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A Computational Assessment Model for the Adaptive Level of Rehabilitation Exergames for the Elderly

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Abstract

Rehabilitation exergames can engage the elderly in physical activities and help them recover part of their deteriorating capabilities. However, most existing exergames lack measures of how suitable they are to specific individuals. In this paper, we propose the Computational Person-Environment Fit model to evaluate the adaptability of the exergames to each individual elderly user.

Introduction

Rehabilitation exercises aim to help the elderly recover lost capabilities and live independently. As an alternative mechanism for delivering rehabilitation exercises to the elderly, exergames can motivate them to follow the rehabilitation routines through the appealing and easy-to-follow interfaces and interesting tasks, which decreases the monotony of repetitive exercises. Moreover, the elderly may play the rehabilitation exergames at home without having to travel to the clinics. However, prior studies on exergames seldom consider the adaptive level of an exergame to an individual elderly. It is not easy to suggest suitable exergames to a specific individual, taking into account his/her personal situations.

In this paper, we propose the Computational Person-Environment Fit (CoPEF) model. It jointly considers the personal and environmental situations facing an elderly user to determine the adaptive level of the rehabilitation exergames to the elderly. The original Person-Environment (P-E) fit model has been proven to be useful in assessing home environment adaptive levels (Iwarsson and Slaug 2010). However, prior studies on P-E fit model mainly focused on the physical environment and the majority of them only conducted qualitative analysis. Therefore, we aim to adapt the CoPEF model to obtain quantitative results for virtual exergame environments, which are becoming increasingly ubiquitous today.

The CoPEF Methodology

CoPEF consists of three steps. The first two steps require us to identify the barriers involved in the exergames and the individual's functional limitations. The third step is to apply the computational framework to quantify the adaptive level.

Step 1. Assessment of barriers in exergames

This assessment quantifies the barriers in a give exergame hindering the elderly from playing effectively. It corresponds to the environment stimuli in the conventional P-E model. We identified 31 barriers which may prevent the elderly from playing the exergames. The 31 barriers can be categorized into five groups: 1) external environment, 2) cognition, 3) hearing, 4) vision, and 5) motion.

The detailed information of the exergames can be provided by the game developers. We quantify the severity of the barriers in a particular exergame by assigning scores from zero to three. If we denote the score of the ith barrier as S_{Bi}, then we have $S_{Bi} \in \{0, 1, 2, 3\}$, where $i = 1, 2, \ldots, 31$. A higher score denotes a more serious barrier, while zero indicating the absence of this barrier.

Step 2. Assessment of functional limitations

Motor and cognitive impairments exist among many seniors. However, the degree of impairments varies across individual. We identified 13 major functional limitations for the elderly. These limitations can be categorized into two groups: 1) physical functional limitations and 2) perception and cognition limitations.

Based on the each individual elderly's conditions, we score the severity of their functional limitations ranging from zero to six. If we denote the score of the jth limitation of an elderly individual as S_{Lj}, then we have $S_{Lj} \in \{0, 1, 2, 3, 4, 5, 6\}$, where $j = 1, 2, \ldots, 13$. If an individual does not suffer from the jth functional limitation, $S_{Lj} = 0$. On the other hand, a higher score represents a more serious condition.

Step 3. Computation of the adaptive level

Based on the requirements of each exergame, the interactions between the 31 barriers in Step 1 and the 13 functional limitations in Step 2 can be classified into three groups according to how much they may hinder the elderly: 1) Full-Restriction (FR), 2) Partial-Restriction (PR), and 3) Non-Restriction (NR). FR suggests that the elderly who suffer from these functional limitations are unable to play an exergame with the corresponding barriers. PR suggests the

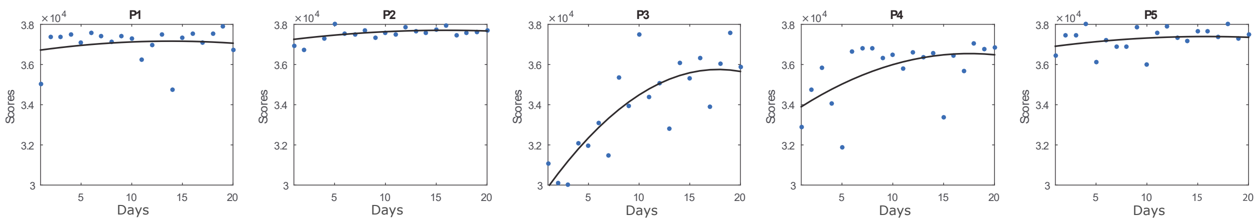

Figure 1: Participants' performance comparison in the Virtual Table Tennis game platform.

players will encounter some obstacles during the game play, but they are still able to play the game. PR provides the right amount of challenge for an elderly user to reap the benefits of rehabilitation exercises. NR suggests the functional limitations have no influence on certain barriers in the exergame.

The degree of the interactions between the barriers and the functional limitations differ across both the exergames and the elderly. Therefore, we use coefficients to quantify the interactions between them. Let c_{ij} denote the coefficient between the ith barrier and jth limitation. The c_{ij} value should be determined by the restriction group it belongs to, which is defined as follows:

$$c_{ij} = \begin{cases} \infty, & \text{if } c_{ij} \in FR, \\ 1, & \text{if } c_{ij} \in PR, \\ 0, & \text{if } c_{ij} \in NR, \end{cases} \tag{1}$$

After introducing c_{ij}, we can compute the total score of the adaptive level S_T, which is determined by an individual's functional limitations (S_L), barriers in the exergame (S_B), and their interaction (c):

$$S_T = \sum_{i=1}^{31} \sum_{j=1}^{13} (c_{ij} \times S_{Bi} \times S_{Lj}), \tag{2}$$

where S_T denotes the adaptive level of a given exergame to a specific elderly user.

According to Lawton and Nahemow (Lawton and Nahemow 1973), both relatively high or low scores are negative to an individual's adaptation. Therefore, we define S_{min} and S_{max} to denote the minimum and maximum values of S_T for the appropriate range of adaptation, in which the therapeutic goals could be most effectively attained. The values of S_{min} and S_{max} should vary among different exergames which contain various barriers. Following the suggestions of the rehabilitation professionals, we define S_{min} and S_{max} as follows:

$$S_{min} = \sum_{i=1}^{31} S_{Bi}, \quad S_{max} = \sum_{i=1}^{31} (2 \times S_{Bi}). \tag{3}$$

From Eq. 3, we can find that for a particular exergame and a particular individual, if any c_{ij} belongs to FR, then S_T definitely exceeds S_{max}. In other words, the elderly patients are not recommended to play the exergames in this case.

Empirical Evaluations

In April 2016, five elderly participants were invited to join our empirical study, in which they played the Virtual Table Tennis (VTT) exergame. Over a 20-day period, they spent 30 minutes on average playing the game. We compute the total CoPEF scores S_T for each participant in VTT (P1:118, P2:126, P3:236, P4:254, P5:108). The minimum and maximum values of S_T in VTT for appropriate adaptation S_{min} and S_{max} are 128 and 258. From the results of CoPEF we can identify that the scores of P1, P2, and P5 are less than S_{min}, which suggests VTT is not adaptable for them to play. The scores of P3 and P4 are within the $[S_{min}, S_{max}]$ interval, which represents the appropriate adaptive levels of VTT to these two participants.

Figure 1 shows the actual trend of game scores obtained by each participant. It can be observed that the performance of P1, P2, and P5 remains relatively stable. However, the performance of P3 and P4 exhibits significant improvements. These empirical findings are consistent with our predictions that VTT will be beneficial to P3 and P4, but may be too easy for P1, P2, and P5. The fact that the predictions of the computed CoPEF scores are consistent with the empirical studies reflects the usefulness of CoPEF.

Conclusions and Future Work

Exergames are proven to be effective for the rehabilitation. In this paper, we define the CoPEF model to compute the adaptive level of the exergames to individual elderly, and then to recommend the appropriate exergames. The empirical results show that our CoPEF model is effective. In future, we will further evaluate the validity of the CoPEF model by conducting more user studies on various exergames.

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