of considering how older adults view the home environment as an indicator of their performance in navigating various housing characteristics in assessing accessibility. Taking falls as an example, the authors extended the discussion of home hazards from the support of the home environment to the functional status of older adults and their perceived availability of home spaces in getting around and engaging in important regular activities. In order to find the best fit, they stated that understanding the relationship between the person and the environment is important [100].

Iwarsson et al. developed a tool [101], Housing Enabler, to acquire all older adults' personal limitations and their surrounding environment barriers to intuitively assess the adaptive level of the environment to each individual [26]. Although the Housing Enabler instrument was proposed, Iwarsson et al. [99] state that only a few studies have been conducted applying this instrument and other potential measurement tools of environment, falls, functional status, and suitability of housing among older adults. Since housing is extremely diverse, even in the small neighborhoods, older adults' experience of housing is difficult to effectively standardize, quantify, and measure [102], particularly for older adults experiencing many physiological problems throughout their lives, leading to many impairments and disabilities. Angela et al. [103] explored the relationship between the supportiveness of outdoor environment and older adults' life quality based on the concept of P-E fit. They found a consistent and positive correlation between the perceived environmental support and older adults' quality of life for nature-related outdoor activities [103]. As Oswald et al. [104] stated, environmental barriers include only partial competence-press as it associated with housing. In other words, hazards and mobility barriers in housing can only explain the functional and health-related outcomes among older adults.

Within the P-E fit perspective, the person part mainly refers to various attributes of the person, including biological health, sensory capacity, and motor skills, and

pays particular attention to those attributes specific to older adults [89]. The health-related aspects were examined in most existing P-E fit research; however, other aspects of people's resources and constraints in aging, such as social stratification and motivation factors, are also viable according to theoretical constructs of P-E fit research [105, 106]. For example, according to a study of age-friendly community, older adults stayed in rural areas experience better P-E fit when they are adjacent to an open space and natural areas, socially connected, and have access to diverse housing options such as affordable housing with accessible services and supports [107, 108]. They incorporated this paradigm into their concept of age-friendly environments and communities, and provided us another elegant example of the broader theory of P-E fit, identifying testable components in the environment other than functional capabilities of P-E fit for empirical research. Additionally, Eales et al.'s [107] conception of "active" versus "stoic" older adults provides another perspective for comparing the outcomes of P-E fit in different groups of older adults, increasing the complexity and richness of the ecological theory of aging literature, broadening the borders of P-E fit theory and addressing the gaps in knowledge.

More generally, most applications of P-E fit theory mainly focus on older adults' declined competence and aim to design an age-friendly surrounding environment for older adults. However, older adults' psychological needs and other personal characteristics are also important in P-E fit [105, 106]. Thus, our research would consider older adults' both physical capability and personal characteristics to improve the P-E fit between our target users and exergames.

3.3 P-E Fit in Technology for Older Adults

Assistive technologies are proved to play a role in maintaining older adults' autonomy, safety, and quality of life. Therefore, P-E fit is expected to be improved by the design of environment with supportive technologies [109]. Technology possibly play different roles in various housing environments [110]. The categories of the technologies were considered in assistive devices including 1) compensating for sensory, cognitive and motor difficulties; 2) monitoring and response systems, including emergency response to crisis conditions and early warning of less serious and emerging problems; and 3) assistance of social communication [109].

Miskelly [111] indicated that health monitors, video-monitoring and electronic sensors (for example, fall detectors, smoke and heat alarms, pressure pads and door monitors) are current examples of assistive devices that can improve older adults' feelings of safety and capability at home environment. Marquardt et al. [112] reported a beneficial role of assistive devices to reduce the symptoms of dementia in the early stages. Löfqvist et al. [113] investigated the perceived unsatisfied needs for assistive technologies and devices related overall health, daily independence, and environmental barriers of older adults. Health indicators, self-report data, and observations of older adults' living environment were collected in this study from sampling older adults living in Sweden. Outcomes emphasized that assistive technologies played a key role in improving P-E fit between older adults and the environment, whereas it seemed less important for issues related to social and communication support.

However, older adults may find difficulty when using the assistive technology devices in usability and comprehension [114]. For example, Orpwood et al. stated that technological help that is reassuring, controllable, user-friendly, and familiar is required for older adults to be involved in the product [115]. Designers and producers are expected to consider the ease of use of technological devices and the adequate training of elderly users to ensure the new technology to be accepted by older adults [116].

These studies suggest that the appropriate relationship between an individual's competence and the environment press can improve older adults' adaptation and motivation to the external environment. Thus, P-E fit in technology design for older adults should be carefully considered to increase users' adaptation, which motivates our research on improving the P-E fit between older adults and exergames.

Chapter 4

Familiarity

Research on familiarity is distributed across several different areas. The first area that familiarity has been often discussed is recognition memory. Familiarity is thought to be one of the two discrete recognition memory processes, the other one is recollection [43]. The second field is consumer research, which discussed that consumers' familiarity with different products may take a role in the context of consumer choices [117, 118]. The third field is gerontology. Researchers suggest familiar home and surrounding environment design would improve older adults' feelings of safety and confidence [119, 120]. The fourth field is human computer interaction (HCI). The metaphor and familiarity design may improve the usability of the technologies for elderly users [121, 122]. In this section, we reviewed prior familiarity research in recognition memory, gerontology, and HCI that highly related to our research.

4.1 Familiarity in Recognition Memory

Familiarity is considered as an unconscious, automatic process which requires little attention [123]. Being familiar with a system means that we are ready to interact with it easily and intuitively based on our prior knowledge [124]. A common assumption of human's memory is that the information can be triggered in two different ways, either as a scalar value of familiarity or as a structured recall of an event (recollection) [125]. This distinction can be illustrated by our common experiences that we often recognize a person as familiar but can not remember

who the person is or where they were previously encountered [43]. In other words, the pre-existing representations in the memory make a known stimulus easier to process, and retrieved more quickly, creating a sense of fluency which is usually interpreted as familiarity [126, 127].

Familiarity-based information retrieval has commonly been associated with activities of perirhinal cortex [128], but also lateral prefrontal, including temporal regions and inferior frontal gyrus. In the prefrontal cortex, an anterior medial region was found to be relevant to recollection, but lateral regions, including the anterior and dorsolateral prefrontal cortex, were relevant to familiarity. Skinner and Fernandes [129] used event-related functional magnetic resonance imaging (fMRI) to examine the recollection and familiarity process. The results show that recollection and familiarity are characterized by different patterns of brain activity in frontal, parietal, sensory, and medial temporal cortices. Yonelinas et al. [130] also found a distinction between familiarity and recollection in-memory process through fMRI. The fMRI study of Wang et al. [131] found the episodic retrieval of know statements recruited scalp regions associated with familiarity, but no recollection. Studies using event-related potentials (ERP) data also found the similar results of the scalp regions associated with familiarity. Finnigan et al. [132] found that an N400 (around 400 ms) effect recorded over the parietal scalp varied with presentation frequency, and the effect was considered to reflect familiarity. Jäger et al. [46] first found a double dissociation of familiarity and recollection of recognition memory through ERP, Woodruff et al. [45] also evaluated ERP data in their experiment and found a negative-going ERP deflection that onsets around 300 ms post-stimulus varied inversely with familiarity, and this effect was maximal over the left frontal scalp. Thus, both the fMRI and ERP studies have found that the left frontal scalp is associated with familiarity strength.

The research mentioned above usually evaluates participants' fMRI or ERP data towards static words or pictures. In EEG measures, action execution and observation are proved to be related to a relative decrease in power in the alpha and beta frequency bands, which is usually called event-related desynchronization (ERD) [133, 134]. Dance movement observation research found that participants' familiarity with the observed dance significantly influences the ERD data in alpha and lower beta bands [135, 136]. Paula et al. also found a higher alpha ERD results when the participants are more familiar with the stimuli during an action

observation EEG experiment [137]. The previous investigations have shown that the ERD data of an observed action is influenced by familiarity.

Previous research has indicated that aging leads to a decrease in memory recollection, but the influence on familiarity is minor [138]. Naveh-Benjamin [139] showed that it is easier for older adults to recognize stimulus (perceptual information) than encode and retrieve associations between stimulus (conceptual information). Yonelinas [43] also indicates that aging has a negative effect on recollection, but does not influence familiarity. Nicole et al. [140] evaluated memory mechanisms among healthy young adults, healthy older adults, and individuals with amnesic mild cognitive impairment (aMCI). Their results found that recollection was decreased in older adults and participants with aMCI compared to young adults. However, familiarity did not show any difference among the groups. The prior research indicates the familiarity process in older adults' recognition memory is not influenced by aging or aMCI. Therefore, it is useful to apply familiarity design for older adults to evoke their prior experiences.

4.2 Familiarity in Gerontology

The familiarity research in gerontology mainly focuses on the surrounding environment design for older adults. It states that people are more willing to increase their functional and social capabilities when they encounter familiar stimuli such as objects, sounds and environments [30, 141]. Son et al. [142] stated that familiarity can enhance functional abilities (e.g., physical, psychological, and emotional) of older adults. Familiarity also can provide older adults with emotional meaning and increased safety, usability, and attractiveness of the environment. For example, Brittain et al. [120] found that familiar surroundings can provide older adults with greater confidence to go outdoors. Barry [143] suggested the incorporation of familiarity into home design can bring positive changes in older adults' daily lives.

Demirbilek and Demirkan [119] studied the influence of the environment on aging factors. They found older adults prefer to live in their familiar environments in the "getting older" phase of their lives, which is a prime important aspect to consider when designing their homes. For older adults, familiarity can bring them emotional meaning and increase the safety, usability, and attractiveness of the

environment. Barry [143] also encouraged to incorporate familiarity design into the home environment to bring positive changes. He suggested that home design should preserve the character attributes of each specific elder individual. Boger et al. [144] assessed the impact of familiarity design on the usage of different faucets by older adults with dementia symptoms. The results showed that familiarity design plays a substantial role in the usability of faucets (effectiveness, efficiency, and satisfaction) for the elderly. Boger et al. [144] indicated that the familiarity trends may well be applicable to other products and activities. In sum, it has proved in gerontology research that familiarity design is beneficial for older adults.

4.3 Familiarity in Human Computer Interaction

Familiarity plays an important role in any product usage. Tognazzini suggested that the operation of an interactive system is best achieved by means of a metaphor or analogy, which indicates the importance of familiarity [121]. If a user feels familiar with a product, then he or she is more likely to understand its purpose and usage [145]. Being familiar with a system means we are ready to operate it in an appropriate way based on our prior experiences [124]. Sufficient experiences may lead to the development of an internal model, or stereotype, about how one expects something to work [30].

Familiarity has been applied in several new technology designs for older adults. For example, Leonardi et al. [22] designed WIMP (Window, Icons, Menus, and Pointing) interfaces with familiar interaction modalities to enhance user experience for older adults, such as replacing the “erase” command with scrubbing the finger. Turner [122] conducted an empirical study involving a group of older adults learning to use a personal computer and experience the services it provides. He suggests familiarity serve an important role in learning to use technology and his analysis results suggest to integrate technology into older adults’ everyday life to improve familiarity. Hollinworth and Hwang [146] designed the *tmail* application with familiar visual objects (e.g., email messages shown in the inbox resemble paper envelopes) and behaviors (e.g., messages and images can be moved by touching and sliding). All the elderly participants found the visual objects in this familiar interface are easy to understand and they can quickly master how to use *tmail*.

Thus, we believe incorporating familiarity design in exergames can also improve older adults' game experiences.

Part II

Familiarity Model Development

Chapter 5

Modelling Familiarity

5.1 Introduction

¹To keep healthy and prevent from 3H complications, regular physical exercises are necessary for most older adults. As technology advances, gamified rehabilitation exercises, or exergames, has been shown to be more attractive to older adults with entertaining game graphics and interactive tasks [12]. Meanwhile, older adults can do physical activities at home or community centers without worrying about potential injury when going outside. Exergames are proved to be more effective in motivating physical activities and improving health and physical function in older adults than traditional exercises [37].

However, it is not easy to motivate older adults to voluntarily play exergames unless the games are attractive enough [23]. One of the key reasons that make exergames unappealing to older adults is the lack of engagement and enjoyment [22]. Current exergames are mostly designed for the younger generation without considering the recreational requirements for older adults. Moreover, some of the new technologies and devices may be over-complex and difficult for older adults to use [22], which is called maladaptation in the Person-Environment (P-E) fit theory originated from the gerontology research [24]. According to this theory, a person's Behavior (B) reflects how well the Person's competence (P) matches the Environmental press

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(E): $B = f(P, E, P \times E)$ [24]. As shown in Fig. 1.1, optimal adaptation will occur only when older adults' personal competence can appropriately fit the surrounding environment. Good adaptation will result in a feeling of comfort and enhance engagement and enjoyment [24]. However, maladaptation can occur in the following two cases: older adults with high competence in low press environments (low motivation) and older adults with low competence in high press environments (low ability).

As maladaptation occurs when personal competence does not match the environmental press, we suggest that maladaptation can be mitigated by familiarity, which characterizes the relationship between a person and something (such as the environment) that the person has had considerable experience with [30]. The rationale is that familiarity is one of the key memory processes in the dual-process (recollection and familiarity) memory model [43]. Recollection is the process of retrieving details of past events and experiences. In contrast, familiarity is a general feeling that the event was previously experienced [147]. Familiarity reflects a more global measure of memory strength or stimulus recency [130]. Moreover, familiarity often appears to be preserved in aging process compared to recollection [43]. Thus, the feeling of familiarity can help a person to recall their past emotions and experiences.

Previous research shows that familiarity has an activating effect to arouse older adults' past feelings and emotions [31]. In a familiar environment, old adults may feel more comfortable and be more willing to improve their social and functional capabilities. Moreover, familiarity can evoke the older adults' past implicit and explicit memories [30], from which to recall the approaches to interact with the familiar environment [32]. However, the cohort of older adults has little exposure to new technologies such as video games compared to the younger generation [146]. Technologies and games may be over-complex and difficult to follow for older adults. Current commercial exergames fail to consider the mental model and past experience of older adults, which leads to the unfamiliar relationship between the technologies and older adults [22]. Therefore, we propose that familiarity design can improve P-E fit between the older adults and exergames.

Psychologically, familiarity refers to “the relationship between an individual and something that the individual has had a considerable amount of experience with” [30]. It is usually treated as a single-dimensional construct in previous research; it is often approximated by frequency of encounter or evaluated using subjective assessment

with a single metric [33–35]. However, viewing familiarity as a single-construct is hard to standardize. Users’ subjective rating standards may vary from person to person, which causes unconvinced results. In addition, a single-dimensional approach is not insightful enough to understand familiarity and to provide meaningful design guidelines. In psychology and sociology research fields, Yonelinas reviewed the studies of two types of memories: recollection and familiarity [43]. He presented there are some factors, such as prior experience and level of processing, can influence familiarity. In the work of Jie Zhang et al. [148], they proposed a familiarity measurement for agent based on the factors that affect human’s feelings of familiarity. However, this model mainly works for the multi-agent system, which seldom considers the influence of personal prior emotions on familiarity.

In this chapter, we identify five sub-constructs for familiarity based on literature, including prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, to shed light on multiple dimensions of familiarity. Meanwhile, we propose two salient stimuli in exergame (*Interface* and *Task*) that may influence users’ familiarity feelings.

5.2 Familiarity in P-E Fit

As shown in Figure 1.1, Lawton and Nahemow defined three zones, i.e., positive affect zone, tolerable affect zone, and negative affect zone, where adaptive, marginally adaptive and maladaptive behaviors can be produced, respectively. Familiarity characterizes a positive relationship between a person and the past experienced environment, which can improve the fit between older adults and the environment. On the one hand, when older adults encounter familiar items and environments, there will be an activating effect to arouse their past feelings and emotions [31, 149]. Then the familiar feelings will enhance older adults’ motivation to interact with the environment and enhance the adaptation. On the other hand, familiarity will evoke older adults’ past implicit and explicit memories. Older adults will recall the approaches to interact with the familiar environment from their memory so as to enhance their functional abilities and adaptation [142]. Therefore, we propose the factor familiarity can improve the P-E fit between older adults and exergames.

FIGURE 5.1: Improved P-E fit model.

Fig. 5.1 illustrates how familiarity can impact P-E fit model. We argue that familiarity can potentially enlarge the positive affect zone by improving both older adults' ability and motivation, referred to as zone A and zone M respectively. Based on the original P-E fit formula, we extend it as:

$$B = f(P, E, P \times E | F), \quad (5.1)$$

where F represents familiarity that can induce positive adaptation changes.

Therefore, we incorporate familiarity into the original model and suggest that familiarity design can improve older adults' experience in exergames (Figure 5.2).

FIGURE 5.2: Familiarity in P-E fit model.

5.3 Five Sub-constructs of Familiarity

Previous research mainly treats familiarity as a single-dimensional construct that is mainly measured by the frequency of encounter or subjective self-assessment [35, 144]. However, such a view does not provide meaningful sub-dimensions for a better understanding of familiarity. In this research, we identify five sub-constructs of familiarity. We now introduce the five sub-constructs that have been demonstrated to be correlated to familiarity in the literature.

5.3.1 Prior Experience

Prior experience refers to a person's previous experiences related to the current stimulus. The prior experience stored in memory influences the level of perceived familiarity. As stated by Yonelinas [43], familiarity depends on the detailed memory of prior knowledge and experience. Familiarity is not treated as an inherent characteristic of a stimulus; rather, it is thought to arise when fluent processing of the stimulus is attributed to past experience with that stimulus [43]. Jacoby [147] argued that familiarity is not restricted to perceptual information, but also includes the prior experience in one's mind. Lim et al. [150] stated that familiarity is a relative concept, which depends on the prior experience of each user. They

suggest a system can be designed to simulate routine actions that users are familiar with from their everyday experiences. Moreover, accordingly to O'Brien et al. [151], prior experience has a positive impact on user performance when interacting with new technology. Therefore, prior experience plays an important role in the perception of familiarity.

Familiarity relies on the memory of prior experiences. The source of prior experience can come from the stimulus itself or the objects that are semantically related to the stimulus. The level of prior experience associated with a stimulus can be influenced by whether older adults have ever heard of, searched for information about, used, or owned a certain related object [148]. The evaluation of prior experiences may vary from different stimuli.

5.3.2 Positive Emotion

Positive emotion refers to people's past positive feelings elicited by a similar stimulus and has been shown to positively influence familiarity. Positive feelings can make certain environmental stimuli stand out, become more salient, and evoke deeper processing and better memory [152]. Past moments imbued with emotions are easy for us to recall, and these occasions seem to be remembered most vividly and durably [149]. Meanwhile, the study has shown that memories of past events are often accompanied and influenced by emotions [153].

Laboratory studies conducted by Levine and Edelstein [154] suggested that positive emotions lead to greater attention on general and relational knowledge; on the contrary, negative emotions result in a focus on specific details. Positive emotions tend to promote heuristic, creative and flexible information processing modes, while negative emotions tend to promote a more analytical and data-driven information processing mode [155]. Familiarity does not require remembering and recalling the details of a past event. Rather, general feelings are more important. Moreover, studies have shown that memories associated with negative (or unpleasant) emotions fade faster than memories associated with positive (or pleasant) emotion [156, 157]. Therefore, positive emotions linked to past events are more likely to produce a sense of familiarity and improve the current experience.

In addition, the emotional intensity of past events also affects memory and familiarity. Emotionally intense events tend to be remembered longer, with greater vividness and a greater sense of recollection [158]. Thus, the intensity of such emotion is crucial to evaluate positive emotion.

5.3.3 Occurrence Frequency

Occurrence frequency refers to the frequency of a stimulus encountered by an individual as stored in his/her memory. Many studies have indicated that the more times people encounter a stimulus, the deeper memory they will have. According to the autobiographical memory theory from Thompson et al. [159], rehearsal frequency is related to the self-reported strength of personal memories to a stimulus. Meghan et al. [160] also suggested that occurrence frequency can influence the vividness of an event in a user's memory. They propose that occurrence frequency can impact the extent to which events retain or lose effectiveness over time in two ways. One effect may be direct, for example, emotions might tend to be maintained with high rates of rehearsal because people savor their successes and persevere over their failures. A second causal route suggests that a high occurrence frequency helps to maintain memory strength and promote the retention of event-related effects.

Moreover, studies have shown that occurrence frequency positively influences the feeling of familiarity. As suggested by Jacoby [161], repetition of usage increases the familiarity of items. Yonelinas [43] also stated that the repetition of the stimuli leads to increases in familiarity and recollection. Xiong's experiment [162] on word frequency effect in explicit memory tasks showed that people's feeling of familiarity is sensitive to the frequency of encounter. The experiment of Moreland and Zajonc [163] on photographs of faces also found that repeated exposure to a certain item will increase the feeling of familiarity. Therefore, familiarity is greatly influenced by the occurrence frequency of the stimuli.

5.3.4 Level of Processing

Level of processing refers to the depth of processing in one's memory. Compared with shallow processing (perceptual-based), deep processing (meaning-based) leads

to a consistent enhancement in familiarity, due to the prominent improvement in both recognition and recall [43]. Many findings have suggested that the meaning-based processing can better support familiarity. For example, the word retrieval experiments of Jeffrey [164] found that familiarity is enhanced by prior meaningful processing. Jacoby [147] found that solving anagrams increased perceived familiarity with a certain word compared to the case where the word is presented in its normal form to be read. Anthony et al. [123] examined the effects of conceptual processing and perceptual similarity on familiarity-based word recognition. The results show that familiarity is more sensitive to conceptual processing (deep processing) than to perceptual processing (shallow processing).

Rhodes and Anastasi [165] found that people engaged in a deep-level-of-processing task recalled a significantly greater proportion of information than those with a shallow-level-of-processing task. Therefore, how deeply a person processed a similar stimulus in prior experiences may significantly influence the level of familiarity with the current stimulus. To evaluate the level of processing, whether meaning-based prior interactions with the stimulus should be assessed.

5.3.5 Retention Rate

Retention rate refers to how much of the memory about a stimulus is retained and is negatively affected by the time interval between two encounters. Information in the memory is lost over time when there is no attempt to retain it. The longer the interval between the encounters, the greater the decrease in the user's feeling of familiarity. As highlighted by Yonelinas [43], familiarity exhibits pronounced forgetting effects across long-term delays (i.e., minutes to months). Hockley [166] found that familiarity is significantly decreased with the increase of time intervals for both single words and pairs of words with association. Thompson et al. [159] also suggested that an increase in retention interval would result in a decrease in memory.

Recognition memory for item information (single words) and associative information (word pairs) was tested by the experiment of Hockley and Cinsoli [167]. The results suggest that familiarity decreases with delays (of 30 mins, 1 day, 2 days and 7 days). Retention rate can also be evaluated according to the forgetting curve [168].

FIGURE 5.3: Familiarity model based on P-E fit theory.

Based on the above five sub-constructs, the conceptual familiarity model in the P-E fit theory can be shown in Figure 5.3. These sub-constructs are further determined by older adults' prior interactions and experiences with the similar contexts and objects. We present a formalized representation of the proposed familiarity model as follows: X (prior eXperience), E (positive Emotion), O (Occurrence frequency), P (level of Processing), and R (Retention rate), the level of familiarity for each stimulus F_i can be denoted as:

$$F_i = \langle X, E, O, P, R \rangle. \quad (5.2)$$

The total familiarity (F) for the context or environment can be expressed as the sum of n salient stimulus in the environment:

$$F_{Total} = \langle F_1, F_2, F_3, \dots, F_N \rangle = \sum_{i=1}^N w_i F_i, \quad (5.3)$$

where w_i is the weight of different stimulus in the context or environment. Therefore, an important step to evaluate familiarity is to determine the salient stimuli in different environment.

5.4 Familiarity Model in Exergame

To model the overall familiarity in exergame, another important step is to determine the salient stimuli in exergames. According to Adams's research [169], the key components of video game design are core mechanics and user interface of the game (see Fig. 5.4). The core mechanics generate the game play methodology and determine the effect of the player's actions upon the game world. The user interface mediates between the core mechanics of the game and the player. Based on Adams's research on general games and prior research on exergame design guidelines for older adults [28, 29], we identify two major stimuli that have influence on familiarity in exergames, namely *Interface* ($F_I = \langle X_I, E_I, O_I, P_I, R_I \rangle$) and *Task* ($F_T = \langle X_T, E_T, O_T, P_T, R_T \rangle$). *Interface* denotes the virtual context and environment of the exergame. *Task* refers to the required motions of the users when playing the exergame. Therefore, the total familiarity for an exergame can be expressed as:

$$F_{Total} = \alpha F_I + \beta F_T, \quad (5.4)$$

where $\alpha, \beta \in [0, 1], \alpha + \beta = 1$.

Older adults may share different past experiences, this familiarity model can evaluate the degree of familiarity for each elderly individual to the exergames so as to select the optimal exergames to exercise.

5.5 Chapter Summary

In this chapter, we suggest that older adults' feelings of familiarity can improve their adaptation to exergames. Exergame design that can evoke a feeling of familiarity in older adults may stir up their fond memories. They may also help older adults recall

FIGURE 5.4: Game design.

approaches to deal with similar environments and improve their exergame playing capabilities [32]. We posit that familiarity can potentially enlarge the positive affect zone in P-E fit model by enhancing older adults' both motivation and ability. Thus, we suggest that familiarity design can increase older adults' engagement in exergames and improve the P-E fit. Although the feeling of familiarity is related to people's past experiences and varies from person to person, we can always find some shared experiences and stories for the older adults from the same region, culture or with the same hobbies.

To understand familiarity, we proposed the conceptual familiarity model and identified five sub-constructs of familiarity, namely prior experience, positive emotion, occurrence frequency, level of processing and retention rate. The five sub-constructs aims to provide a deeper understanding of familiarity and inspire the multi-dimensions of familiarity design. Meanwhile, we identified two salient stimuli in exergames, namely *Interface* and *Task*. Older adults' total familiarity feelings to each exergame are influenced by both stimuli. Therefore, familiarity evaluation and design guidelines for exergames should pay attention to both exergame *Interface* and *Task*.

Chapter 6

Designing Familiar Exergames

6.1 Introduction

¹In this chapter, we present the familiarity design guidelines for age-friendly exergame design. The idea to provide such design guidelines comes from our analysis of the previous literature, where familiarity was not carefully considered in previous exergame design guidelines for older adults. Current exergame design guidelines mainly pay attention to the physical capability decline of older adults, which is crucial for older adults to complete the exercises during game play. However, only considering their declined physical capabilities is not enough to design an age-friendly exergame. Studies have indicated that the digital divide between older adults and exergames is often caused by the unfamiliar interface and task designs [21, 41, 42]. Since older adults' feelings of familiarity can improve their game experience, a set of applicable familiarity design guidelines can help game designers to develop an age-friendly exergame and improve the P-E fit between older adults and exergames.

The guidelines we present here were inspired by the five familiarity sub-constructs and suggestions from literature reviews. The insights from our observations in the previous study also contribute to these guidelines. The five guidelines correspond to the five sub-constructs in the familiarity model. For exergame design, the guidelines

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should be applied to both *Interface* and *Task* design to ensure designed exergames are familiar for your target users. Based on the design guidelines, we designed the *Escape Room* exergame to exercise older adults' upper-limb with consideration of the familiarity design. Based on the suggestions from the health professionals, the rehabilitation exercises and challenges in the exergame were carefully designed for our target older adults.

6.2 Familiarity Design Guidelines

Previous research works have provided general guidelines for exergame design for older adults [28, 29]. Most of these guidelines focus on catering to older adults' declining capabilities, such as *avoid small objects* and *give visual and auditive feedback*. In this section, we propose a set of familiarity design guidelines for exergames according to the proposed five sub-constructs of familiarity and the insights gained from our field study.

1) *Correspondence with the real world*: The objects, scenes, and activities in exergames should correspond to the real world so that they can be related to users' prior experiences. Norman [170] has advocated using objects in our every day, such as doorknobs and light switches, as inspiration and sources for guiding how interaction and interfaces of computers should be designed. Therefore, the familiar objects in the scenes help the users understand the whole game environment. In addition, the control of in-game tasks should be done in a similar manner as in the real world; this helps the older adults to quickly adapt and complete the game tasks with their prior real-world experience. Although users' prior experiences are different, the correspondence with the real world can always help users to recall more of their prior experience. As mentioned by Herstad and Holone [124], if objects, scenes, and activities can reasonably correspond to the real world, users can recall their prior experience and respond appropriately to whatever might normally come along.

2) *Evoking positive emotion*: Older adults are often familiar with the stimuli that they have deep emotional attachment to, especially those with positive emotions [152]. Due to the diverse personal experiences of users, it may be difficult to identify the stimuli that can evoke positive emotions in each individual. Therefore,

it is important to find some common features that target users share, such as their culture or hobbies. For example, table tennis is one of the most popular sports in Singapore. The *Ping Pong* exergame is designed based on table tennis activity. About half of our participants expressed that they feel very excited and happy to play this exergame. Objects that can generally arouse positive emotion can also be used, such as the beautiful flowers and green valley environment [171]. Customization of the design for long-term users should also be taken into consideration to evoke their emotions.

3) *Providing meaningful stimuli*: Meaningful stimuli for older adults can help to evoke deep level-of-processing and create a feeling of familiarity. According to Craik and Lockhart [172], semantic processing extracts the meaning of a stimulus and aids the memory to recall with depth. Although other memory features are lost as people age, it seems that we can retain the strength of memory encoding derived from higher level-of-processing [173]. Hence, providing meaningful stimuli in exergames can potentially enhance the playing experience by evoking deeper level-of-processing. A meaningful analysis of information with deep processing in older adults' minds leads to a better memory recall [124]. By extracting the meanings of stimuli and linking them to a pre-existing network of semantic associations, a deep level of processing will be involved, which enhances the feeling of familiarity.

4) *Selecting stimuli with high repeated exposure*: The mere-exposure effect indicates that people tend to develop a preference for stimuli after repeated exposure; this is referred to as the familiarity principle [174]. Older adults tend to be more familiar with the stimuli that they encountered with high frequency. Selecting game stimuli with high repeated exposure in older adults' daily life can increase both their feeling of familiarity and preference to the exergames. In our experiment, the *Ping Pong* exergame is selected by some participants as the favorite exergame mainly because they had often played or watched table tennis games in their daily lives. Understanding the target users and finding the stimuli that are most often encountered by them can help the design of more familiar exergames.

5) *Considering recent experience*: The forgetting curve shows that memory retention declines over time [168]. When people have no reason to retain a memory, that memory is gradually lost. Compared with experience from a distant past, recent experience may lead to higher levels of familiarity.

6.3 Escape Room Exergame

To cope with the decline of the elderly's upper limb capabilities, we developed the *Escape Room* exergame. General escape room games require players to solve various puzzles and complete tasks in the locked rooms. In our *Escape Room* exergame, physical exercises are designed as tasks. Five sets of upper limb movements within the capability of older adults are identified in this exergame, including the movements of hand, elbow, forearm, shoulder, and wrist. In order to engage older adults in this exergame, we follow the proposed familiarity design guidelines to present an age-friendly exergame. Mechanically, games should consist of game actions, game challenges, and game settings. Game actions are supposed to be completed through physical exercises in exergames. In this section, we present our work on the *Escape Room* exergame design and development.

6.3.1 Game Actions

Upper limb strength and coordination play an important role in carrying out Instrumental Activities of Daily Living (IADLs), e.g. cleaning the house, preparing meals, shopping for groceries, which are required for an individual to live independently in a community [175]. Therefore, maintaining good upper limb functional capabilities is of great importance for older adults. However, a decline in upper limb functional capabilities faced by many older adults [176, 177]. Thus, our exergame would focus on the exercises of older adults' upper limbs.

To effectively rehabilitate older adults' upper limb capabilities, the exercises should possess the following characteristics:

1. An objective to train the desired movement purposefully;
2. Movement is repetitive, elaborate and task-specific;
3. Movements must be within the capability of the target users.

Extracted from previous research on upper limb rehabilitation, five sets of upper limb movements are identified, which includes shoulder, elbow, forearm, wrist and hand/finger movements [178]. The objective of our designed exergame is to include

the five sets of upper limb movements with the above characteristics while providing an engaging and familiar game experience to the target users. Our implementation will train all the five sets of upper limb movements within an active range of motion, focusing on flexibility and with a fixed number of repetitions.

6.3.2 Game Challenges

In the exergame design, challenges can perform as short term goals for moving through the game as well as long term goals for moving through the exercise process. The long term goal of game completion should be connected with the goal of fulfilling the patient's personal goals. The goals can be specific, like being able to stand up from a chair or regaining the ability to walk a short distance, or general goals of regaining independence [179]. Maintaining independence is one of the general objectives identified by the older adults.

The ability to perform IADLs has been widely recognized as a sign of independent living and the IADLs are applied in many serious game design. For example, Hondori et al. [73] used tasks of daily life in their game design. They noticed that patients gained confidence in performing real activities by practicing similar virtual activities during therapy. Sadihov et al. [180] designed one of their games as wiping table, as exercises performed in conventional therapy are often based on IADL. *Escape Room* exergame is advantageous to reach the general goal of independent living by completing the specific IADLs in a virtual context.

To design meaningful challenges, Nicholson [181] indicates that a balance between physical effort and mental inspiration to solve the puzzles is required. This means that the puzzle elements in challenges should not be so complex to cause frustration. Another design suggestion by Nicholson is having a clear solution for puzzles. Having a clear goal is also supported by Lohse et al [182], who states that goals can lead to a higher chance of acceptance. These design aspects and the requirements of rehab drove our decision to remove puzzle elements from this implementation. In our designed exergame characteristics, exercises should be trained purposefully and with repetition. In most cases, the amount of actions performed by players in each session is fixed. Increasing the amount of repetition through the complexity of puzzles may lead to frustration for older adults and this is not acceptable. As such, challenges are designed to be completed by repeating several designated

upper limb movements for specific IADLs with fixed repetitions. Movements are performed without any time limit with no failure of challenges.

6.3.3 Game Settings

In order to create a coherent experience familiar to our target users, the setting should be within the same context as the game challenges. This means that the reason to perform challenges should be easily identified by the older adults in the provided game setting. For example, Tsoupikova et al. [183] developed a game in the context of a tea party. The actions performed by their users in game involves catching cookies scurrying away on the table, filling teacups with teapot, pinching sugar cubes into teacup, etc. The setting of a tea party makes sense for players to perform these actions as it gave reason behind them.

The generic escape room game is flexible in using different settings and rooms to create challenging puzzles coherent to the settings. This can be seen in games like *An Escape Series 3* [184], where the player tries to escape from a telephone booth. In this escape game, the main puzzle is solved through interaction with the paid telephone by inserting coins into a machine, picking up the handset and dialing numbers. This flexibility allows us to follow a particular context and a set of activities suitable for this context.

As such, we use the setting of the common living room in the game context as a natural location for older adults to perform IADLs. The game challenges can be populated based on the logical positions of intractable items. For example, a phone can be on a coffee table, whereas dishwashing can be done at the kitchen sink.

6.3.4 Familiarity Design

The feeling of familiarity is related to people's past experiences and varies in each individual. Thus, it is important to understand your target users and design familiar exergames from their shared experiences and stories. Older adults lived in Singapore are the target users of *Escape Room* exergame. According to the National Survey of National Citizens in Singapore [185], 85.5% of older adults aged 55 and above stay in a public housing unit managed by the Housing Development

FIGURE 6.1: Example of Singapore HDB Room.

FIGURE 6.2: Escape Room Game Environment.

Board (HDB flat, Figure 6.1). In order to build a familiar *Interface* (F_I) for older adults, the *Escape Room* environment is referenced from the common 3-room Housing HDB flat (Figure 6.2). To design familiar *Tasks* for older adults, six IADLs are selected to be designed in the exergame: *clearing the table*, *tidying bookshelf*, *hanging laundry*, *washing dishes*, *switching television channels* and *opening the lock of the house gate*. Next, we will introduce the *Interface* and *Tasks* design in *Escape Room* exergame based on our proposed familiarity design guidelines.

6.3.4.1 Game Interface

Correspondence with the real world: We set the game context in an HDB flat to cover a larger group of our target users. The escape room is recognizable for the users to set in a daily living setting with intractable daily living objects. Our implementation used a similar layout and size of a real-life 3 room flat. The walls and floor tiles are created to match designs of these flats with essential installations like gates, doors, furniture, household items, windows and window grills designed to

FIGURE 6.3: An example of 3-room flat in 1972.

look as closely real-life as possible (Figure 6.2). All these installations and objects may help older adults quickly recognize the whole room environment.

Evoking positive emotion: The socioemotional selectivity theory states that older adults are inclined to look to the past with a positive emotional experience as they age [186]. Thus, the implementation is also referenced from the common 3-room HDB flat in Singapore established in the 1970s (Figure 6.3). The aim was to recreate the correct layout of the living rooms of that time and evoke their past emotions. As with older flats in Singapore, colors of the house are monotonous, with white square tiles. The old-style fans are either wall-mounted or standing and lighting is created by ceiling lights. The windows and main door are installed with checkered window grills, a design prevalent in that particular time of Singapore. Thus, some installations and furniture in *Escape Room* exergame are designed in the old style to evoke older adults' past positive emotions (Figure 6.2), such as the fan, door, and television design, which seldom been found in current house decoration.

Providing meaningful stimuli: Research has shown that older adults consider the past experiences as the most active and potent time [187]. The past stimuli are emotionally meaningful for most of our target users. Meanwhile, as a linkage between individual and family, home environment is given meaning through psychosocial processes relating the older adults [188]. Thus, the stimuli in the game *Interface* should be meaningful for our target users. Moreover, because people's

past meaningful experience may be different, meaningful stimuli can be customized for each elderly individual in the *Interface* design. In the *Escape Room* exergame design, generic interface was applied to provide meaningful stimuli for more of our target users.

Selecting stimuli with high repeated exposure: When we selecting the HDB flat as the game environment, we believe the whole environment should have high repeated exposure for Singaporean older adults who have lived in HDB flat for a relatively long time. For the specific objects in the environment, we carefully selected and designed items that usually appear in the home environment, such as cabinet, table and fridge, to ensure high repeated exposure for older adults.

Considering recent experience: As 85.5% of older adults aged 55 and above currently lived in an HDB flat, most older adults should have recent experience with the game environment. Although some old-style objects were designed in *Escape Room* exergame to evoke older adults' meaningful experience, objects, such as newspapers, dishes, and books, that users may have recent interaction with are also involved in the *Interface* design to increase the familiarity.

6.3.4.2 Game Task

Six IADLs were selected in the game tasks, including *clearing the table*, *tidying bookshelf*, *hanging laundry*, *washing dishes*, *switching television channels* and *opening lock of house gate*. These tasks require the elderly players to perform different sets of upper limb movements to complete. Some examples of the tasks are shown in Figure 6.4. Next, we introduce the familiarity design in-game tasks.

Correspondence with the real world: As most IADLs are complex actions requiring combined upper limb movements, we selected six suitable IADLs in the game task and break these tasks into basic upper limb movements. Table 6.1 shows the upper limb movements in the tasks. All the required basic upper limb movements in exergame are carefully selected and corresponded to the real tasks in consideration of familiarity, which ensures the older adults can quickly understand the game tasks and take exercises.

Evoking positive emotion: During the game tasks design, we try to evoke older adults' past positive emotions through positive feedbacks. We designed two states

FIGURE 6.4: Examples of Game Tasks.

(messy and clean) of the tasks in the exergame. The cleanliness of the house after task completion can arouse users' positive emotions. Meanwhile, we use keys as an award after the completion of each task. For example, a key would be found if the users clean the table. Other positive feedbacks, such as winning sounds and scores, are also applied to evoke their positive emotions.

Providing meaningful stimuli: The presented tasks were derived from older adults' daily activities. Older adults who often conduct these activities should have deep processing in their minds. As IADLs are important for an individual to live independently in a community, we suppose that the selected game tasks are meaningful for most able-bodied older adults. Moreover, if users are good at housekeeping, such tasks should be more meaningful for them with the arousal of their past experiences and skills.

Selecting stimuli with high repeated exposure: All the IADLs should have high repeated exposure for older adults who live independently. In order to select the

TABLE 6.1: Game tasks with corresponding IADL and upper limb action.

Game Task	IADL Category	Motion	Image
<i>Clearing the table</i>	Housekeeping	Shoulder adduction	A line drawing of a person's upper body. The right arm is extended downwards and inwards towards the midline of the body. A red arrow points from the shoulder towards the hand, labeled 'ADDUCTION'.
<i>Tidying bookshelf</i>	Housekeeping	Shoulder flexion	A line drawing of a person standing. The right arm is raised straight up. A curved arrow indicates the range of motion from the arm being extended downwards (labeled 'extension' at 0°) to being flexed upwards (labeled 'flexion' at 180°).
<i>Hanging laundry</i>	Laundry	Shoulder flexion	A line drawing of a person standing. The right arm is raised straight up. A curved arrow indicates the range of motion from the arm being extended downwards (labeled 'extension' at 0°) to being flexed upwards (labeled 'flexion' at 180°).
<i>Washing dishes</i>	Food preparation	Elbow flexion	A line drawing of two hands. The right hand is holding the left forearm. A curved arrow shows the forearm moving from a straight position towards the shoulder (labeled 'Flexion') and back down (labeled 'Supination').
<i>Switching television channels</i>	-	Elbow flexion	A line drawing of two hands. The right hand is holding the left forearm. A curved arrow shows the forearm moving from a straight position towards the shoulder (labeled 'Flexion') and back down (labeled 'Supination').
<i>Opening the lock of the house gate</i>	Transportation	Forearm supination	Three line drawings of a forearm and hand. The first shows the forearm in a 'Supination' position (palm up). The second shows it in a 'Neutral' position. The third shows it in a 'Pronation' position (palm down).

game tasks with more repeated exposure, the frequency of different IADLs performed by the older adults was considered. Compared to finance management and grocery shopping, housework may be performed more by older adults. In 2011, the National Survey of National Citizens surveyed a total of 10,000 households with at

least one household member aged 55 and above [185]. The National Survey used the IADL performance indicator in their interview with older adults, where 91-99% of the respondents were able to perform the activities independently. Taking from the survey and results, IADLs is important for the daily living of able-bodied Singaporean older adults. Thus, we believe the chosen game tasks are conducted by most of our target users with high repeated times.

Considering recent experience: Recent experience was considered the same as repeated exposure. Since we cannot know each user's recent experience, the tasks which are conducted more frequently would be regarded as more recently. Thus, we believe the older adults have recent experiences with the game tasks.

6.4 Chapter Summary

In this Chapter, we proposed a set of applicable familiarity design guidelines for exergames. These guidelines can help designers infuse familiarity into exergame design for older adults to improve their game experiences. It's worth mentioning that these guidelines can also be applied to other games and intelligent interfaces design for older adults. Following the familiarity design guidelines, we designed the *Escape Room* exergame. The game interface was referred to a typical Singapore house in the 1970s. The IADLs were designed as the game tasks in *Escape Room* exergame to improve the intelligibility of the required motions for elderly players. This exergame aims to provide a familiar experience for our target users.

Chapter 7

Familiarity Instrument

7.1 Introduction

Although familiarity design has been shown to be beneficial for enhancing players' perception and adoption of exergames, there still lacks a practical instrument to measure players' perceived familiarity with a specific exergame. The instrument may benefit both exergame designers and players. On the one hand, such an instrument can help game designers to evaluate whether familiarity design has been successfully incorporated into their designed exergames. On the other hand, a familiarity instrument can help players to choose exergames that will induce a higher level of familiarity, which is especially desired for older players.

In prior research, single-metric methods were mainly used to assess familiarity. Three ways were often applied: a Likert scale question (from very unfamiliar to very familiar) to ask users to evaluate their feeling of familiarity [34, 189]; yes-no questions to ask whether the stimulus is familiar [35, 126, 190]; and familiarity level determination of a stimulus according to its years of exposure or commercial availability [144]. However, single-metric methods are hard to standardize the evaluation of familiarity.

In this chapter, we propose a familiarity instrument for exergame players to evaluate their familiarity with two salient stimuli in exergames: *interface* and *task*. Interface refers to the virtual environment and context in the exergame display. Task refers to the control of objects in the virtual environment and context by the

body motions of exergame players. To measure players' perceived familiarity with an exergame's interface and task, we evaluate the five sub-constructs of familiarity identified in Chapter 5, which include prior experience, positive emotion, occurrence frequency, level of processing, and retention rate. The instrument consists of ten questions regarding the five sub-constructs of familiarity on exergame interfaces and tasks. All the questions adopt a seven-point Likert scale and require the respondent indicating the degree of agreement. Higher total points in this instrument indicate that the user has a higher perceived familiarity with a specific exergame. Next, we will introduce the proposed familiarity instrument in detail.

7.2 Familiarity Instrument

As familiarity can effectively influence players' game experience to exergames, a simple and efficient familiarity evaluation method is useful for selecting appropriate exergames for each player. Moreover, the familiarity evaluation method can be applied by the game designers to test whether their designed exergames are familiar to the target users. Thus, an applicable familiarity instrument was developed in this thesis. The instrument uses a seven-point Likert scale, where statements are made and the respondent indicates the degree of agreement or disagreement. Prior research shows that a long questionnaire is negative to influence users' survey experience and results in a decline of response quality [191]. Thus, we include only one question for each sub-construct of familiarity based on the five sub-constructs of familiarity identified in the previous Chapter. As two salient stimuli (*Interface* and *Task*) were proposed in exergames, a total of ten questions are assembled in this instrument to evaluate a player's perceived familiarity with an exergame. The instrument is shown below. Table 7.1 indicates the corresponding familiarity sub-construct all the questions assessed.

Familiarity Instrument

Interface							
1. I have much prior experience with <i>the displayed environment</i> (heard of, searched for information, or have been to).	1	2	3	4	5	6	7
2. While remembering <i>the displayed environment</i> , the emotions are extremely positive.	1	2	3	4	5	6	7
3. I frequently come across <i>the displayed environment</i> in my daily life.	1	2	3	4	5	6	7
4. Before today, I got a deep impression and fully understand the function of <i>the displayed environment</i> .	1	2	3	4	5	6	7
5. I came across <i>the displayed environment</i> very recently.	1	2	3	4	5	6	7
Task							
6. I have much prior experience with <i>this task</i> . (heard of, searched for information, owned and played).	1	2	3	4	5	6	7
7. While remembering <i>this task</i> , the emotions are extremely positive.	1	2	3	4	5	6	7
8. I frequently do <i>this task</i> in my daily life.	1	2	3	4	5	6	7
9. Before today, I got a deep impression and fully understand the rules and skills of doing <i>this task</i> .	1	2	3	4	5	6	7
10. I have done <i>this task</i> very recently.	1	2	3	4	5	6	7

1: Strongly disagree; 2: Disagree; 3: Slightly disagree; 4: Neutral; 5: Slightly agree; 6: Agree; 7: Strongly agree

TABLE 7.1: Correspondence between instrument questions and familiarity sub-constructs

Sub-constructs	Corresponding Questions
Prior Experience	1, 6
Positive Emotion	2, 7
Occurrence Frequency	3, 8
Level of Processing	4, 9
Retention Rate	5, 10

It should be mentioned that “*the displayed environment*” and “*this task*” in the instrument can be replaced based on the different interface and task designs of exergames. For example, in *Escape Room* exergame, we changed “*the displayed environment*” to “designed home environment” and “*this task*” to “doing housework and other IADLs” in the questionnaires according to the designed interface and task. We currently set the same weight for each question and the total familiarity score is the summary of the results to the ten questions. Higher scores indicate that the player perceives higher familiarity with the exergame. Meanwhile, we may look into the results of each question to evaluate whether each sub-construct of familiarity has been well incorporated into the game design. To decrease the cognitive load for older adults and avoid potential mistakes, all positive statements were used in this instrument. Help from caregivers or family members may be needed for some older adults to fill this instrument to decrease the yes saying bias.

It can be found from the instrument that the five questions for *Interface* and *Task* are similar. Thus, the five questions can be easily altered to obtain the familiarity levels for different stimuli other than exergame interface and task. For example, the instrument can also be applied to evaluate older adults’ familiarity levels to computer software, APP and even their surrounding environment. However, it is important to find out the salient stimuli in each object and calculate the total familiarity scores.

7.3 Chapter Summary

In this chapter, we propose an applicable familiarity instrument to evaluate exergames’ familiarity levels to different older adults. Users’ answers to the ten Likert scale questions would be collected in this instrument, which are related to

the identified five sub-constructs of familiarity in *Interface* and *Task* of exergames. The total scores of the ten questions are supposed to reflect the levels of familiarity. This instrument aims to help older adults select more familiar exergames to play and maximize the effectiveness of exergames. Meanwhile, game designers can apply this instrument to evaluate whether familiarity design has been successfully incorporated into exergames for their target players.

Part III

Validation Studies

Chapter 8

Experimental Research Methodology

8.1 Introduction

Part II of this thesis presented our proposed familiarity model, design guidelines and instrument. The familiarity model sheds light on multiple dimensions of familiarity and lays the foundation for familiarity design and evaluation. The proposed familiarity design guidelines and instrument may help the game designers and players to maximize the exercise effect of exergames for older adults. Meanwhile, other games and intelligent systems targeted for elderly users may also apply the proposed guidelines and instrument to improve user experience through familiarity design. In this part, we focus on the experimental studies involved with elderly participants to test the effectiveness of familiarity design on improving older adults' game experience and the validity of the proposed familiarity model, guidelines and instrument.

To ensure the reliability and validity of the studies, we referred to the commonly used study methods and data analysis methods in HCI research. The most frequently used methodologies including field studies, surveys, observations, interviews and usability studies [192]. Each of these methods has its own advantages and disadvantages. Unobtrusive user observation in the natural settings enables the researchers to identify the most representative patterns to use product in a natural state, but observation research can be time-consuming and fruitless [193].

The survey approach allows the researchers to reach a large number of participants in a relatively short period of time, but the collected data may not represent deep understanding of the research questions [194]. Interview approach allows the researchers to clarify the problems and further investigate subsequent questions when participants provide interesting feedback [195]. However, interviews take significantly more time than surveys. Usability tests provide a fast and relatively low-cost approach to identify key usability issues in an interface or an application, but the test cannot guarantee that all key design issues can be identified [196].

Research methodologies are influenced by the researcher's hypotheses, their rationale for using the research approaches inherent to the study, and their consideration of the justification of how these approaches are used throughout the research process. It is a highly context-dependent issue to choose which method to use in HCI research and studies. The selection of the methods may be influenced by the primary objective of the study, the participant pool, time constraints, funding, and the researchers' experience. This Chapter will introduce the research methodologies applied in the studies in this thesis and explain why these methodologies were applied to evaluate the study hypotheses.

8.2 Study Methods

8.2.1 Phenomenography

Phenomenography is an observational qualitative research method. Marton [197] described the objective of phenomenography research as “description, analysis, and understanding of experiences; that is, research which is directed towards experiential description”. Phenomenology was first used to deal with issues in the content aspects of learning, that is, how the students understand the learning content in different ways; and issues in the the active aspects of learning, that is, how the students experience the learning conditions and the learning behaviors in different ways [198]. Many researchers have adopted this method to qualitatively investigate different ways people experience something or think about something [199–201].

Marton has described phenomenography as “a research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and

understand various aspects of, and phenomena in, the world around them” [197]. Bowden [202] used the model shown in Figure 8.1 to demonstrate the purpose of a phenomenographic study. This model emphasizes that a phenomenographic study aims to investigate the relationships between the subjects and the phenomenon instead of the phenomenon itself.

FIGURE 8.1: Phenomenographic Relationality

Unlike the general observational research, the subjects are not categorized before the experiment in phenomenographic study. It requires a holistic analysis of individual experiences. “In phenomenography individuals are seen as the bearers of different ways of experiencing a phenomenon, and as the bearers of fragments of differing ways of experiencing that phenomenon. The description we reach is a description of variation, a description on the collective level, and in that sense individual voices are not heard. Moreover, it is a stripped description in which the structure and essential meaning of the different ways of experiencing the phenomenon are retained, while the specific flavors, the scents, and the colors of the worlds of the individuals have been abandoned” [203]. Thus, in phenomenographic research, data is collected at the individual level, but the purpose of analysis is to discover the collective awareness and the difference in how the phenomenon is experienced.

Phenomenographic studies focus on “investigating the experience of others and their subsequent perceptions of the phenomenon - their reflections on the phenomenon” [204]. Researchers report on the participants’ experience about the world, rather than the first-order perspective, that is, they already make assumptions and statements about the world before the experiment. The second-order

perspective is more useful in our study to investigate the influence of familiarity design on older adults' game experience. This ensures participants' feedback on the exergame design is from their perspective and not our interpretation.

8.2.2 Survey

A survey is a set of well-defined and well-written questions that an individual is required to answer [205]. It is a very convenient and powerful method to collect data from many individuals. Surveys are frequently used to describe people, explain their behaviours, and to explore information in uncharted waters [206]. Participants can conduct their own surveys without the presence of researchers; therefore, the data collected by the surveys is not as in-depth as other research methods, such as interviews and focus groups [207]. The advantage of the survey in the study is the capability to quickly obtain a relatively large number of responses from the participants. The “big picture” of the results can be investigated through surveys, such as how participants are interacting with the products, what problems they may face during the usage of the products and how they solve the problems. Meanwhile, the results of the survey can be applied with statistical analysis to get an accurate estimation.

The roots of survey research may be “social surveys” conducted by English and American researchers and reformers around the 20th century, who planned to document the severity of social issues such as poverty [208]. By the 1930s, the US government has conducted surveys to document the social and economic conditions in the country. Around the same time, researchers also applied survey research into election polling to predict presidential election [209]. Beginning with market research and election polling, survey research has entered multiple academic fields, such as sociology, public health, and political science, where it still remains one of the main methodologies to collect data.

Since the 1930s, psychologists have made significant progress in the design of questionnaires, including some techniques that are still in use today, such as Likert scales [210]. Survey research has close historical connection with the social psychological research on attitudes, prejudice, and stereotypes. Early attitude researchers

were also one of the earliest psychologists to look for larger and more diverse samples instead of the convenient samples of university students used in conventional psychology.

Survey is also the ideal method in many HCI research and studies. With careful design and strict control, the collected survey data would have high validity. Survey research should be one of the most appropriate methods to measure awareness, attitude, intention, user characteristics, feedback on user experiences, and over-time comparisons [211]. Surveys may not be suitable for making accurate measurements or just to identify usability issues in the interface; however, surveys are often applied as part of a comprehensive assessment of user experience test [211]. In our study, survey is mainly used to collect participants' game experiences towards different exergames. Since surveys mainly rely on participants to self-administer and require them to remember the data that occurred at the previous point, a lot of details of the data collection process should be paid attention to ensure the data to be valid and useful. Most of the participants in our studies are older adults, it is difficult to ensure they can complete the questionnaires smoothly by themselves. Thus, at least one researcher is accompanied by the participant during the survey to avoid invalid data.

8.2.3 Interview

Surveys can be very useful to easily reach a large number of participants. However, surveys are limited: respondents only answer the multiple-choice questions and the open-ended questions are often left unanswered. This can lead to surveys that usually end up being extensive but not deep enough. Interview is a more in-depth research method. By asking questions that explore interviewees' broad concerns about an issue and giving respondents the freedom to provide detailed answers, researchers may use interviews to collect some data that are difficult to capture [207]. If interviewees have the opportunity to answer the open-ended questions that encourage thinking and reflection, interviewees may spend more time discussing, generating ideas, and sharing insights that would otherwise be lost in survey research.

Although sociologists have conducted interview-based research for some time, the work of Barney and Anselm [212] pioneered the integration of qualitative interviews

into their field research and subsequently developed solid theoretical methods for qualitative data analysis. Spradley [213] was among the first to systematically outline interview as a distinct methodology, and this was followed by some methodology textbooks, such as Patton [214] and Arksey and Knight [215], that all provide very detailed guidance on how to design an interview-based research and how to best elicit information by interviewing respondents.

Conducting interviews are more difficult than surveys. It requires a lot of practice to develop the skill of interview. The researchers' main tasks in the interview session include sitting with one or more respondents, listening carefully, taking notes, deciding to give what kind of comments to pursue further questions, and trying to seek and understand non-verbal responses from the respondents, all of which require substantial effort. Interviews are particularly appropriate and useful for understanding the story behind a respondent's experiences. The interviewer can look for more in-depth information around the topic. Interviews would be helpful as follow-up to some survey respondents, for example, to further investigate and understand their responses in survey [216].

Data analysis is another major challenge in interview research. As qualitative research, interview aims to discover central themes of what the respondents experienced and understand the meanings of the themes. The main task of data analysis in interview research is to understand what the respondents mean [217]. It takes a great deal of time to transform the original notes and audio recordings of the respondents' answers to broad questions, for example, an hour of audio recording can take up to ten hours to transform [218]. Separating important information from the unimportant and distinguishing good results from the bad can also be a challenge.

Interviews also share some inherent shortcomings with surveys. They both suffer from problems of recollection for respondents because of the separation of the data collection and the actual tasks. As participants report on their experiences and perceptions of needs, they are only sharing with you what they still remember. Although this may still provide much useful information, it is, by definition, a step away from the reality. When you ask users for comments on a product, the respond you get in the interview may differ from the respond that the same person may present when actually experiencing the product [207]. The interview-based research is also limited to a small number of participants due to the high workload

requirements. It is easy for surveys to be sent to a large number of respondents. However, interviews have more restrictions. If each interview takes one hour, the researcher must spend an hour chatting with the interviewee and several hours analyzing the results.

To avoid these potential disconnects, we combined both surveys and interviews in our studies to collect both broad and deep results from the participants. All the participants filled the survey questions and their general feelings to the exergames were collected. The interview seeks to cover both a factual and a meaning level of the participants' game experiences.

8.3 Data Analysis Methods

8.3.1 Statistical Analysis

Statistical analysis is the science of discovering the underlying patterns and trends by collecting, exploring, and presenting large amounts of data. It allows us to determine our confidence that the observed patterns and trends from the participants can be generalized to the entire population [219]. It is also a powerful tool to help us discover the differences in the data and identify relationships between various variables.

Before conducting the significance test, the data should be cleaned, carefully coded, and properly organized to meet the requirements of a specific statistical software package. The appropriate significance test methods should be applied according to the nature of the collected data and the experiment design. If multiple conditions or groups were involved in the experiment, in most cases, the ultimate goal of the researchers is to find the differences between the conditions or groups. If the between-group design is applied during the experiment, the two groups of participants will perform two different tasks (in most cases, they will be the intervention and control groups). If the within-group design is applied, each participant will accomplish both tasks. According to the design of the experiment, different statistical methods will be applied to analyze the results.

Most statistical methods can be applied to compare the means of multiple groups, such as the control and intervention groups. For example, a simple t-test can

compare the means of two groups, where an independent sample t-test is used for between-group design, and paired sample t-test is used for within-group design [220]. When using a between-group experiment design and involving only a single independent variable, the one-way Analysis of Variance (ANOVA) test enables us to compare the means of three or more groups. Factorial ANOVA test is more appropriate when the between-group experiment design involves two or more independent variables. These methods are all parametric tests which require the data to be normally distributed and interval scale.

Some of the data we collected during the study cannot meet the requirements of normal distribution and interval scale, for example, the results of Likert scale questions in the survey. The non-parametric tests should be used. The Chi-squared test is widely applied to analyze the categorical data with frequency counts [221]. Other commonly used non-parametric tests include the Mann-Whitney U test [222], the Kruskal-Wallis one-way ANOVA by ranks [223], and the Friedman's two-way ANOVA test [224]. The non-parametric tests enable us to analyze the significance values of the survey results.

Another objective of our studies is to identify the relationships between different factors. The most widely used correlation test is the Pearson's correlation coefficient test [225]. The interpretation of the correlation results r was based on Cohen [226], who differentiates between small effect ($r = 0.1$), medium effect ($r = 0.3$) and large ($r = 0.5$) effects. Regression analysis can investigate the relationship between one dependent variable and multiple independent variables [227]. In HCI-related studies, model construction and prediction are the two main objectives to conduct regression analysis. In our study, we are interested in model construction, which is to identify the quantitative relationship between one dependent variable and multiple independent variables.

8.3.2 Thematic Analysis

Thematic analysis is widely applied to analyze qualitative data in previous research [228]. It is a method to systematically identify and organize the data and provides insight into the patterns of meaning (themes) across the entire data set.

Through focusing on the meaning of the data set, thematic analysis enables researchers to see and understand the collective experiences and shared meanings of the participants.

Braun and Clarke [228] proposed six phases of thematic analysis. This is an approach to learning thematic analysis and to conduct the analysis. The six phases are showing below.

1. **Familiarizing yourself with the data:** This phase involves reading and re-reading the data to immerse and familiarize with the contents of the data.
2. **Generating initial codes:** This phase focuses on generating concise labels (codes) to identify important characteristics of the data that may be relevant to answering the research questions. It involves encoding the entire data set and then organizing all the code and all relevant extracted data for later analysis.
3. **Searching for themes:** This phase aims to examine the codes and organized data to identify the broader patterns of data meaning (potential themes). It then requires to collate the data related to each potential theme so that you can use the data and check the feasibility of each potential theme.
4. **Reviewing potential themes:** This phase involves examining the potential themes against the data set, making sure that the themes can tell a compelling story about the data, and answering the research questions. At this stage, themes are usually refined with splitting, combining, or discarding the potential themes. In the thematic analysis methodology, a theme is usually defined as a pattern of shared meaning supported by a central concept or idea.
5. **Defining and naming themes:** This phase aims to perform a detailed analysis of each theme, including determining the scope, focus and the “story” of each theme. It also include identifying each theme’s informative name.
6. **Producing the report:** This final phase focuses on weaving the analytical narratives and data extracts together and contextualizing the analysis results in relation to the existing literature.

Although the six phases are continuous and each phase is based on the previous phase, Braun and Clarke [228] stated that the analysis is usually a recursive process that moves back and forth between different phases. This method can help us to analyze the qualitative data and summarize the participants' feedback to the exergames.

8.3.3 Content Analysis

The content analysis method has been proved to be an efficient qualitative data analysis method for categorizing the content of visual and verbal data. Content analysis is applying any technology to make inferences by systematically and objectively identifying special characteristics of the information [229]. It is a systematic coding and classification method used to browse a large amount of textual information unobtrusively to determine the trends and patterns of words used, their frequency of use, their relationships, and the structure and discourse of communication [230, 231]. Using content analysis, researchers can quantify and analyze the existence, meanings, and relationships of these particular words, themes, or concepts.

The method will encode categories to indicate the meaningful pieces of the data and interesting content. Previous research indicates that content analysis generally involves six major steps [230]:

- Formulate the research questions and identify the structures involved;
- Select the content to be examined and define the unit of analysis;
- Specify the categories and develop the coding scheme;
- Determine the sample;
- Assess reliability and validity;
- Analyze data and interpreting the findings.

Content analysis is an effective qualitative data analysis method to examine patterns in communication and interview data. We can apply this method to evaluate whether familiarity design in the exergame has been perceived by the participants.

8.4 Chapter Summary

This chapter described the major experimental research methodologies applied in our studies. This research involves four studies to evaluate participants' game experience and the familiarity design in the exergames. Both qualitative and quantitative experimental methods were applied in the studies. Data collection and analysis methodologies in our four studies were briefed in this chapter, and the resultant details are reported in the following chapters.

Chapter 9

Study I: Exploring the Effectiveness of Familiarity Design

9.1 Introduction

¹In this Chapter, we aim to explore whether familiarity has a positive effect on improving older adult's adaptation to exergames. We designed the *Ping Pong* Exergame infused with table tennis activities for exercising older adults' upper limbs. The game offers older adults an enjoyable interactive table tennis environment for physical exercise and cognitive training. Since table tennis is one of the most common sports in Singapore², *Ping Pong* may provide familiar game environments and tasks for older adults who often play table tennis or watch table tennis on TV.

A longitudinal study involving 44 able-bodied Singaporean older adults was conducted. The participants are required to play *Ping Pong* once a week for continuous five weeks and their game performance and feedback to the exergame were collected. The participants were divided into three familiarity groups based on their prior experiences to table tennis. The experiment results show that participants who are more familiar with table tennis received higher game scores and they

¹This chapter is published as Hao Zhang, Chunyan Miao, Qiong Wu, Xuehong Tao, and Zhiqi Shen, The Effect of Familiarity on Older Adults' Engagement in Exergames, *Human Aspects of IT for the Aged Population. Social Media, Games and Assistive Environments*, HCII, Springer, 2019.

²<https://www.channelnewsasia.com/news/singapore/table-tennis-gains-popularity-in-singapore-8127732>

FIGURE 9.1: Ping Pong Exergame.

rated higher satisfaction and enjoyment scores in their feedback. Three categories about the influence of familiarity on older adults' game experience were identified through the qualitative data in this study. The results indicate that familiarity can influence older adults' both ability and motivation to a certain exergame, which means the P-E fit can be improved by familiarity.

9.2 The Ping Pong Exergame

In this experiment, we invite the elderly participants to play *Ping Pong* exergame designed by the Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY). *Ping Pong* is an upper limb exercise game in the theme of table tennis (Figure 9.1). Some fundamental cognitive tasks such as selective attention have also been infused into *Ping Pong* for cognitive training. To play *Ping Pong* exergame, a participant simply stands in front of a Microsoft Kinect and naturally waves his/her chosen arm as if holding a table tennis bat. He/she needs to identify and hits the ping pong ball with designated color and ignore others (to practice selective attention). In this way, *Ping Pong* offers both physical and cognitive training to older adults. Table tennis is one of the most common sports for older adults in Singapore³ and *Ping Pong* offers older adults an enjoyable table tennis environment for physical exercise. For older adults who frequently play table tennis, the interface and interaction mode of *Ping Pong* tend to be more familiar for them.

³<https://www.channelnewsasia.com/news/singapore/table-tennis-gains-popularity-in-singapore-8127732>

9.3 Participants

Forty-four able-bodied Singaporean senior citizens (10 males and 34 females) volunteered to participate in this study. The study was conducted at a community center in Singapore. Participants were aged between 58 to 90 ($M = 71.7, SD = 7.88$). They were divided into three familiarity groups (never play, played a few times, often play) according to their prior experiences to table tennis, which are summarized in Table 9.1. After the experiment, each participant received compensation in the form of shopping vouchers worth 20 Singapore dollars. Institutional Review Board approval was obtained ahead of the experiment.

TABLE 9.1: Participants categorization based on their prior experiences to table tennis.

	Never play	Played a few times	Often play
Group	A	B	C
No.	7	10	27
Mean Age	75	74	70
SD	3.28	2.23	1.26

9.4 Experiment Design

A five-week longitudinal study is conducted to collect participants' long-term performance change and their satisfaction levels to *Ping Pong* exergame. A questionnaire (Table B.1) with five-level Likert scales [210] was designed to collect participants' subjective opinions. The questionnaire includes rated scores for enjoyment, satisfaction, and perceived difficulty while playing *Ping Pong* exergame. Meanwhile, participants' game performance was automatically tracked by the game system. These results allow us to compare the motivation and ability of the participants in different groups, so as to find the impact of familiarity on users' P-E fit. The following four hypotheses were tested in this study:

H1: *Familiarity positively impacts older adults' performance in exergames.*

H2: *Familiarity reduces older adults' perceived difficulty of exergames.*

H3: *Familiarity improves older adults' enjoyment while playing exergames.*

H4: *Familiarity improves older adults' satisfaction for exergames.*

Hypothesis 1 and Hypothesis 2 are related to participants' ability while Hypothesis 3 and Hypothesis 4 concerns their motivation while playing *Ping Pong* exergame. After participants filling the questionnaire, semi-structured interviews were conducted to collect their feedback and game experience to *Ping Pong* exergame.

9.5 Phenomenography as a Qualitative Method

Phenomenography, as a qualitative research method, was first used to investigate why some students were better at learning than others [198]. In phenomenographic research, researchers aim to study how people experience and interact with a given phenomenon, which “is an internal relationship between the experiencer and the experienced” [197]. Although phenomenography was established in an education-related research area, it has been also used in a wide range of other disciplines for qualitative study, including health care and design [232, 233]. Like other qualitative research methods, phenomenography focuses on subjects' understanding of their reality. There are three particular characteristics of phenomenography. Firstly, phenomenographic research can capture the variation of the users with different features to understand and interact with certain phenomenon. Secondly, phenomenography is designed to find the possible relationship between subjects and the phenomenon. Thirdly, phenomenographic research can also illuminate the subjects' performance in certain phenomenon through data collection and analysis. For these three reasons, we applied phenomenography as a qualitative method in this study.

To collect qualitative data during this study, we used observation and interviews to understand participants' ideas about the exergame. Investigators conducted the observation when participants were playing the exergame and watching others playing, including participants' words, actions, body languages and interactions with others. In the interview part, we conducted semi-structured interviews after the last game session. The interview questions included participants' feedbacks to the exergame and their game experience. Then we consider the possible relationship between participants and exergame and how familiarity can influence this relationship.

FIGURE 9.2: Participants are playing *Ping Pong* exergame.

9.6 Procedure

Participants are required to play *Ping Pong* exergame once a week in the community center for five consecutive weeks (Figure 9.2). Upon the first arrival at the experiment venue, all participants filled in a consent form and a short demographic survey before the experiment start. Each participant was allocated a QR code to track their long-term performance. During the experiment, participants were required to play the exergame for about 20 minutes each time. Throughout the whole experiment, one researcher accompanied each elderly participant in case they encounter any problem during the experiment. The researcher also communicated with the participants about their feedbacks to the exergame. After completing all five game sessions, the participants filled the questionnaire to collect their opinions about *Ping Pong* exergame. Then a semi-structured interview lasts about 15 minutes was conducted for each participant to understand their game experience to the exergame. Although we divided the participants into three groups based on their prior experiences of table tennis, they were not aware of the grouping during the whole experiment.

9.7 Results

Thirty-eight out of forty-four participants completed all the five sessions of the experiment. The other six participants each completed four sessions due to their unavailability in one of the five weeks. All participants joined the first and last game sessions. Next, we would analyze the quantitative and qualitative data collected during this study.

9.7.1 Statistical Results

In the quantitative data analysis, we mainly focused on the four proposed hypotheses. We applied the Analysis of Variance (ANOVA) [219] and Kruskal-Wallis test [223] to compare the difference between different familiarity groups. ANOVA is a widely applied statistical method to distinguish the means of three or more groups. One-way ANOVA was mainly applied in this analysis that adopt a between-group experiment design and only one independent variable was investigated with three groups. When only two groups need to be compared, the computation of ANOVA will be simplified to T-tests, which is used to compare the mean values of two groups [220]. To control the influence of users' age on their game performance, we also applied the Analysis of Covariance (ANCOVA) [234] to statistically control for the effects of other variables (Age) that are not of primary interest, known as nuisance variables. Since ANOVA can only be used to analyze the continuous data, for non-parametric data (such as Likert scale results), we applied the Kruskal-Wallis test to analyze the data. The Kruskal-Wallis test is also called one-way ANOVA on ranks, which is a non-parametric approach to compare three or more independent sample groups with equal or different sample sizes. The simplified version of the Kruskal-Wallis test is the Mann-Whitney U test [222], which is used for comparing only two groups.

Considering the fact that a person's age may have a significant influence on his/her game performance, we conducted ANOVA and pairwise t-test to investigate the age differences among the three groups. From the statistical results (as shown in Table 9.2), it can be observed that all the computed $p > 0.05$, which indicates that there is no significant age difference among different groups. Based on these results, we can exclude the effect of age to some extent on players' performance in different groups.

TABLE 9.2: Pairwise t-test and ANOVA results for group age difference.

Pairwise T-Test	t	p
Group A&B	0.16	0.877
Group A&C	1.53	0.135
Group B&C	1.62	0.114
ANOVA: $F(2, 41) = 2.01, p = 0.15$		

H1: Does familiarity improve participants' performance? Participants' performance can be reflected by the in-game scores they received after each game session. We recorded their game scores for all the game sessions and calculated the average scores as their final game performance. We first conducted ANCOVA to check the interactive effect between familiarity and age on participants' performance. The ANCOVA results show that the interactive effect between familiarity and age on participants' performance is not significant ($F(2, 41) = 1.33, p = 0.321$). Then, one-way ANOVA was conducted to compare the performance between different familiarity groups. Table 9.3 shows the ANOVA results. The results indicate that there is a significant performance difference between the three groups. In addition, the group with higher levels of familiarity received higher scores. The effect size for Group A and Group C equals to 1.05. These results support Hypothesis 1 that familiarity can positively impact older adults' performance in exergames.

TABLE 9.3: Game performance ANOVA results.

	Mean Score	<i>SD</i>
Group A	2658	375.2
Group B	2905	225.3
Group C	3076	417.5
ANOVA: $F(2, 41) = 3.61, p = 0.036$		

H2: Does familiarity decrease participants' perceived difficulty? To evaluate the participants' perceived difficulty, we collected their self-rated understanding of the game rules through a five-level Likert scale in the questionnaire. Higher scores represent that the participants perceive less difficulty and they are more confident to complete the game tasks. As Hypothesis 2 is also related to the participants' ability to play the exergame, we first conducted ANCOVA to see the interactive effect between familiarity and age. The ANCOVA result indicates that this interactive effect is not significant ($F(2, 41) = 0.81, p = 0.611$) and the influence of age on participants' rated scores is not significant ($F(2, 41) = 0.93, p = 0.578$). Then, the Kruskal-Wallis test was conducted to compare rated scores among different familiarity groups and the results are shown in Table 9.4. The results indicate a significant difference in rated scores in different familiarity groups. The effect size for Group A and Group C equals to 0.46. However, the mean score of Group B is smaller than Group A, which is contrary to the hypothesis. To test

whether the difference between Group B and Group A is significant, we then conducted a pairwise analysis through the Mann-Whitney test. The Mann-Whitney test result indicates that there is no significant difference between the two groups ($z = 0.745, p = 0.456$). In summary, the data provide partial support for Hypothesis 2. In particular, the group with the highest level of familiarity to table tennis would perceive significantly less difficulty when playing PPE than other groups.

TABLE 9.4: Perceived difficulty Kruskal-Wallis test results.

	Mean Score	SD
Group A	4.0	0.22
Group B	3.7	0.26
Group C	4.4	0.14
Kruskal-Wallis: $H = 7.61, p = 0.022$		

H3: Does familiarity improve participants' enjoyment? Participants' enjoyment was also collected through a five-level Likert scale in the questionnaire. We conducted the Kruskal Wallis test to compare the rated enjoyment among different familiarity groups. Table 9.5 shows the Kruskal Wallis test results, which indicate that the influence of familiarity on participants' enjoyment is not significant ($p > 0.05$). The effect size for Group A and Group C equals to 0.89. Hypothesis 3 is not supported by the results. However, the p value is smaller than 0.1 and the effect size is large, which presents some effects of familiarity on improving players' enjoyment. Meanwhile, the mean values of the rated enjoyment increase with higher levels of familiarity, which indicates some effect of familiarity on improving participants' enjoyment during the exergame.

TABLE 9.5: Enjoyment Kruskal-Wallis test results.

	Mean Score	SD
Group A	3.57	0.37
Group B	3.60	0.27
Group C	4.19	0.16
Kruskal-Wallis: $H = 4.91, p = 0.086$		

H4: Does familiarity improve participants' satisfaction? In the questionnaire, we asked participants to rate their overall satisfaction to play *Ping Pong* exergame with a five-level Likert scale. The Kruskal-Wallis test results of rated satisfaction in different groups are shown in Table 9.6. The effect size for Group

A and Group C equals to 0.48. The results indicate that familiarity has a significant influence on participants' overall satisfaction. From the mean scores, we can find that groups with a higher level of familiarity rated higher satisfaction scores. Therefore, Hypothesis 4 is strongly supported by our data.

TABLE 9.6: Overall satisfaction Kruskal-Wallis test results.

	Mean Score	<i>SD</i>
Group A	3	0.22
Group B	3.1	0.18
Group C	3.7	0.13
Kruskal-Wallis: $H = 8.93, p = 0.012$		

Participants' longitudinal game performance: During the longitudinal study, the *Ping Pong* exergame was supposed to be more familiar to the participants with more times they played. Table 9.7 shows the participants' average scores in each week. The "Observation" column indicates the numbers of the participants in that week. All the participants attended the game play session in the first and last week. From the mean scores we can find the improvement of participants' performance with their increased familiarity levels to the *Ping Pong* exergame. We conducted a t-test between the average scores in first and last week. The result shows participants' performance was significantly improved in Week 5 ($t = -4.51, p < 0.01$). Then we conducted a simple linear regression for each participant based on their performance in five weeks. The averaged slope of the regression results for all the participants is 124, which indicates participants' game scores would increase by 124 points per week. Therefore, we summarized that participants' game performance was improved with increasing of their familiarity levels to the exergame.

TABLE 9.7: Participants' performance on each week.

Week	Mean Score	<i>SD</i>	Observation
1	2663.2	662.8	44
2	3009.5	494.6	42
3	3006.0	490.6	40
4	3144.0	627.4	40
5	3145.0	449.6	44

9.7.2 Phenomenographic Results

The qualitative data of participants' game experience was collected from observation and interview. The phenomenographic study of the data revealed three qualitatively different categories of game experiences related to familiarity for older adults. The categories were formed following the criteria outlined by prior phenomenographic research [197]. In this research, each category tells us a distinct game experience when playing familiar exergame, including learning efficiency, enjoyment, and social communication. The meanings for each category are described in the following section with representation observation and interview results.

Category 1: Familiarity is a way to improve older adults' learning efficiency.

In this study, investigators taught the participants when they first played the *Ping Pong* exergame. During our observation, some participants can quickly understand the rules and master the skills to play the exergame. They can manage to hit back the coming ping pong ball at a perfect time as if they hold a paddle in their hand. They also received a very high game scores at the end of each game session. After the game session, we interviewed them immediately about why they can quickly master the game. Some representative answers are showing below:

- *"It is just like playing table tennis. I often play table tennis with my friends and I can predict when I should hit back."*
- *"I often watch table tennis on the TV, the exergame is easier than a real table tennis match, I don't need to move my feet and just chose the correct balls and hit."*

Through their interview and observation results, we found participants with some prior experience to table tennis can quickly master the skills to play this exergame. Their standing posture, hitting position and timing are more professional than other participants. Therefore, they took less time to learn the exergame and received a high game score. From the observation and interview, we believe older adults' familiar feelings to the exergame can improve their learning efficiency.

Category 2: Familiarity is a way to improve older adults' enjoyment

Exergames can encourage older adults to take exercises with interesting tasks in entertaining environments. The phenomenographic results indicate participants' familiar feelings to the exergame can increase their enjoyment during game play. During the observation, most of the participants enjoyed the exergame. The following examples are some participants express why they enjoy playing the *Ping Pong* exergame:

- *"Because I often play table tennis, I received a very high score in this game. The high score makes me feel very happy."*
- *"Table tennis is quite fun and I used to play table tennis with my grandson and friends. The skills to play this game are the same as the way to play table tennis and I enjoy playing this game."*

The interview results show that many participants with prior experience to table tennis give very positive feedbacks to *Ping Pong* exergame. Their existing feelings and skills to table tennis can encourage them to be engaged in this exergame. Thus, familiarity design should also be a way to improve older adults' enjoyment and satisfaction with the exergame.

Category 3: Familiarity is a way to improve older adults' social communication

In addition to learning efficiency and enjoyment improvement, the study also found familiarity can improve participants' social communication. Some example of the observation of representative actions from participants who are more engaged in social communication are showing below:

- Stand near the game devices and watch others playing the exergame after completing their own game session.
- Guide other participants to play the exergame.
- Discuss game skills with other participants.
- Encourage their family, friends even strangers to join the game session.

We believe all these actions can indicate the participants' high interest to *Ping Pong* exergame and can also increase their social communications. They communicate with each other about the exergame and expand their social network. We interviewed participants who are very engaged in social communication. The representative reasons for their actions are showing below:

- *"Because I'm good at playing table tennis and this exergame, I can teach others and share my experiences with other participants. I will be very happy if others can receive a high game score after my guidance."*
- *"I discuss with other participants because I want to improve my skills and scores. When I'm playing table tennis with my friends, I also discuss with them about the skills."*
- *"I think this game is quite enjoyable, so I want to ask my friends who often play table tennis with me to try and play this exergame."*

The interview results show that participants who are more familiar to the exergame would be more confident to communicate with others and share their experiences. Meanwhile, if the game is familiar to the participants, it can also help deepen the relationship with their friends that possess similar prior experiences. Thus, we believe familiarity can also be a way to improve older adults' social communication.

9.8 Discussion

In this section, we discuss the experimental results and summarize the contribution of our work. We explored the effect of familiarity on the P-E fit between older adults and exergames. Older adults' lack of ability and lack of motivation may result in a poor P-E fit with the environment. Hypothesis 1 and Hypothesis 2 concerns older adults' ability during the exergame play. The results indicate that participants' prior experience to table tennis significantly influence their game performance and their perceived game difficulty. During the study, we found some participants who are familiar with table tennis showed professional posture and mastered the rhythm of hitting quickly. They quickly understand the rules of *Ping Pong* exergame and received high scores after the game sessions. In terms of perceived difficulty, we

found only Group C rated higher scores for their understanding of the game rules. This suggests that the participants who often play table tennis are really confident to play *Ping Pong* exergame. Although participants in Group B did not rate higher score for their understanding of game rules than those in Group A, the in-game performance of Group B is actually significantly higher than Group A. Therefore, although the participants only play table tennis a few times in their daily life and they are not confident enough of their table tennis skills, they still perform better than participants with no experience of table tennis at all.

Hypothesis 3 and Hypothesis 4 focus on participants' motivation while playing *Ping Pong* exergame. However, Hypothesis 3 is not supported by the statistical results, which means that participants' enjoyment is not significantly improved with familiarity. Yet some effect of familiarity can be found because the mean enjoyment scores are growing with the increased level of familiarity. Moreover, participants' enjoyment is influenced by many factors. For example, five weeks of the same exergame playing may decrease their enjoyment. Hypothesis 4 is supported by the collected data. Higher satisfaction represents that the participants more enjoy playing the exergame, which can improve the P-E fit between older adults and the exergames. In addition, we found no significant difference of rated scores for enjoyment and satisfaction between Group A and Group B. However, a significant increase of those scores is observed in Group C. This indicates that the influence of familiarity on improving older adults' motivation is more effective when the exergames are highly familiar for them.

Participants' game performance was found to be related to their familiarity levels to the exergame. This familiarity was influenced by the actual encounter of the exergame and increased with more times of occurrence. However, this improved performance may be also affected by the learning effect, which can be a significant factor in mid and long-term studies. The learning effect is a positive or negative effect from an intervention that only becomes pronounced after certain times of occurrence. Familiarity should also increase after several times of occurrence. Thus, the effect of familiarity and learning effect may share the same mechanism. However, more studies should be conducted to understand the familiarity and learning effect.

Three categories about the influence of familiarity on older adults' game experience were summarized in the phenomenographic results. The improvement of

users' learning efficiency indicates older adults' ability can be enhanced with a familiar feeling. The enjoyment and social communication improvements correspond to their motivation enhancement in P-E fit model. The qualitative data also suggests that older adults' ability and motivation in exergames can be improved with familiarity.

9.9 Chapter Summary

In this chapter, we suggest that older adults' feelings of familiarity can improve their adaptation to exergames. We posit that familiarity can potentially enlarge the positive affect zone in P-E fit model by enhancing older adults' both motivation and ability. A study involving 44 Singaporean older adults was conducted to evaluate the impact of familiarity. The experimental results show that familiarity can positively influence participants' ability and motivation in the exergame. Thus, we suggest that familiarity design can increase older adults' engagement in exergames and improve the P-E fit. From the study, we find that different people may experience different levels of familiarity feeling with the same exergame. Although the feeling of familiarity is related to people's past experiences and varies from person to person, we can always find some shared experiences and stories for the older adults from the same region, culture or with the same hobbies.

Chapter 10

Study II: Evaluating Escape Room Exergame

10.1 Introduction

¹*Escape Room* exergame was carefully designed following the familiarity design guidelines, in this Chapter, we conducted a pilot study to evaluate whether the exergame is familiar to our target older adults. Meanwhile, participants' satisfaction with *Escape Room* exergame was also assessed in this pilot study. Qualitative study methods were mainly applied in this study. Five participants were invited to play *Escape Room* exergame and shared their feedback to the exergame through semi-constructed interviews. Content analysis was used to analyze the qualitative data on the five sub-constructs of familiarity. The study results indicate that the *Escape Room* exergame was familiar for all the participants and they are highly satisfied with the exergame.

10.2 Participants

To be eligible for the study, participants should have lived in Singapore for more than ten years to be a typical representative of our target users. Five able-bodied

¹This Chapter is published as Hao Zhang, Zhiqi Shen, Jun Lin, Yiqiang Chen and Yuan Miao, Familiarity Design in Exercise Games for Elderly. *International Journal of Information Technology* 22(2), 1–19, SCS, 2016

Singaporean older adults (4 females, 1 male) aged between 59 to 70 (Mean= 63.6, SD= 3.77) participated and volunteered as the participants. Semi-structured interviews were applied to collect participants' feedbacks to *Escape Room* exergame. Four participants spoke Mandarin Chinese during the interview and one participant used English. All the interviews were recorded and transcribed into English if the participants speak Chinese. Each participant received shopping vouchers worth 20 Singapore dollars after the interview as compensation.

10.3 Procedure

The study procedure for each participant consisted of a short demographical survey, an exergame play session, and a semi-structured interview. During the exergame play session, each participant was required to play the *Escape Room* exergame twice. One experimenter would accompany the participants and provide necessary help during the game play. During the interview, we asked participants to share their opinions with the game environment and tasks and explain what made them feel negative or positive emotions. Meanwhile, their feelings of familiarity and overall satisfaction with the exergame were collected. The participants were also welcomed to share their design suggestions to improve the *Escape Room* exergame.

At the beginning of the game session, guidance was provided for all the participants on how to play the game. The total game session took around 15 minutes and the semi-structured interview session for each participant lasted for 20 to 30 minutes. The total study was scheduled between 35 to 45 minutes for each participant.

10.4 Content Analysis Results

During the game play session, all the participants, after being taught and going through two tasks at most, are able to continue playing the game and complete different tasks without additional guidance. We applied content analysis to analyze the interview data [230]. By systematically coding the content, we summarized participants' responses and grouped them into these five sub-constructs of familiarity to investigate whether the familiarity design is experienced by the participants.

The data related to the five sub-constructs were coded into five categories of the content. The content of each category is shown below.

- **Prior Experience:** All the participants, with their prior understanding of HDB flat, reported that they were able to identify the game environment to be a living room in an HDB flat (X_I). One participant indicated, *“It (the game environment) looks almost the same as my home.”* Another participant said, *“Looks like a 3-room flat, same as my home. Mine is also a 3-room flat.”* Three participants pointed out that they can recognize the *Escape Room* game environment because they have similar gates, old televisions, or fans at their homes. When being asked about the game environment, the participants can easily associate it with their understanding of HDB flat. For the game task (X_T), four participants indicated that they are very knowledgeable about these tasks and the other one participant said *“I sometimes do housework, but my knowledge about housework still needs to be improved.”* The results show that the participants possess at least basic prior experience of the game tasks.
- **Positive Emotion:** The participants also shared with us their past feelings about the game interface (E_I). One of the participants said *“Of course we love the environment, it is similar to where we live after all.”* Only one participant didn’t show obvious emotion to the game environment. When asked about their prior feelings about doing these tasks at home (E_T), all participants told us they like doing the housekeeping tasks. One participant said, *“My grandson would come and play. I tidy up, clean dust, sometimes cook, and I like that.”* Another participant suggested, *“I think there can be a stove for cooking. I love cooking.”* Their feedbacks show that when the tasks are associated with their family or their own interests, they will show more positive emotions.
- **Occurrence Frequency:** The participants told us that their home environment is similar to the game environment and they stay at home almost every day, which indicates the high levels of occurrence frequency in terms of the game interface (O_I). As for the game tasks (O_T), one participant said *“We wash dishes and cook on our own nearly every day.”* and another participant said *“I do often hang our clothes on hanging poles, but I will hang them on a*

metal pole and push it to the outside.” Some participants reported that the activities implemented in the tasks have a close resemblance to the activities they need to perform daily, so they can complete the tasks faster and easier.

- **Level of Processing:** When asked about the difference between the game environment and their home, most participants can point out some differences clearly. One participant reported the difference of gate design, and said *“It’s just that the steel gate looks different.”* Another participant said, *“The windows are different. Mine is bigger. Mine is the older one, and this could be the newer designs. Mine spans across the wall.”* From the responses of the participants, they know the HDB room in detail, which indicates their deep understanding of the environment (P_I). For the game task (P_T), it is obvious that the participants not only perceive these tasks but do the housework in person, which indicates a high level of processing.
- **Retention Rate:** Retention rate indicates the interval between encounters. When we asked how long they haven’t seen the similar design of HDB flat, all the participants responded that they see it every day (R_I). For the game tasks (R_T), four participants reported that they do the housework every day and the other participant reported that she has done similar housework at home three days ago. This result represents that the participants have high retention rates of the interface and tasks of the exergame.

Table 10.1 summarizes the coded categories of qualitative results, in which “No.” columns represent the numbers of the participants who positively responded that they can experience the five sub-constructs in the exergame. The table shows that more interface familiarity was perceived by the participants than task familiarity. In total, most of the participants felt high levels of the five sub-constructs of familiarity during game play. The interview results show that the *Escape Room* exergame is highly familiar for them, which also indicates the effectiveness of the familiarity design guidelines.

10.5 Findings

However, our experiment showed that some elderly participants could also remember experiences from the distant past. These meaningful experiences are etched in

TABLE 10.1: Summary of participants' feedbacks to the five sub-constructs in *Escape Room* exergame

	Game Interface		Game Task	
	No.	Example Reason	No.	Example Reason
Prior Experience	5	<i>It looks the same as my home</i>	4	<i>I often do these housekeeping tasks</i>
Positive Emotion	4	<i>I like the environment because it is similar to where I live</i>	3	<i>I like doing housework for my family</i>
Occurrence Frequency	5	<i>I often stay at home</i>	3	<i>I do housework nearly every day</i>
Level of Processing	4	<i>I know my home very well</i>	4	<i>I'm very good at housework</i>
Retention Rate	5	<i>I just came from my home</i>	3	<i>I do housework nearly every day</i>

their memory and evoked positive emotions. Therefore, if the related experience is meaningful and can arouse the target users' positive emotions, they should be included in the exergame design.

The participants have also commented that the game will have positive effects for older adults. One participant said, "*The exercises performed in the game are quite good for the elderly like me. They are quite convenient.*" One participant remarked that the game is engaging because it is similar to daily activities. Another participant said, "*This is more of doing daily activities. It exercises my hands. Useful for hand exercise.*" These results show that older adults accept that exergames can help them to maintain their physical capabilities in an entertaining environment.

In general, all the participants indicated a high level of familiarity with the *Escape Room* exergame. They are familiar with the game environment, the required motions and tasks. Familiarity was also found to be effective in improving participants' game experience. For example, one participant said: "*The game feels very familiar for me, and it is easy to learn. I'm very satisfied with this exergame and I hope to play it in the future.*" Thus, we believe familiarity game design can help to bridge the digital divide between older adults and exergames and increase their motivation to play the games.

10.6 Chapter Summary

In this Chapter, we conducted a case study involving five Singaporean elderly participants to evaluate the familiarity design in *Escape Room* exergame. The qualitative results demonstrate that the *Escape Room* exergame has incorporated all five sub-constructs of the familiarity model in its design, which indicates the effectiveness of our proposed familiarity design guidelines.

Chapter 11

Study III: Evaluating Familiarity Model

11.1 Introduction

¹Five sub-constructs was proposed based on literature, including prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, to shed light on multiple dimensions of familiarity. In this Chapter, we aim to evaluate the validity and reliability of the proposed familiarity model.

Fifty-nine Singaporean older adults were invited to join this study. Four upper-limb exergames designed with different interfaces and tasks were involved in this study to ensure the reliability of the study. Questionnaire and interview data about participants' feedback and their assessment of the five sub-constructs on different exergames were collected. The results show that the construct validity of the model is good and all the five sub-constructs have significant positive correlations with familiarity. Moreover, there is a significant positive correlation between the familiarity level and users' satisfaction with the exergames. Semi-construct interviews were conducted after the game play session for 34 participants. The interview results indicate that familiarity is an important consideration when the participants evaluating different exergames. In total, Study III shows a good fit of our

¹This Chapter is published as Hao Zhang, Qiong Wu, Chunyan Miao, Zhiqi Shen, Cyril Leung, Towards Age-friendly Exergame Design: The Role of Familiarity, *CHI PLAY 19: Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play*, ACM, 2019.

FIGURE 11.1: Interfaces of the exergames used in the experiment: (a) Basketball Genius; (b) Flying Eagle; (c) Ping Pong; (d) Escape Room.

proposed familiarity model and the effectiveness of familiarity on improving older adults' satisfaction with the exergames. Next, we first introduce the four upper-limb rehabilitation exergames applied in our study. Then Study III is described in detail with our discussion on the study results.

11.2 Upper-limb Rehabilitation Exergames

To help older adults retain good physical capabilities so that they can enjoy independent living for as long as possible, the Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY)² has designed and developed a number of rehabilitation exergames using Kinect as the non-intrusive motion detection device. To evaluate our proposed familiarity model, we selected four exergames in Study III, including the *Ping Pong* and *Escape Room* exergames that have been

²<http://www.ntulily.org/silver-games/>

applied in previous studies. The interfaces of the four exergames are shown in Figure 11.1, which all target upper limb rehabilitation for older adults. All these games are jointly designed in close collaboration with rehabilitation specialists. The movements of upper-limb for controlling in-game objects follow the proven upper-limb rehabilitation exercises. However, the game interfaces and tasks follow different themes, which may incur different levels of familiarity with older adults. Next, we will briefly introduce the four upper-limb rehabilitation exergames.

Basketball Genius infuses the upper-limb rehabilitation exercises into a basketball training game [235]. Rehabilitation activities are disguised into common basketball playing techniques, such as shooting and dribbling. The game interface is designed as an indoor basketball court to offer the users a sense of immersion and fun. When playing this game, a basketball is shown on the screen and the players need to wave or lift their both arms to complete the shooting or dribbling tasks. The motion amplitude and rhythm are important to accomplish the tasks successfully.

Flying Eagle requires users to mimic the movement of the wings of a flying eagle with their arms [236]. To provide a more immersive and engaging game interface, the environment is designed based on a grassy valley. An eagle is shown on the screen, and the player needs to flap his/her arm(s) like an eagle in order to drive the eagle to fly. The eagle will fly at different speeds and heights according to the players' swing frequency and amplitude, which can help players exercise their upper limbs based on their own health situations.

Ping Pong is based on a table tennis game and is used for exercising older adults' upper-limb functions [237]. To play this exergame, the participants wave their arm (left or right) to hit back the incoming ping pong balls as if holding a table tennis paddle. Hence, the user is placed in a natural setting and uses intuitive body movements to control in-game objects. Moreover, their brain neurons are activated by various stimulating features in the environment, e.g., different ball colors, wave rhythms, etc.

Escape Room requires the users to complete some upper-limb rehabilitation exercises to obtain keys to escape [55]. The game environment is designed based on a common 3-room flat in Singapore. Moreover, six Instrumental Activities of Daily Living (IADLs) are used to design the game tasks. These tasks require players to perform different sets of upper limb movements.

11.3 Participants

Fifty-nine able-bodied Singaporean older adults (42 females and 17 males) were randomly selected to participate in the study. The participants were aged from 56 to 80 ($Mean = 67.3, Median = 68, SD = 6.1$). All participants had lived in Singapore for more than ten years. Older adults who have participated in Study I or Study II were excluded in this study to avoid the learning effect. The experiment took approximately 1.5 hours for each participant to complete. Thirty-four participants voluntarily attended a semi-structured interview and shared their game experience after the exergame playing session, which took around 15 minutes to complete. After completing the experiment, each participant received shopping vouchers worth 20 Singapore dollars as recognition.

11.4 Study Design

To collect the participants' opinions for each exergame, a 7-point Likert Scale questionnaire (Table B.2) was designed for self-assessment of familiarity and user satisfaction. Participants were asked to indicate their level of agreement (from strongly disagree to strongly agree) to the statements in the questionnaire. We collected participants' response to both exergame *Interface* and *Task*. *Interface* refers to the virtual context and environment of the exergame. *Task* refers to the required motions of the users when playing the exergame. In the questionnaire, 5 statements related to the five sub-constructs of familiarity are asked for exergame *Interface* and *Task*, respectively. The statements are tailored for each exergame. For example, *Level of Processing* for *Basketball Genius* game *Task* is assessed through the statement: "Before playing the game, I already fully understood the rules and skills of basketball", and for *Escape Room* game *Task* is assessed through the statement: "Before today, I was already very skilled and experienced at doing housework". There is a total of 14 statements in the questionnaire for each exergame. The other 4 statements assess the participants' overall level of familiarity, user satisfaction, whether they feel the exergame is good for their health, and whether they are willing to play it frequently. The two main hypotheses for the questionnaire results are as follows:

- **H1:** The proposed five sub-constructs are significantly correlated with familiarity.
- **H2:** Familiarity can positively influence older adults' satisfaction with the exergames.

A semi-structured interview was conducted to obtain a deeper understanding of the participants' attitudes towards different exergames. The participants were asked to choose their favorite exergame and share the reasons behind it. They could also express their opinions on how the exergames could be improved. All the interviews were recorded and transcribed into English if the participants speak Chinese. The interview helped us collect more information about the participants' preferences and concerns for exergames, which can be used to guide future exergame designs.

11.5 Procedure

All experiments were conducted in a specified room in the LILY research centre, where all the four exergames were set up. Upon arrival, all participants first completed a consent form and a short demographic survey. During the experiment, participants were asked to sequentially play all four exergames in a random order, each for about 15 minutes. After playing each exergame, the participants filled out a questionnaire to collect their opinions about the exergame. Figure 11.2 shows participants playing the exergames and filling out questionnaires. Throughout the whole experiment, one researcher accompanied each elderly participant in case they encountered any problems during the game play or while completing questionnaires. After completing all the exergames and questionnaires, some participants voluntarily joined the one-on-one short interview. The experimental procedure was approved by our Institutional Review Board.

11.6 Results

We collected a total of 222 valid questionnaires from the 59 participants (*Basketball Genius*: 54; *Flying Eagle*: 58; *Ping Pong*: 54 and *Escape Room*: 56) and 34 interview results. We first conducted an analysis of whether the sampling adequacy

FIGURE 11.2: Participants Playing Exergames and Filling Questionnaires.

is good using the Kaiser-Meyer-Olkin (KMO) test [238] and the Bartlett Test of Sphericity [239]. Both the KMO test result (0.898) and the Bartlett test result ($\chi^2 = 1301.2, p < 0.001$) are statistically significant and indicate that the sampling adequacy is good for further analysis.

11.6.1 Analysis Results for H1

To test the multidimensional factor structure of the familiarity model, we first conducted a confirmatory factor analysis (CFA) [240] to examine the construct

TABLE 11.1: Confirmatory factor analysis results.

Factor	Sub-constructs	Factor loading
Familiarity (Alpha=0.89)	Prior Experience	0.87
	Positive Emotion	0.85
	Occurrence Frequency	0.88
	Level of Processing	0.90
	Retention Rate	0.88

validity of the model and the adequacy of the model fit. In our research, we specify five sub-constructs that are related to the latent variable (familiarity). CFA is commonly used in social science research to test whether the data fit a hypothesized measurement model. It is used to test whether measures of a construct are consistent with our understanding of the nature of the familiarity construct. Adequate internal consistency was first observed through the Cronbach's alpha test ($\alpha = 0.89$). The factor loading results are shown in Table 11.1. Comparative fit index (CFI) and standardized root mean square residual (SRMR) are often used to test the goodness of fit of the model. In general, CFI larger than 0.9 and SRMR smaller than 0.08 represents a good fit of the proposed model in CFA test. The results of our CFA test suggest an acceptable fit of the proposed model ($CFI = 0.922, SRMR = 0.033$). All the CFA results show that our proposed five sub-constructs can effectively model familiarity.

The Spearman's correlation coefficients test [241] was then conducted to test the correlations between the five sub-constructs and familiarity. Spearman's rank correlation test is a nonparametric measure of rank correlation. It assesses how well the relationship between two variables can be described using a monotonic function. For each exergame, the score for each sub-construct of familiarity is calculated by averaging the ratings for the exergame's interface and task. The score for familiarity is the rating for the self-assessment question on their overall feeling of familiarity after playing each exergame.

The results of the Spearman's correlation coefficient test between the five sub-constructs and familiarity is shown in Table 11.2. It can be observed that the Spearman's coefficients are all larger than 0.5, indicating positive correlations between the five sub-constructs and familiarity. Moreover, the significance value is less than 0.01, which indicates that the computed correlations are statistically significant. These results support hypothesis H1 that the proposed five sub-constructs

TABLE 11.2: Spearman's correlations between the proposed five factors and familiarity.

	Prior ex- perience	Positive emotion	Occurrence fre- quency	Level of process- ing	Retention rate
Familiarity	0.694	0.614	0.588	0.652	0.511
Sig.	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

TABLE 11.3: Ordered logistic regression of familiarity on combined five sub-constructs.

Observation=222, Prob(> χ^2) < 0.01				
	Coef.	Std. Err.	z	p
Mean Scores	1.289	0.115	11.21	< 0.001

are significantly correlated with familiarity. From Table 11.2, we can also observe that *Prior experience*, *Positive emotion*, and *Level of processing* have comparatively higher correlations with familiarity than *Occurrence frequency* and *Retention rate*.

In order to evaluate the combined effect of the five sub-constructs on assessing familiarity, we further conducted ordered logistic regression [242] of the overall familiarity scores on the mean scores of the five sub-constructs. Ordered logistic regression calculates a regression model for ordinal dependent variables. The results are shown in Table 11.3. It can be observed that the coefficient between the mean score of five sub-constructs and the overall score of familiarity is positive and statistically significant ($Coef. = 1.289, p < 0.001$). This result indicates that the five sub-constructs, when combined, can provide a good measure of familiarity.

FIGURE 11.3: Rated familiarity scores by box plot.

TABLE 11.4: Rated familiarity scores in the four exergames.

Game	Mean	Median	Std. Dev.	Obs.
Flying Eagle	4.83	5	1.817	58
Ping Pong	4.33	4	1.748	54
Basketball Genius	3.94	4	1.709	54
Escape Room	5.84	6	1.535	56

11.6.2 Analysis Results for H2

In order to test H2, we first conducted familiarity and user satisfaction analysis of the four exergames. Because within-group design was used in this study, repeated measures ANOVA test [243] was mainly used to compare the difference among the four exergames. The repeated measures ANOVA compares means across one or more variables that are based on repeated observations. Then, we conducted a correlation analysis of familiarity and user satisfaction.

Familiarity Analysis of the Four Exergames: Figure 11.3 and Table 11.4 show the average familiarity scores for the four exergames rated by the participants. It can be observed that the familiarity for the four exergames in decreasing order is: *Escape Room* > *Flying Eagle* > *Ping Pong* > *Basketball Genius*. Among the

FIGURE 11.4: Rated satisfaction scores by box plot.

TABLE 11.5: Rated satisfaction scores in the four exergames.

Game	Mean	Median	Std. Dev.	Obs.
Flying Eagle	5.78	6	1.415	58
Ping Pong	5.46	6	1.437	54
Basketball Genius	5.00	5	1.671	54
Escape Room	6.09	7	1.443	56

four exergames, the *Escape Room* exergame received a notably higher mean familiarity score ($Mean = 5.84$). A one-way repeated measures ANOVA test found a significant difference among participants' perceived familiarity for the four exergames ($F_{3,160} = 19.32, p < 0.01$). We then did post-hoc pairwise comparisons among the four exergames. This post-hoc pairwise test can compare the difference between every two groups. We found that most pairwise comparisons are significant ($p < 0.01$), except the comparison between *Basketball Genius* and *Ping Pong* ($p = 0.42$), and the comparison between *Ping Pong* and *Flying Eagle* ($p = 0.64$).

User Satisfaction Analysis for the Four Exergames: Figure 11.4 and Table 11.5 show the results of the participants' rated overall satisfaction with the four exergames. The overall satisfaction with the four exergames in decreasing order is:

FIGURE 11.5: Scatter plot of familiarity and satisfaction.

TABLE 11.6: Ordered logistic regression of satisfaction on familiarity.

Observation=222, Prob(> χ^2) <0.01				
	Coef.	Std. Err.	z	p
Familiarity	0.765	0.087	8.81	< 0.001

Escape Room > *Flying Eagle* > *Ping Pong* > *Basketball Genius*. In general, the mean scores for all four exergames are high (≥ 5), and among the four exergames, *Escape Room* received the highest mean score. We also conducted the one-way repeated measures ANOVA test and the results show that there are significant differences in user satisfaction among four exergames ($F_{3,160} = 6.54, p < 0.01$). However, the post-hoc pairwise comparisons indicate that most of the pairwise differences are not significant. Only the pairwise difference between *Escape Room* and *Basketball Genius* ($p < 0.01$), and between *Flying Eagle* and *Basketball Genius* ($p < 0.05$) are significant.

Correlation Analysis between Familiarity and User Satisfaction: To examine the influence of participants' feelings of familiarity on their overall satisfaction with the exergames, we analyzed the correlation between participants' ratings on the two factors. The scatter plot of rated familiarity and user satisfaction is shown in Figure 11.5. Jittering is added into this plot to avoid the overprinting of points. The fitted values indicate that there is a positive effect of familiarity on user satisfaction. To statistically find the correlation between familiarity and users' satisfaction, we ran the ordered logistic regression test. The results are displayed in Table 11.6. It can be observed from Table 11.6 that the coefficient between familiarity and user satisfaction is 0.765, and it is statistically significant ($p < 0.01$). The regression results indicate that the participants tend to give a higher satisfaction score to an exergame when they feel more familiar with it.

11.6.3 Other Results

In the questionnaires, we also asked the participants to rate whether the exergame is good for their health and whether they wanted to play the exergame frequently if they could. To our surprise, all the four exergames received high scores for the two questions, as summarized in Table 11.7. The repeated measures ANOVA test shows no significant difference among the four exergames. This result indicates that

exergames are viewed to be good for health by the participants and can motivate them to play for longer periods.

TABLE 11.7: Other results of the questionnaire.

Game	Good for health		Frequently play	
	Mean	SD	Mean	SD
Flying Eagle	6.05	1.19	5.90	1.25
Ping Pong	5.98	1.05	5.80	1.17
Basketball Genius	5.80	1.31	5.70	1.30
Escape Room	6.34	1.05	6.21	1.21

11.6.4 Analysis of Interviews

After the game sessions, 34 participants voluntarily joined a one-on-one interview. During the interview, they were asked to select their favorite exergames and explain the reasons behind their choices. The results of their choices are as follows: *Flying Eagle*: 5; *Ping Pong*: 11; *Basketball Genius*: 4; *Escape Room*: 14. *Ping Pong* and *Escape Room* received comparatively more selections than *Flying Eagle* and *Basketball Genius*.

To better understand this result, thematic analysis [228] was used to analyze the qualitative data. In this qualitative data analysis method, coding and developing themes of the raw data are important to interpret the data. It emphasizes participants' feelings, perceptions, and experiences during the study. Themes in thematic analysis results represent levels of meaning or patterned response in data relevant to the research questions. Ideally, a theme will appear multiple times across the data set, but a higher frequency of the theme does not necessarily mean that the theme is more important for understanding the data. The judgment from the researchers is the most important tool in determining which themes are more crucial.

We summarized the reasons provided by the participants for their choices into different themes in Table 11.8. The “No.” column in Table 11.8 represents the number of participants expressed similar reasons. The results show that familiarity is one of the most influential factors that affected their choices. When asked why they made such choices, many participants gave their reasons immediately, such as “*Because I do these household tasks every day*” or “*I used to play table tennis*”

TABLE 11.8: Main reasons behind participants' favorite exergame.

Flying Eagle	No.
<i>It provides a lot of exercises.</i>	2
<i>I like the game environment (Valley).</i>	2
No specific reason.	1
Ping Pong	No.
<i>I used to play ping pong with my friends.</i>	6
<i>I like playing ping pong, it makes me feel happy.</i>	3
<i>I always watch ping pong on TV.</i>	1
No specific reason.	1
Basketball Genius	No.
<i>Basketball is enjoyable for me.</i>	2
<i>I used to play basketball.</i>	2
Escape Room	No.
<i>I often do housework and I enjoy it.</i>	7
<i>The game environment is very familiar to me.</i>	5
<i>It's my duty to do housework.</i>	1
No specific reason.	1

when I was younger", which are related to familiarity. Another important factor is the positive feedback offered by the exergame. One participant said, "*I like Ping Pong game because I played very well and got a high score.*" Five other participants gave similar responses that their good game performance can motivate them to play the exergames. This result indicates that exergame designs with more positive feedback, such as high points and other instant encouragement cues, will attract more older adults to play the exergames. The third influential factor is the older adults' capabilities. For example, most participants said they enjoyed the exergames because they did a lot of exercises while playing. However, three participants indicated that the exergames were a bit difficult to follow.

11.7 Discussion

Our analysis results support H1, that is the proposed five sub-constructs, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, are highly correlated with familiarity. The results show that *Occurrence frequency* and *Retention Rate* have a relatively lower correlation with familiarity (coefficient < 0.6) compared with the other three. The interviews shed

some light on these results. It seems that older adults' past experiences, especially those in their early life, are etched into their memory and will not fade away over time. For such experiences, *Occurrence frequency* and *Retention Rate* have a relatively small impact on their perceived familiarity. During the interviews, many elderly participants recalled experiences from when they were very young and often mentioned keywords such as *childhood* and *many years ago*. Although the time interval between their past experiences and the experiment is very long and they did not have similar experiences in recent years, the participants still remember these experiences vividly and treat them as important cues for familiarity. This result is consistent with the result from previous research that familiarity possibly remains long-lived for some experiences [43].

H2 is also well supported by our analysis results, that is familiarity has a positive impact on older adults' satisfaction with exergames. We observed that *Escape Room* received the highest familiarity scores. One likely reason is that the game interface is designed based on a common flat in Singapore and the tasks are designed based on IADLs that are very familiar to Singaporean older adults. Although we thought *Ping Pong* should be familiar to participants as it is one of the most popular sports among Singaporean older adults, the game received lower familiarity scores than *Flying Eagle*. The reason might be that *Flying Eagle* provides a generally pleasant environment (grassy valley) to evoke participants' positive emotions and improve their feelings of familiarity. Since basketball is not a very popular sport among older adults in Singapore, *Basketball Genius* was rated as less familiar by participants.

In general, we found that exergames with attractive game interfaces and tasks can motivate participants to exercise. The pairwise comparison between the four exergames shows that the influence of familiarity on participants' game experience is inconclusive. The reason is that users' satisfaction with exergames cannot be solely determined by familiarity. It has been shown that various features of an exergame can influence users' satisfaction, such as the difficulty of the game, reward mechanism, and even texture design. This suggests that we should also consider factors beyond familiarity in our future exergame design for older adults.

We also received insightful results from the interviews, especially when the participants explained why they enjoyed the exergames. Most participants explained

their choices by recalling their past experiences, such as playing table tennis, basketball and doing housework. Their responses show that they relate to their past experiences when evaluating the exergames and that there is a close connection between their past experiences and the perceived familiarity. Thus, exergame design infused with familiarity to evoke one's memory and past experiences is likely to be more enjoyable for older adults. The improved capabilities were also found from the participants who are more familiar with the exergames. Therefore, the interview results also showed that older adults' P-E fit with the exergames can be improved through their enhanced enjoyment and capabilities from familiarity design.

An interesting observation is that although *Ping Pong* did not receive a high mean familiarity score, it ranked highly as a favorite exergame. The reason may be because more female participants were involved in the experiment and participants who have no prior experience with table tennis would give a low familiarity score. However, participants who are familiar with table tennis would find this game enjoyable and select it as their favorite game. Thus, it is important to investigate the target users before exergame design.

In summary, we believe that familiarity design can help to improve older adults' satisfaction with exergames. The five sub-constructs provide meaningful and higher dimensions for understanding familiarity. Although the feeling of familiarity is related to people's past experiences and varies from person to person, we can always find some shared experiences and stories for older adults from the same region, culture or with the same hobbies. For example, the *Escape Room* exergame is mainly designed for older adults who have lived in Singapore for a considerable amount of time; most of them are familiar with the game environment and in-game tasks. Considering the similarities of a certain group of older adults, it is possible to design an exergame with familiarity that is suitable for a large group of elderly users.

11.8 Chapter Summary

In this chapter, we conducted a field study involving 59 Singaporean elderly participants to evaluate the proposed familiarity model. To ensure the reliability of

the study, four exergames focus on upper limb exercises with different familiarity levels to the participants were involved. The experimental results show a good fit of the proposed familiarity model and significant correlations between the five sub-constructs and familiarity. The results also find a strong correlation between familiarity and participants' satisfaction with the exergames. Based on the experimental results, we may propose an applicable familiarity instrument based on the five sub-constructs.

Chapter 12

Study IV: Evaluating Familiarity Instrument

12.1 Introduction

In this Chapter, we aim to evaluate the validity and reliability of the proposed familiarity instrument in Chapter 7. To collect indicators describing familiarity, we refer to the research in recognition memory, in which familiarity is often discussed. It has been confirmed that the use of familiarity to access information would accompany the electromagnetic activity over scalp [244]. Research has found that this effect was maximal over the left frontal scalp [45]. Event-related potential (ERP) is commonly measured EEG data to understand users' electrophysiological response to a stimulus [245]. Studies employing ERP found that the amplitude of a negative-going ERP deflection that onsets around 300 ms to 500 ms post-stimulus varied inversely with familiarity strength [46, 246]. Thus, we proposed to use ERP data over the left frontal scalp as a reference to test the *Interface* part of the familiarity instrument.

ERP usually measures the data less than 1 second after the onset of the stimulus. *Task* part, however, requires understanding users' familiarity levels to a whole continuous movement or task (e.g. basketball activity), which can not be measured by ERP data. In electrophysiological measures, action execution and observation are related to a relative decrease in power in the alpha (around 8–12 Hz) and beta frequency bands (around 12.5–30 Hz). Event-related desynchronization (ERD)

refers to a short-lasting and localized amplitude decrease of rhythmic activity [247]. Previous research has found that ERD within alpha and beta frequency band during action observation may reflect suppression of sensorimotor mu-rhythm (around 8-13 Hz) [248, 249], which means the alpha/beta frequency band power may decrease when observing actions. Research on dance movement observation found that users' familiarity to dance movement significantly influence their alpha (7.5-13 Hz) and lower beta (13-18 Hz) ERD results, especially during the time frame from 1 to 2 s after movement onset [135, 136], and higher familiarity results in more suppression of the band power. Therefore, we refer to ERD data to evaluate the *Task* part of the familiarity instrument.

A study involved 20 participants (10 younger adults and 10 older adults) was conducted to evaluate the proposed familiarity instrument. There are two reasons that we include both younger and older adults in this experiment. First, the universal applicability of the instrument to people in different age groups can be evaluated. Second, we would like to compare the effect of familiarity on users' satisfaction to the exergame between different age groups. Convergent validity, criterion-related validity, sensitivity and reliability of the instrument were assessed in a lab-based experiment. Meanwhile, we compared the effect of familiarity on improving users' satisfaction with the exergames for younger and older adults. The study shows that the results of the familiarity instrument were highly correlated with the EEG data and the validity and reliability of the instrument were proved. Next, we describe the study in detail.

12.2 Participants

Ten younger adults (Mean= 25.8, SD= 3.10, 5 males) and ten older adults (Mean= 63.4, $SD = 6.72$, 2 males) took part in this study. There are two reasons that we include both younger and older adults in this experiment. First, the universal applicability of the instrument to people in different age groups can be evaluated. Second, we would like to compare the effect of familiarity on users' satisfaction with the exergame between different age groups. None of the participants have ever seen or played the exergames used in this study. All participants had normal or corrected-to-normal vision and none of them had any history of brain disease and injury. Informed consent was obtained from each participant before the experiment.

Shopping vouchers worth 20 Singapore dollars were received by each participant after the experiment as compensation.

12.3 Exergames

Three exergames were involved in this study, including *Ping Pong*, *Basketball Genius* and *Escape Room* exergames. The three exergames are upper limb rehabilitation exergames which require upper limb movements to complete the game tasks. *Basketball Genius* and *Ping Pong* are designed in the themes of basketball and table tennis, respectively. The two exergames require players to simulate the motions to play basketball or table tennis to complete the tasks. The environment of *Escape Room* exergame is designed based on a typical home environment in Singapore and game tasks are designed as instrumental activities of daily living (IADLs). From our prior experiences and studies, we suppose that *Basketball Genius* and *Ping Pong* should be more familiar to some younger participants since more young adults frequently play or watch these sports. *Escape Room* is posited to be more familiar to older adults because all the older participants have lived in Singapore for more than 20 years and they should have more prior experiences to the designed environment.

12.4 Study Design

To test the validity and reliability of our developed familiarity instrument, we collected participants' ERP data to exergame interfaces and ERD data to exergame tasks as reference. Participants' EEG data were collected first to avoid the testing effect. Then the participants were required to play exergames and fill the familiarity instrument.

For ERP data collection, the participants were required to watch screenshots of the three exergames. Ten screenshots of each exergame were shown on the screen in random order and each screenshot would display for five seconds. Participants' final ERP data results in each exergame were obtained by averaging their ERP results to the ten pictures to reduce the effect of errors. For ERD data collection, three videos related to the task of each exergame (i.e., playing table tennis, playing

basketball and doing IADLs) were displayed to the participants in a random order. In each video, three sections (17 seconds for each section) of the same actions in different scenarios (professional and amateur) were shown orderly. Participants' final ERD results in each exergame were obtained by averaging the ERD results to the three sections to reduce the errors.

After the EEG data collection session, the participants were invited to play the three exergames and fill questionnaires. After completing one exergame, the questionnaire related to this exergame was completed first before playing the next exergame. Besides the familiarity instrument, we also collected participants' overall familiarity and satisfaction levels with different exergames through a 7-point Likert scale.

To determine the quality of the familiarity instrument, four primary psychometric measures were assessed: 1) criterion-related validity, 2) convergent validity, 3) sensitivity and 4) internal consistency.

- 1) **Criterion-related validity** refers to the extent to which results on one measure are associated with results from a separate measure, the latter being taken to be the criterion variable [250]. Because it has been proved that the EEG data can reflect users' feelings of familiarity, the correlation between the EEG data and users' answers to the familiarity instrument was analyzed to assess criterion-related validity. The interpretation of the correlation results r was based on Cohen [226], who differentiates between small ($r = 0.1$), medium ($r = 0.3$) and large ($r = 0.5$) effects.
- 2) **Convergent validity** is presumed when two independent evaluation methods are highly correlated [251]. Prior studies usually apply subjective familiarity assessment with a single metric to determine familiarity. Thus, the correlation between the familiarity instrument result and the single-construct familiarity assessment result was analyzed to assess the convergent validity.
- 3) **Sensitivity** describes the ability of the scale to distinguish between different levels of familiarity. It was assessed by comparing users' group-means of their results to different exergames. Because *Escape Room* exergame is designed with familiar interfaces and tasks for our target users, a significant difference of instrument results for different exergames is to be expected when the familiarity instrument is highly sensitive.

- 4) **Internal consistency** refers to the homogeneity of the items in the measure [252] and is the most commonly accepted measure of reliability. It was assessed by calculating Cronbach's alpha for the instrument [253]. An internal consistency of $\alpha > 0.8$ is expected to be good and $\alpha > 0.9$ is excellent [254].

After assessing the validity and reliability of the familiarity instrument, we compared the effect of familiarity on improving users' satisfaction with the exergames in different age groups.

12.5 Procedure

The EEG data collection has proceeded in a quiet room in our research centre and the game playing session was conducted at a specified exergame room. After signing the consent form, the participant was first required to fill a short demographic questionnaire. Then the investigator confirmed that the participant was seated in comfort and wore the EEG cap for the participant. Four videos were shown to the participants during the EEG data collection. One video related to the screenshots of the three exergames lasts about 4 minutes and the other three videos related to game tasks last about 1 minute. There was a 1-minute break in the middle of each video. In total, the participants need to wear the EEG cap for 10-15 minutes to collect all the data. After the EEG data collection, participants were invited to the game room and played the three exergames in a random order for 5-10 minutes each. When accomplishing the play session of one exergame, the participants were invited to fill the questionnaire for that exergame. After completing all the exergames and questionnaires, the participants would receive their compensation and may leave the research centre. The experimental procedure was approved by our Institutional Review Board.

12.6 EEG Recording and Data Processing

The EEG data was measured and continuously recorded using Emotiv EPOC+¹ device and its software EmotivPro². The headset included 16 Ag-AgCl electrodes

¹<https://www.emotiv.com/epoc/>

²<https://www.emotiv.com/emotivpro/>

FIGURE 12.1: Position of EEG electrodes¹.

aligned with the 10-20 system (Figure 12.1) and a band-pass filter of 0.16 – 83 Hz. After collecting the data, the Independent Component Analysis (ICA) [255] was then conducted to remove ocular artifacts from the EEG data, and then selected appropriate components from the ICA results to reduce the noise generated from the participants' eye and facial muscle movement.

ERP data processing: The ERP data from the left frontal electrode F3 channel was used in data analysis. After the data pre-processing, the cleaned EEG signals in the F3 channel were then cut into epochs that started –100 ms before the onset of each interface picture (0 ms), and ended 1,000 ms after the onset of the same picture. Amplitude values $\pm 150\mu V$ were excluded. For each participant, 10

pictures for each exergame interface were shown during the data collection. The ERP data in F3 were summarized from the 10 onsets of the pictures for each exergame. Thus, we obtained the final ERP results from the F3 channel ranging from -100 ms to 1,000 ms onset of stimuli for each participant in three different exergames.

ERD data processing: The EEG was filtered in five frequency bands from the EmotivPro software, i.e. Theta (4–7 Hz), Alpha (8–12.5 Hz), Low Beta (12.5–16 Hz), High Beta (16–30 Hz) and Gamma (30–100 Hz). Three sections were involved for each exergame task video.

For each section, the filtered raw data were divided into 8-second time segments, starting from the visual control condition (3 seconds) and ending at 5 seconds after movement video onset. The amplitudes of single trials were squared, averaged according to the experimental conditions and converted to percentage change in band power during movement video observation relative to the visual control condition (the mean power within the first 3 seconds) [247]. The time interval between 0 and 5 second after the onset of the movement was partitioned into five segments of with a duration of 1 second and then submitted to statistical analysis, which refers to the prior research [135, 136]. The final ERD results in all the segments (one control and five 1-second duration segments) for each exergames were averaged by the three sections.

TABLE 12.1: Spearman’s rank correlations between the ERP data and interface results.

	300-500 ms	300-400 ms
Prior Experience	0.656***	0.535***
Positive Emotion	0.418***	0.369***
Occurrence Frequency	0.470***	0.362***
Level of Processing	0.557***	0.444***
Retention Rate	0.577***	0.517***
Total Interface	0.680***	0.571***

* : $p < 0.1$; ** : $p < 0.05$; *** : $p < 0.01$

TABLE 12.2: Spearman’s rank correlations between overall task results and ERD data in different segments and frequency band.

Segment	Alpha	Lower Beta	Higher Beta
0-1 s	−0.243*	−0.295**	−0.339***
1-2 s	−0.430***	−0.416***	−0.265**
2-3 s	−0.320**	−0.361***	−0.134
3-4 s	−0.259**	−0.319**	−0.077
4-5 s	−0.190	−0.295**	−0.174
0-5 s	−0.391***	−0.482***	−0.277**

* : $p < 0.1$; ** : $p < 0.05$; *** : $p < 0.01$

12.7 Results

12.7.1 Criterion-related Validity

ERP data and Interface familiarity: Most of the prior research has recognized that the left frontal (F3 channel) ERP mean amplitudes between 300 ms and 500 ms post-stimulus are sensitive to familiarity strength [45, 130, 244]. The lower familiarity strength would result in a larger negative-going mean ERP amplitudes. The study of Jäger et al. [46] found ERP data during the time window between 300 ms and 400 ms correlates with familiarity. Thus, two time windows were tested in our correlation test. We summarized the results of the five questions to “Game Interface” in the instrument as the total *Interface* results. The Spearman’s correlation coefficients test was then conducted to assess the correlations between the ERP data and the *Interface* results. The results are shown in Table 12.1. The five sub-constructs all show at least moderately positive correlations with the ERP data, and all the results are significant. More importantly, the total interface result is highly correlated with the ERP data in both time windows (300-500 ms: $r = 0.680^{***}$; 300-400 ms: $r = 0.571^{***}$). Overall, the criterion-related validity for *Interface* part of familiarity instrument has been supported.

ERD data and Task familiarity: The ERD data in alpha and beta frequency band was found sensitive to familiar action observation, especially during the time frame from 1 to 2 s after movement onset, and higher familiarity results in more decrease of the band power. Because we have separated the time interval between 0 and 5 s after movement onset into five segments of 1-s duration. We first calculate the correlations between the overall *Task* results (summary of the five task-related

questions) and ERD results of the five segments in three frequency bands (alpha, lower beta, higher beta). The results are shown in Table 12.2. Significant negative correlations were found between overall *Task* results and ERD data on alpha and lower beta band. As the ERD data during the time frame from 1 to 2 s after movement onset has been proved to be correlated with familiarity movement [135, 136], we then conducted the Spearman's correlation coefficient test on all the task questions in the familiarity instrument and the ERD data on 1-2 s segment. The results are shown in Table 12.3. Most of the task questions show significant negative correlations with the ERD data. All these results support the criterion-related validity for *Task* part of familiarity instrument.

12.7.2 Convergent Validity

Prior studies usually apply the single-metric assessment to measure familiarity, and we also included the overall familiarity question in our questionnaires. Thus, the convergent validity is measured through the correlations between the familiarity instrument results and participants' rated overall familiarity. The results show that there are significant correlations between the rated overall familiarity with *Interface* ($r = 0.620, p < 0.001$), *Task* ($r = 0.705, p < 0.001$) and the total familiarity results from the instrument ($r = 0.743, p < 0.001$), which supports the convergent validity of the instrument.

TABLE 12.3: Spearman's rank correlations between task results and ERD data during 1 to 2 s time frame.

	Alpha	Lower Beta
Prior Experience	-0.287**	-0.270**
Positive Emotion	-0.238*	-0.230*
Occurrence Frequency	-0.428***	-0.402***
Level of Processing	-0.349***	-0.352***
Retention Rate	-0.419***	-0.360***
Total Task	-0.430***	-0.416***

* : $p < 0.1$; ** : $p < 0.05$; *** : $p < 0.01$

TABLE 12.4: Kruskal-Wallis test on instrument results among different exergames.

	Observations	Mean Score	<i>SD</i>
<i>Basketball Genius</i>	20	43.6	2.71
<i>Ping Pong</i>	20	43.7	2.49
<i>Escape Room</i>	20	56.7	1.83
Kruskal-Wallis: $\chi^2 = 14.91, p < 0.001$			

TABLE 12.5: Kruskal-Wallis test on older participants' instrument results among different exergames.

	Observations	Mean Score	<i>SD</i>
<i>Basketball Genius</i>	10	39.8	2.59
<i>Ping Pong</i>	10	41.1	2.73
<i>Escape Room</i>	10	61	2.26
Kruskal-Wallis: $\chi^2 = 17.19, p < 0.001$			

12.7.3 Sensitivity

To assess the sensitivity of the instrument, the Kruskal-Wallis test was conducted to assess if the familiarity instrument results are able to distinguish between low and high familiarity conditions. *Escape Room* exergame is specifically designed to create familiar environments and tasks for our target users, which is supposed to have higher scores from the instrument. The results in Table 12.4 show that *Escape Room* exergame obtained significantly higher familiarity scores than the other two games. No significant difference between *Basketball Genius* and *Ping Pong* was found in the pairwise Mann-Whitney test ($z = 0.027, p = 0.98$). Because older adults are our main target users, we conducted the above tests again based on the instrument results only from the ten elderly participants. The Kruskal-Wallis test results for the older age group are shown in Table 12.5. The results also show a significant difference between *Escape Room* and the other two exergames. The Mann-Whitney test found no significant difference in instrument results in the older age group between *Basketball Genius* and *Ping Pong* ($z = 0.379, p = 0.70$). To sum up, the results suggest that the proposed familiarity instrument can distinguish between exergames with high and low familiarity with the players.

12.7.4 Internal Consistency

The reliability analysis revealed high internal consistency for the familiarity instrument, with Cronbach's $\alpha = 0.89$. The values were calculated using all the ten questions in the instrument.

12.7.5 Comparison between the two age groups

ERP results comparison: The summarized ERP results in the three exergame interfaces are shown in Figure 12.2, Figure 12.3 and Figure 12.4. The x-axis represents the time of the events and y-axis represents the collected electric potential data. For *Basketball Genius* exergame, younger participants' ERP results between 300 ms and 500 ms are larger than older adults, which suggests that younger participants are more familiar with the interface of *Basketball Genius* exergame. Older participants' ERP results between 300 ms and 500 ms are also lower than younger participants for *Ping Pong* exergame. These results are consistent with our expectations that younger adults should be more familiar with the sports exergames. For *Escape Room* exergame, we can find from the figure that older participants' summarized ERP results are slightly larger than younger adults between 300 ms and 500 ms. However, the control data (ERP data between -100 ms and 0 ms) also

FIGURE 12.2: Summarized ERP results for Basketball Genius exergame.

FIGURE 12.3: Summarized ERP results for Ping Pong exergame.

FIGURE 12.4: Summarized ERP results for Escape Room exergame.

shows larger results for older adults in this figure. Thus, the familiarity level of *Escape Room* interface to younger and older participants may not have a significant difference.

ERD results comparison: Because the ERD data in alpha band was found more sensitive to familiarity, we summarized younger and older participants' ERD data

TABLE 12.6: Mean ERD results on alpha frequency band for the participants in 1-2 seconds segment.

Game	Young Adults		Older Adults	
	Mean	SD	Mean	SD
Basketball Genius	-0.278	0.133	0.048	0.151
Ping Pong	-0.142	0.091	0.056	0.281
Escape Room	-0.202	0.136	-0.692	0.049

on alpha frequency band during the time frame from 1 to 2 seconds in Table 12.6. The results show that young adults' average ERD data in *Basketball Genius* and *Ping Pong* is lower than older participants, which indicates they are more familiar with the game tasks than older adults. However, the T-test results show that the ERD differences between the two age groups are not significant for both *Basketball Genius* ($t = 1.617, p = 0.123$) and *Ping Pong* ($t = 0.511, p = 0.670$) exergames. The results are contrary to our expectation that sports activities should be more familiar to younger adults. Two possible reasons lead to these results. Firstly, we are using the percentage change of the frequency band to represent participants' ERD results, which can be influenced by the ERD amplitude during the control condition and may increase the noise. Secondly, 10 participants for each age group were included during the data analysis, which may easily lead to insignificant results. Thus, more participants may be needed in future studies to find the difference in task familiarity between young and older adults. For *Escape Room* exergame, older adults' ERD data is significantly lower ($t = -3.389, p < 0.01$) than young adults, which indicates the tasks in *Escape Room* exergame is more familiar to older adults.

Questionnaire results comparison: Mann-Whitney test was mainly used in this part to compare the results from two age groups. In general, no significant difference in participants' instrument results in all three exergames between the two age groups was found ($z = 0.66, p = 0.51$). However, older adults rated a significantly higher familiarity scores ($Mean = 61, SD = 2.26$) to *Escape Room* than younger adults ($Mean = 52.4, SD = 2.20$): $z = 2.31, p = 0.02$. Compared to younger adults ($Mean = 5.4, SD = 0.20$), older adults ($Mean = 6.17, SD = 0.13$) rated significantly higher satisfaction scores to the exergames ($z = 2.86, p < 0.01$). However, this difference is not significant if we compared the results by each exergame (*Basketball Genius*: $z = 1.79, p = 0.074$; *Ping Pong*: $z = 1.80, p = 0.073$; *Escape Room*: $z = 1.36, p = 0.17$). There is a significant correlation between users' familiarity

and their satisfaction with the exergame ($r = 0.444, p < 0.001$), which suggests familiarity design is effective to improve players' game experience. We found an interesting result when we were calculating the correlation between participants' task familiarity and their satisfaction with exergames. The correlation was only found significant for older adults ($r = 0.496, p < 0.01$), and it was not significant for younger adults ($r = 0.359, p > 0.05$), which indicates familiarity is more effective to improve users' game experience for older adults than younger adults. In summary, older adults show higher familiarity feelings to *Escape Room* exergame and they are more satisfied with the exergames than younger adults. The influence of familiarity design, especially *Task* design, on users' satisfaction with the exergames is more salient to older adults than younger adults.

12.8 Discussion

Although the effect of familiarity on improving users' game experience to the exergames may vary between young adults and older adults, the familiarity instrument should be useful to evaluate the familiarity levels for all the users. Thus, criterion-related validity has been supported by all of our participants. To find whether the instrument validity is supported for both groups, we conducted the correlation test including only younger or older age group. The results show that the correlation between ERP data and *Interface* familiarity is high for both young adults ($r = 0.631, p < 0.001$) and older adults ($r = 0.751, p < 0.001$). There is also a negative correlation between ERD data (1-2 s segment) and *Task* familiarity for both young adults (alpha band: $r = -0.313, p = 0.09$; lower beta band: $r = -0.480, p = 0.007$) and older adults (alpha band: $r = -0.555, p = 0.002$; lower beta band: $r = -0.391, p = 0.03$). These results show that the familiarity instrument is effective for both age groups. It may be used to evaluate all users' familiarity with different games, applications, and software. One possible impact of the instrument for general users is to evaluate the familiarity levels of a relatively complicated system and improve the usability of it.

In the convergent validity assessment, we compared the overall familiarity rating and the total scores of the familiarity instrument. In previous research, familiarity was usually evaluated by a single-metric assessment, such as the overall familiarity rating [34], frequency of encounter [35] and duration of the objects commercial

availability [144]. Because frequency of encounter is one of our sub-construct (occurrence frequency) and duration of objects commercial availability are not suitable to test all the exergame *Interface* and *Task*, we finally select the overall familiarity rating during the convergent validity assessment. Relatively few methods of evaluating familiarity through questionnaires in previous research is another reason that only one external evaluation method was chosen in our study. We suggest this familiarity instrument can help to evaluate users' familiarity levels to different exergames effectively and efficiently.

In the sensitivity assessment, we posited *Escape Room* was more familiar for the target users than the other two exergames, because the exergame was carefully designed with familiar game interfaces and tasks. The results of the familiarity instrument in this study supported a similar pattern and support our hypothesis and sensitivity of the instrument. The significant difference in users' familiarity levels to *Basketball Genius* and *Ping Pong* was not found despite more participation of basketball was reported in Singapore [256]. One possible reason is that the participation rates of both sports are not high in Singapore and participants who seldom played these sports before would rate low scores of the instrument, which leads the two exergames to receive similar mean familiarity scores.

When comparing two age groups, their familiarity levels to *Ping Pong* and *Basketball Genius* were not significantly different. We expected younger adults should be more actively participate in these sports and be more familiar with the two exergames. When analyzing the results, we found older adults could often remember their prior experiences vividly and still enjoyed them though they hardly participated in these sports for a long time. They could easily recognize the sports and believe they are familiar with them. Thus, their rating scores to "Prior experience", "Positive emotion" and "Level of processing" were high. For *Escape Room* exergame, the game is more familiar to older participants. The possible reason is that all the older participants have lived in Singapore for more than 20 years and the game interface is consistent with their internal image of the home environment. However, some of our younger participants are international students. They are less familiar with the typical Singapore home environment. The result suggests that it is important to investigate the target users to design a familiar exergame for them. The effect of familiarity design on improving players' game experience is found more remarkable for older adults compared to young adults. The result is

consistent with socioemotional selectivity theory [186], which maintains that people's motivations change from being expansive and acquiring knowledge to being finite and requesting for emotion satisfaction as people age. Familiarity design can evoke older adults' past experiences to achieve their emotional goals and improve their satisfaction with the exergames. In addition, the older adults gave significantly higher satisfaction scores to the exergames in total than younger adults did, which proves the attractiveness of exergames for older adults to take exercises.

12.9 Chapter Summary

In this Chapter, we conducted a study involving 10 younger adults and 10 older adults to measure the validity and reliability of the proposed familiarity instrument. Criterion-related validity, convergent validity, sensitivity and internal consistency of the instrument were evaluated in the study based on prior familiarity research in recognition memory. The results indicate good validity and high reliability of the familiarity instrument. Meanwhile, we found that familiarity design in exergame is more effective to improve users' game experience for older adults than younger adults.

Part IV

Conclusions

Chapter 13

Conclusion and Future Work

13.1 Thesis Summary

This thesis has focused on improving the person-environment fit between older adults and exergames through familiarity design. We first identified that familiarity design can improve older adults' both performance and satisfaction while playing the exergames and improve their game experience. The possible rationale is that familiarity is one of the key memory processes in the dual-process (recollection and familiarity) memory model and familiarity often appears to be preserved in aging process compared to recollection. To better understand familiarity, a familiarity model with five sub-constructs has been identified to shed light on multi-dimensions of familiarity. Based on this model, a set of familiarity design guidelines was proposed to help the exergame designers to design familiar exergames for the target users. Finally, an applicable familiarity instrument was proposed to evaluate each individual's familiarity with the exergames. In this section, we will summarize the contributions in detail.

13.1.1 The Effectiveness of Familiarity Design

Exergames are effective to encourage older adults to take exercise. However, due to the perceived difficulty and complexity in adapting to new technologies, it is often difficult to encourage older adults to participate and be engaged in exergame play. The P-E fit theory indicates that two major problems lead to older adults'

maladaptation to the environment, which are lack of motivation and ability. From the literature review, we suggest familiarity can improve the P-E fit by enhancing older adults' both motivation and ability. The Study I involving 44 Singaporean older adults was conducted to evaluate the impact of familiarity. The study results showed that older adults who were more familiar with the exergame received higher game scores and enjoy the exergame more. Thus, we suggest familiarity design can improve the P-E fit between older adults and exergames and enhance their game experience.

13.1.2 Familiarity Model

To obtain a better understanding of familiarity, we proposed five sub-constructs of familiarity based on existing literature and research, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate. The five sub-constructs are supposed to influence the familiarity levels of different stimuli to older adults. Two salient stimuli, namely *Interface* and *Task*, were defined to influence older adults' familiarity feelings in exergames. In order to test the correlations between the sub-constructs and familiarity, Study III involving 59 Singaporean elderly participants was conducted. Four exergames that focus on upper limb exercises were selected in this study. The experimental results indicate a good fit of the five sub-constructs to model familiarity and the five sub-constructs are all significantly correlated to familiarity. Meanwhile, a strong correlation between familiarity and participants' satisfaction with the exergames was also found in this study. The familiarity model exhibits the multi-dimensions of familiarity, which is beneficial for our further familiarity research.

13.1.3 Familiarity Design Guidelines

A set of familiarity design guidelines was proposed based on the familiarity model, including 1) *Correspondence with the real world*, 2) *Evoking positive emotion*, 3) *Providing meaningful stimuli*, 4) *Selecting stimuli with high repeated exposure* and 5) *Considering recent experience*. The guidelines can help designers incorporate familiarity into the exergame design and improve older adults' game experiences. Following these guidelines, we designed the *Escape Room* exergame for older adults

in Singapore. To evaluate the familiarity levels of *Escape Room* exergame to our target users, we invited five Singaporean older adults in Study II to play and give their feedback to this exergame. The study results indicate that all the participants feel this exergame is familiar for them, and the five sub-constructs of familiarity have also been incorporated into the game design. Study II shows the effectiveness of the familiarity design guidelines. The design guidelines can be also applied to other games, software and new technologies designed for older adults.

13.1.4 Familiarity Instrument

The familiarity instrument was then proposed to easily evaluate the familiarity levels of the exergames to each elderly individual. Older adults or their family members can use this instrument to select familiar exergames and game designers can apply the instrument to evaluate whether their games are familiar for the target users. The familiarity instrument was designed based on the familiarity model and the salient stimuli in exergames. To evaluate the validity and reliability of the instrument, we conducted Study IV involving 10 young adults and 10 older adults. The objective EEG data was collected to assess the criterion-related validity of the instrument. The study results indicate reasonable validity and reliability of the familiarity instrument. We also found in this study that the effect of familiarity on improving users' enjoyment in the exergames is more pronounced for older adults than young adults.

13.2 Future work

The research conducted in this thesis could be extended in various aspects. A few of these possible research directions are discussed in this section from four parts: the improvement of the current familiarity model, the interpretation of familiarity instrument results, the customization of familiarity design, and the familiarity design for older adults in other new technologies.

13.2.1 Improving the familiarity model

The five identified sub-constructs of familiarity are derived from previous familiarity literature and research. Our experiment has shown that the five sub-constructs are positively correlated with familiarity. However, there are several limitations of the current work. Firstly, there may exist some factors other than the five identified sub-constructs that influence familiarity, which requires further exploration through more in-depth literature review and experimentation designed with varied settings and more participants. Secondly, the weight of each sub-construct on familiarity is not determined in this thesis and we apply the equal weight during the study. As we have found different correlations between the five sub-constructs and overall familiarity, the sub-constructs may have different importance to influence the feelings of familiarity for older adults from different backgrounds, cultures, personalities and age groups. Thus, more investigations on various groups of older adults should be conducted in the future work to understand the weights of the five sub-constructs for different elderly individuals. Thirdly, the interaction effects may exist between the five sub-constructs. For example, more *Prior experience* can cause deep *Level of processing*. Future work on the interaction effect of the five sub-constructs can also improve the current familiarity model.

13.2.2 Interpreting the instrument results

The proposed familiarity instrument aims to evaluate users' familiarity levels to different exergames and higher summarized scores of the ten questions in the instrument represent higher familiarity levels. A limitation of this work is that we still need an interpretive method to define the standard of acceptable familiarity scores, whether it is the average score (i.e. 35) or maybe a higher score. Interpreting scoring can be complex and further studies and analysis with more participants are needed to determine the marginal standard for good familiarity design.

13.2.3 Customizing familiarity design

We state that familiarity design can improve older adults' game experience and create an age-friendly exergame. However, the familiarity design should be customized for different user groups, exergame purposes, and game-playing context.

For example, from our experiment, we found that some participants who are not familiar with table tennis did not find the *Ping Pong* exergame attractive, but for those participants who are very skilled in table tennis, *Ping Pong* seems to be a very good design option. Thus, customization of familiarity design can cater to the requirements of different older adults. In future work, more feedback will be gathered from the end-users to verify the applicability and feasibility of the proposed guidelines for different situations and target users. The customization of familiarity design can be achieved by deep investigation and survey on the target older adults.

13.2.4 Applying familiarity design in more technologies

Many new technologies have been used to help older adults improve their physical functioning and wellbeing, including virtual reality [36], augmented reality [257] and other video games [258]. For all these new technologies designed for older adults, familiarity design can assist users quickly understand and interact with the technologies and increase users' satisfaction. In the future, the familiarity research on different technologies can be conducted to design more age-friendly products for older adults. The salient stimuli in different products should be identified to evaluate and guide the familiarity design. More specific familiarity design guidelines in each product can be proposed in the future. With familiarity design, we believe older adults can more easily interact with and enjoy the new technologies.

Appendix A

List of Publications

1. Hao Zhang, Qiong Wu, Chunyan Miao, Zhiqi Shen, Cyril Leung, Towards Age-friendly Exergame Design: The Role of Familiarity, *CHI PLAY 19: Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play*, ACM, 2019.
2. Hao Zhang, Sense of Familiarity: Improving Older Adults' Adaptation to Exergames, *CHI'19: the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 2019.
3. Hao Zhang, Chunyan Miao, Qiong Wu, Xuehong Tao, and Zhiqi Shen, The Effect of Familiarity on Older Adults' Engagement in Exergames, *Human Aspects of IT for the Aged Population. Social Media, Games and Assistive Environments*, HCII, Springer, 2019.
4. Hao Zhang, Chunyan Miao, Han Yu and Cyril Leung, A Computational Assessment Model for the Adaptive Level of Rehabilitation Exergames for the Elderly, in *Proceedings of the 31st AAAI Conference on Artificial Intelligence (AAAI-17)*, 2017. (Student Abstract)
5. Hao Zhang, Chunyan Miao and Han Yu, Fuzzy Logic Based Assessment on the Adaptive Level of Rehabilitation Exergames for the Elderly, *5th IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2017.
6. Hao Zhang and Xinjia Yu, Motivational Socio-Emotional Selectivity Model, *The 5th International Conference on Ageless Aging (ICAA)*, 2017.

7. Robin Chan, Hao Zhang and Chunyan Miao, “Serious Game Design for Stroke Rehabilitation,” *International Journal of Information Technology* 23(1), SCS, 2017
8. Hao Zhang, Di Wang and Zhiqi Shen, Computational Assessment on Adaptive Level of Rehabilitation Exergames for Elderly Stroke Patients, *International Conference on Crowd Science and Engineering (ICCSE)*, 2016.
9. Hao Zhang, Zhiqi Shen, Jun Lin, Yiqiang Chen and Yuan Miao, Familiarity Design in Exercise Games for Elderly. *International Journal of Information Technology* 22(2), 1–19, SCS, 2016.

Appendix B

Study Questionnaires

TABLE B.1: Study I Questionnaire.

Age:	Sex: Male / Female
1. How would you evaluate your general health currently?	1 Very poor 2 Poor 3 Fair 4 Good 5 Very good
2. How would you rate your prior experience to play table tennis?	1 Never play 2 Played a few times 3 Often play
3. I find that starting the game is...	1 Very difficult 2 Difficult 3 Fair 4 Easy 5 Very easy
4. Rate your enjoyment of the game.	1 Not at all enjoyable 2 Not so enjoyable 3 Neutral 4 Moderately enjoyable 5 Very enjoyable
5. Rate your satisfaction with the game.	1 Not at all satisfied 2 Not so satisfied 3 Neutral 4 Moderately satisfied 5 Very satisfied

TABLE B.2: Study III Questionnaire.

1: Strongly disagree; 2: Disagree; 3: Slightly disagree; 4: Neutral; 5: Slightly agree; 6: Agree; 7: Strongly agree

Your Age:	Gender: Male / Female						
1. I frequently play basketball in my daily life.	1	2	3	4	5	6	7
2. I frequently come across indoor basketball court environments in my daily life.	1	2	3	4	5	6	7
3. Before playing the game, I already fully understood the rules and skills of basketball.	1	2	3	4	5	6	7
4. Before playing the game, I already fully understood the functions of indoor basketball court environments.	1	2	3	4	5	6	7
5. Before playing the game, I already had a very positive emotion towards basketball.	1	2	3	4	5	6	7
6. Before playing the game, I already had a very positive emotion towards indoor basketball court environments.	1	2	3	4	5	6	7
7. I have played a real game of basketball very recently.	1	2	3	4	5	6	7
8. I came across an indoor basketball court environment very recently.	1	2	3	4	5	6	7
9. I am very knowledgeable about basketball.	1	2	3	4	5	6	7
10. I am very knowledgeable about indoor basketball court environments.	1	2	3	4	5	6	7
11. This exercise game feels very familiar to me.	1	2	3	4	5	6	7
12. I think this exercise game is very enjoyable.	1	2	3	4	5	6	7
13. I think this exercise game is good for my health.	1	2	3	4	5	6	7
14. I'd be willing to play this exercise game frequently.	1	2	3	4	5	6	7

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