Towards Age-friendly Exergame Design: The Role of Familiarity

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ABSTRACT
Exergames have been shown to be effective in helping older adults maintain their physical abilities. However, it is sometimes difficult for older adults to experiment with exergames due to a perceived digital divide. In this work, we propose to bridge this divide through infusing familiarity design into exergames. Specifically, we identify five sub-constructs of familiarity, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate. We evaluate the correlations between these five sub-constructs and familiarity through a field study involving 59 Singaporean older adults. Four exergames designed with different interfaces and tasks were sequentially played by the participants. 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 that all five sub-constructs have significant positive correlations with familiarity. Moreover, there is a high positive correlation between the participants' perceived familiarity of the exergame and their satisfaction with the exergame. Informed by these results, we propose familiarity design guidelines based on the five sub-constructs for age-friendly exergames.

CCS Concepts
•**Human-centered computing** → **HCI design and evaluation methods;** *Empirical studies in HCI;*

Author Keywords
Familiarity, exergame, older adults, game satisfaction

INTRODUCTION
The global population aged 60 years and above numbered 962 million in 2017 and is projected to reach nearly 2.1 billion by 2050 [61]. Older adults may face various health related issues as they age, such as a reduction in physical capabilities. It has been reported that older adults have twice as many disabilities and four times as many physical limitations as people under 60 years of age [16]. A common problem faced by many older adults is a decline in upper limb functional capabilities [63, 22]. 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 [40]. Therefore, maintaining good upper limb functional capabilities is of great importance.

Previous research has shown that rehabilitation exercises can effectively preserve upper limb functionalities [7]. 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 [55].

To improve the adherence to rehabilitation exercises, a great variety of exergames (i.e., games for exercise purposes) with entertaining game graphics and tasks have been proposed [54]. For example, exergames employing body sensing devices, such as the Microsoft Kinect, allow older adults to control in-game tasks with their natural body movements and incorporate physical exercises. Studies have shown that exergames are effective in helping older adults maintain their physical capabilities [5, 17, 70]. Various exergames have been designed for this purpose. However, due to the perceived difficulty and complexity in adapting to new technologies, it is often difficult for older adults to participate and be engaged in exergame play [2]. As highlighted by Loos and Zonneveld [39, 38], this difficulty is often caused by the unfamiliar game interface and task designs.

Indeed, familiarity plays an important role in reducing the perceived difficulty and complexity in navigating in the game environment, and in creating a feeling of harmony and comfort [32]. Psychologically, familiarity refers to the relationship between an individual and something that the individual has had considerable amount of interaction and experience with [32]. The feeling of familiarity can help a person to recall their past feelings and experiences. Thus, by incorporating el-

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ements of familiarity in exergame design, it might be possible to narrow the digital divide and make exergames more attractive and engaging to older adults. Exergame designs that can evoke a feeling of familiarity in older adults may stir up fond memories. They may also help older adults recall approaches to deal with similar environments and improve their exergame playing capabilities [3].

Motivated by the aforementioned benefits, we propose to incorporate familiarity into exergame design for older adults. Familiarity is usually treated as a one-dimensional construct in previous research; it is often approximated by frequency of encounter or evaluated using subjective assessment with a single metric [28, 18, 46]. 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 work, we propose five sub-constructs for familiarity based on the literature, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate, to shed light on multiple dimensions of familiarity. We evaluate 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 show that all five sub-constructs have significant positive correlations with familiarity. Moreover, there is a significant positive correlation between familiarity level and users' satisfaction with the exergames. Based on these findings, we propose five familiarity guidelines, for designing and developing age-friendly exergames to improve older adults' game experience and satisfaction with exergames.

There are three major contributions from this work. Firstly, we propose to incorporate familiarity into exergame design to improve older adults' game experiences. The field study shows that familiarity has a significant positive correlation with older adults' satisfaction with the exergames. Secondly, we propose five sub-constructs for familiarity, which deepen the understanding of familiarity through shedding light on its sub-dimensions. The experimental analysis shows significant positive correlations between the five sub-constructs and familiarity. Thirdly, based on the identified five sub-constructs, we propose familiarity design guidelines for exergame designers to develop more age-friendly exergames.

RELATED WORKS

In this section, we review existing research works that are related to our work from two main aspects: the existing designs for rehabilitation exergames, and previous familiarity evaluation and design approaches for new technology.

Rehabilitation Exergames

Compared with traditional rehabilitation exercises, exergames can make users feel more engaged and motivated, by providing attractive graphical virtual environments and easy control with natural body movement [65]. Exergames are usually implemented on wireless controllable platforms, such as the Nintendo Wiimote and the Microsoft Kinect. These wireless devices require minimal operational support and allow older adults to play with few restrictions [71]. Rendon et al. [51] found a positive effect of exergames on improving dynamic balance and balance confidence in older adults. Uzor and Baillie [62] suggested that older adults show better adherence to rehabilitation exercise with exergames compared to traditional exercises. Loos and Zonneveld [39] showed that playing exergames can have a positive effect on older adults' physical and social wellbeing. Other research [57, 17] have also demonstrated the benefits of exergames on physical outcomes for older adult.

Given the benefits of exergames, a lot of research efforts have been devoted to improving exergame designs for better user experience. For example, Rizzo and Kim [54] emphasized that visibility, feedback, and identification of the target users are three important human factors for exergame design. Balaam et al. [2] suggested that entertainment oriented exergames are effective in engaging older adults. Similarly, Alankus et al. [1] found that motion-based exergames, which combine motion detection with fun elements, can stimulate people to exercise voluntarily. Burke et al. [11] identified *meaningful play* and *challenge* as two principles of game design that have particular relevance to motivating older adults. 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. John et al. [42] proposed to adapt exercise intensity in real-time based on the player' heart rate to avoid over exertion. To provide a better game experience, some exergame design guidelines for frail older players have been proposed [19, 50]. However, few existing research works have considered familiarity in exergame designs to improve the game experience for older adults.

Familiarity

Familiarity is thought to be an unconscious, automatic process that demands minimal attention [64]. Previous research has shown that aging leads to a decrease in memory recollection, but does not influence familiarity [49]. Being familiar with a system means that we are ready to interact with it in an easy intuitive way based on our prior knowledge [23]. Familiarity plays an important role in any product usage. If a user feels familiar with a product, then he or she is more likely to understand its purpose and usage [44]. Son et al. [56] 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. [9] found that familiar surroundings can provide older adults with greater confidence to go outdoors. Barry [4] suggested the incorporation of familiarity into home designs to bring positive changes in older adults' daily lives.

Prior research works usually evaluate familiarity as a single dimensional construct. Some research measure familiarity based on frequency of encounters [46, 6]. Subjective assessment is another commonly used method to measure familiarity [28, 18]. Viewing familiarity as a single dimensional construct limits our understanding of what factors are there to influence familiarity and how they can be used to impact exergame design. Hence, in this work, we explore various sub-dimensions of familiarity to help us generate meaningful design guidelines for developing age-friendly exergames.

Familiarity has been applied in several new technology designs for older adults. For example, Leonardi et al. [34] designed WIMP (Window, Icons, Menus and Pointing) interfaces with familiar interaction modalities to enhance user experience for older adults. Hollinworth and Hwang [27] designed an e-mail application for older users with familiar visual objects and operations. These familiar interfaces have been well received by older users due to their ease of use. However, none of the existing research has considered familiarity in exergame design for older adults.

FIVE SUB-CONSTRUCTS OF FAMILIARITY

Previous research works generally treat familiarity as a one dimensional construct that is mainly measured by frequency of encounter or subjective self-assessment [46, 6]. 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, which have been shown to be correlated to familiarity in the literature.

Prior Experience

Prior experience refers to a person's previous experiences related to the target stimulus. The source of prior experience can come from the stimulus itself or the objects that are semantically related to the stimulus. The prior experience stored in memory influences the level of perceived familiarity. As stated by Yonelinas [68], familiarity depends on the detailed memory of prior knowledge and experience. Jacoby [29] argued that familiarity is not restricted to perceptual information, but also includes the prior experience in one's mind. Lim et al. [36] stated that familiarity is a relative concept, which depends on the prior experience of each user. Therefore, prior experience plays an important role in the perception of familiarity. 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. Moreover, according to O'Brien at al. [47], prior experience has a positive impact on user performance when interacting with new technology.

Positive Emotion

Positive emotion refers to people's past positive emotions 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 [8]. Past moments imbued with emotions are easy for us to recall, and these occasions seem to be remembered most vividly and durably [26]. Meanwhile, memories of past events are often accompanied and influenced by emotions [14]. Laboratory studies conducted by Levine and Edelstein suggested that positive emotions lead to greater reliance on general and relational knowledge [35]; in contrast, negative emotions lead to a focus on specific details. Familiarity does not require remembering the details of a past event. Rather, general feelings are more important. Moreover, studies have shown that the affect associated with negative (or unpleasant) memories tends to fade faster than the affect associated with positive (or pleasant) memories [33, 53]. Therefore, positive emotions linked to past events are more likely to produce a sense of familiarity than negative emotions. 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 [58].

Occurrence frequency

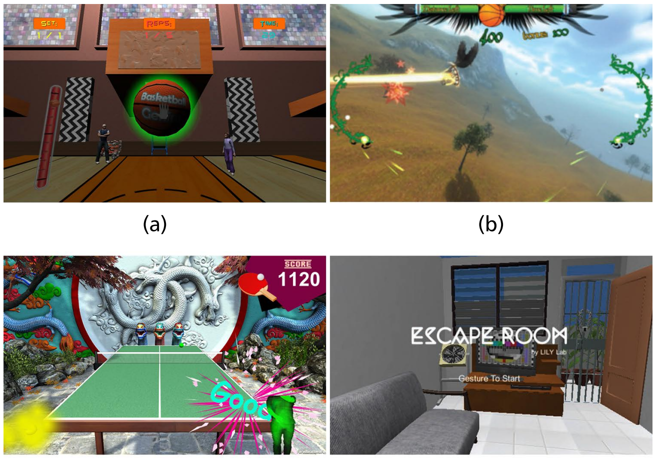
Occurrence frequency refers to the frequency of a stimulus encountered by an individual as stored in his/her memory. Many studies have indicated that the more times people encounter a stimulus, the deeper memory they will have. According to Thompson et al. [59], rehearsal frequency is related to the self-reported strength of personal memories to a stimulus. Meghan et al. [37] also suggested that occurrence frequency can influence the vividness of an event in a user's memory. Moreover, studies have shown that occurrence frequency positively influences the feeling of familiarity. As suggested by Jacoby [30], repetition of usage increases the familiarity of items. Yonelinas [68] also stated that the repetition of the stimuli leads to increases in familiarity and recollection. Xiong's experiment [67] showed that people's feeling of familiarity is sensitive to the frequency of encounter. Moreland and Zajonc [41] also found that repeated exposure to a certain item will increase the feeling of familiarity. Therefore, familiarity is greatly influenced by the occurrence frequency.

Level of Processing

Level of processing refers to the depth of processing in one's memory. Compared with shallow processing (perception-based), deep processing (meaning-based) leads to a consistent enhancement in familiarity, due to the prominent improvement in both recognition and recall [68]. A number of findings suggest that meaning-based processing can better support familiarity [60]. For example, Jacoby [29] 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. [64] found that familiarity is more sensitive to conceptual processing (deep processing) than to perceptual processing (shallow processing). Rhodes and Anastasi [52] found that people with a deep-level-of-processing recalled a significantly greater proportion of information than those with a shallow-level-of-processing. Therefore, how deeply a person processed a similar stimulus in prior experiences may significantly influence the level of familiarity with the current stimulus.

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. The longer the interval between the encounters, the greater the decrease in the user's feeling of familiarity. As highlighted by Yonelinas [68], familiarity exhibits pronounced forgetting



(a) (b) (c) (d)

Figure 1. Interfaces of the exergames used in the experiment: (a) Basketball Genius; (b) Flying Eagle; (c) Ping Pong; (d) Escape Room.

(a) Clearing the Table (b) Hanging Laundry (c) Washing Dishes (d) Tidying Bookshelf

Figure 2. Examples of game tasks in the Escape Room exergame.

effects across short-term and long-term delays (i.e., minutes to months). Hockley [24] 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. [59] suggested that an increase in retention interval would result in a decrease in memory. The experimental results of Hockley and Cinsoli suggest that familiarity decreases with delays (of 30 mins, 1 day, 2 days and 7 days) [25].

THE FIELD STUDY

To understand how the above-mentioned five sub-constructs are correlated with familiarity in the context of exergame playing, we conducted a field study involving 59 Singaporean older adults. The 59 participants were asked to play four well-established upper-limb rehabilitation exergames in a random sequence, and then their questionnaire and interview data were collected for analysis.

The two main hypotheses for this study 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.

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)[1] has designed and developed a number of rehabilitation exergames using Kinect as the non-intrusive motion detection device. For this study, we selected four exergames, as shown in Figure 1, which 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 to 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 [12]. 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 [13]. 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 [48]. 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 [71]. The game environment is designed based on a common 3-room flat in Singapore. Moreover, six Instrumental Activities of Daily

[1] http://www.ntulily.org/silver-games/

Living (IADLs) are used to design the game tasks, including *clearing the table*, *tidying bookshelf*, *hanging laundry*, *washing dishes*, *switching television channels* and *opening the lock of the house gate*. Some example game tasks are shown in Figure 2. These tasks require players to perform different sets of upper limb movements.

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. The experiment took approximately 1.5 hours for each participant to complete. 34 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.

Study Design

To collect the participants' opinions for each exergame, a 7-point Likert Scale questionnaire was designed for self-assessment of familiarity and user satisfaction. Participants were asked to indicate their level of agreement to all the statements in the questionnaire. For collection of participants' responses to the exergames, we identify two major stimuli that can affect familiarity in exergames, namely *Interface* and *Task*, based on prior research on exergame design guidelines for older adults [19, 50]. *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 levels of familiarity and satisfaction to the exergame, whether they feel the exergame is good for their health, and whether they are willing to play it frequently.

A semi-structured interview was conducted to obtain a deeper understanding of the participants' attitude towards different exergames. The participants were asked to choose their favorite exergame and share the reasons behind. 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.

Figure 3. Participants Playing Exergames and Filling Questionnaires.

Procedure

All experiments were conduced 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 feedback to the exergame. Figure 3 shows participants playing the exergames and filling out questionnaires. Throughout the whole experiment, one investigator 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 semi-constructed interview. The experimental procedure was approved by our Institutional Review Board.

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 verified whether the sampling adequacy is good using the Kaiser-Meyer-Olkin (KMO) test and the Bartlett Test of Sphericity. 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.

Table 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

Table 2. Spearman's correlation coefficients between the proposed five factors and familiarity.

	Prior experience	Positive emotion	Occurrence frequency	Level of processing	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 3. Ordered logistic regression of familiarity on combined five sub-constructs.

Observation=222, Prob($> \chi^2$) $<$0.01

	Coef.	Std. Err.	z	p
Mean Scores	1.289	0.115	11.21	< 0.001

Table 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

Analysis Results for H1

To test the multidimensional factor structure of familiarity model, we first conducted a confirmatory factor analysis (C-FA) to examine the construct validity of the model and the adequacy of the model fit. Adequate internal consistency was observed through the Cronbach's alpha test (Alpha=0.89). The factor loading results are shown in Table 1. Results of the CFA suggest an acceptable fit of the proposed model (CFI=0.922, SRMR=0.033).

The Spearman's correlation coefficients test was then conducted to test the correlations between the five sub-constructs and familiarity. 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 the player's 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 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. This results support hypothesis H1 that the proposed five sub-constructs are significantly correlated with familiarity. From Table 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 of the overall familiarity scores on the mean scores of the five sub-constructs. The results are shown in Table 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.

Analysis Results for H2

In order to test H2, we first conducted familiarity and user satisfaction analysis of the four exergames. Then, we conducted a correlation analysis of familiarity and user satisfaction.

Familiarity Analysis of the Four Exergames: Figure 4 and Table 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 four exergames, the *Escape Room* exergame received a notably higher mean familiarity score

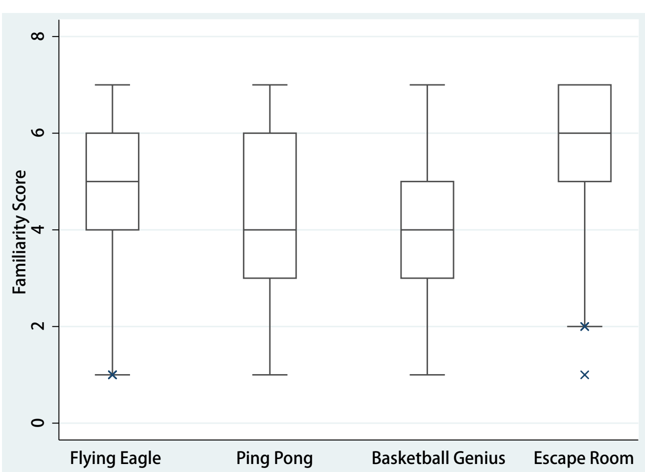


Figure 4. Rated familiarity scores by box plot.

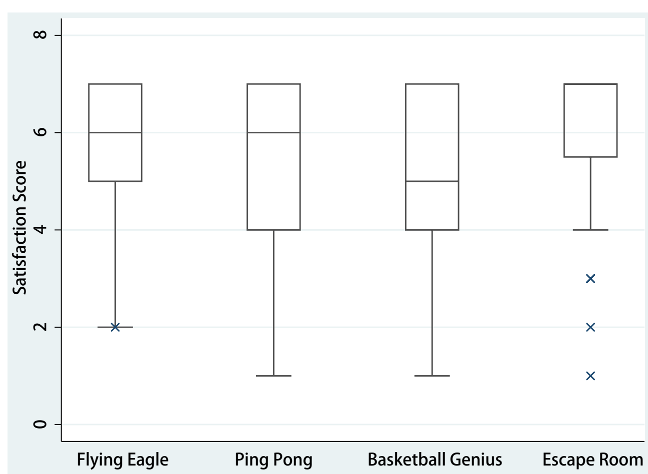


Figure 5. Rated satisfaction scores by box plot.

Table 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

($Mean = 5.84$). 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. We found that most pairwise comparisons are significant ($p < 0.01$), expect 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 5 and Table 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: *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 of 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 6. 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

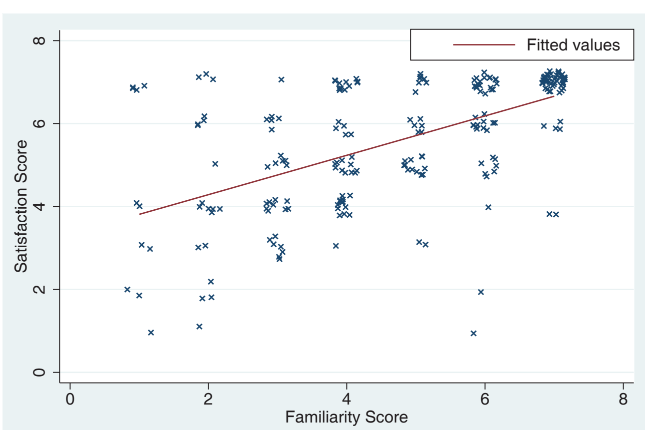


Figure 6. Scatter plot of familiarity and satisfaction.

Table 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

Table 7. Other results of the questionnaire.

Game	Good for health Mean	Good for health SD	Frequently play Mean	Frequently play 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

users' satisfaction, we ran the ordered logistic regression test. The results are displayed in Table 6. It can be observed from Table 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. This finding supports hypothesis H2 that familiarity can positively influence older adults' satisfaction with the exergames.

Other Results

In the questionnaires, we also asked the participants to rate whether the exergame is good for their health and whether they wanted 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 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.

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 was used to analyze the qualitative data and we summarized the main reasons provided by the participants for their choices in Table 8. The "No." column in Table 8 represents the number of participants expressed the 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 everyday*" or "*I used to play table tennis 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

Table 8. Main reasons behind participants' favorite exergame.

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

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.

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 [68].

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.

An interesting observation is that although *Ping Pong* did not receive a high mean familiarity score, it ranked highly as a favourite 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.

FAMILIARITY DESIGN GUIDELINES

Previous research works have provided general guidelines for exergame design for older adults [19, 50]. 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 based on 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 real world, so that they can be related to users' prior experiences. Norman [45] has advocated using objects in our everyday, such as doorknobs and light switches, as inspiration and sources for guiding how interaction and interfaces of computers should be designed. Several participants in our experiment pointed out that they can recognize the *Escape Room* game environment because they have similar gates, old televisions, or fans at their homes. 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 [23], 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 [8]. Due to the diverse personal experiences of users, it may be difficult to identify the stimuli that can evoke positive emotions in each individual. Thus, it is important to find some common features of target users, such as their culture or hobbies. For example, the room environment we designed in the *Escape Room* exergame is based on a typical Singapore flat. Most of the participants said they were familiar with this environment and had a feeling of being at home. In addition, 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, as in *Flying Eagle* [21]. 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 [15], semantic processing extracts the meaning of a stimuli and aids the memory to recall with depth. Memory encoding strength derived from higher level-of-processing appears to be preserved despite losses in other memory functions as people age [20]. Hence, providing meaningful stimuli in exergames can potentially enhance the playing experience by evoking deeper level-of-processing. For example, some tasks in *Escape Room* were designed based on general housework. One participant said, *"It's my duty to do such housework, so I enjoy it."*. Other participants also indicated that they would feel happy if they can clean the room. These tasks were assigned meanings on the elderly participants and increased their satisfaction with the exergames. A meaningful analysis of information with deep processing in older adults' mind leads a better memory recall [23]. 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 [69]. 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 favourite 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 [43]. 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, such as the home environment in *Escape Room* exergame. However, our experiment showed that some elderly participants could also remember experiences from the distant past. These meaningful experiences are etched in 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.

LIMITATION AND FUTURE WORK

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 depth literature review and experimentation designed with varied settings and more participants.

Secondly, the results of our experiment were obtained from a single source, i.e., questionnaire survey. To more objectively evaluate familiarity, in our future work, we propose to obtain a second source of familiarity measurement through event-related potentials (ERP) signals, which have been shown to be very sensitive to familiarity [66, 31]. Combining the results from both sources, we are going to develop an applicable familiarity evaluation instrument for exergames based on the five sub-constructs.

Moreover, the proposed familiarity design should be customized for different 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. In our 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. Meanwhile, we will improve our exergames by infusing more familiarity designs for our target users based on the proposed guidelines.

CONCLUSION

We proposed to incorporate familiarity design into exergames to provide a user-friendly game environment for older adults. In order to obtain a better understanding of familiarity, we identified five sub-constructs of familiarity based on the existing literature, namely prior experience, positive emotion, occurrence frequency, level of processing, and retention rate. In order to test the correlations between the five sub-constructs and familiarity, a field study involving 59 Singaporean elderly participants was conducted. Four exergames that focus on upper limb exercises were selected for this study. The experimental results show that all five sub-constructs are significantly correlated to familiarity and there is a strong correlation between familiarity and the participants' satisfaction with the exergames. Based on the experimental results, 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.

ACKNOWLEDGMENTS

This research is supported, in part, by the Singapore Ministry of Health under its National Innovation Challenge on Active and Confident Ageing (NIC Project No. MOH/NIC/COG04/2017).

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