A Virtual Reality Lower-Back Pain Rehabilitation Approach: System Design and User Acceptance Analysis

Wu-Chen Su[1(✉)], Shih-Ching Yeh[2,3], Si-Huei Lee[4,5], and Hsiang-Chun Huang[3]

[1] Chang Gung University, Taoyuan, Taiwan
wuchen_sue@hotmail.com
[2] School of Mobile Information Engineering (SMIE), Sun Yat-Sen University, Guangzhou 510275, People's Republic of China
[3] Department of Computer Science and Information Engineering, National Central University, Taoyuan, Taiwan
yehshch@mail.sysu.edu.cn
[4] Department of Physical Medicine and Rehabilitation, Taipei Veterans General Hospital, Taipei, Taiwan
[5] National Yang-Ming University, Taipei, Taiwan
leesihuei@gmail.com

Abstract. Low back pain (LBP) affects people of all ages and it is a very common health problem globally. Eighty percent of all people may have experienced LBP in their life. Furthermore, there is no perfect strategy which can be used to treat all kinds of LBP patients. Moreover, LBP rehabilitation takes a long period of time, while patients may lack motivation to finish the entire course of treatment. As a result, LBP poses substantial impact on individuals, organizations and society. Fortunately, the advancement of computing hardware and software offer us a virtual reality based solution in the rehabilitation field. For example, cheaper and highly accurate wearable devices can also be used to coordinate with analytical software packages in order to carry out motion tracking and measure a patient's movement promptly and effectively.

Therefore, in this study, a VR-based LBP rehabilitation system utilizing wireless sensor technologies to assist physiotherapists and patients in undertaking three stages of rehabilitation exercises for low back health is proposed. The major functions of this VR system are as follows: (1) Monitor and correct a patient's posture to establish basic movement patterns. (2) A physiotherapist can customize appropriate rehabilitation programs for an individual patient in order to enhance muscle strength and endurance. (3) Provide supports to a patient so as to establish whole body and joint stability.

A total of twenty LBP patients have been recruited for this study, and a user acceptance of technology questionnaire is used to investigate the effectiveness and efficiency of the system proposed. Participants are treated 2–3 times a week for 4–6 weeks and experimental results demonstrate that uses of this VR system for rehabilitation courses have a high degree of technology acceptance and patients are willing to continue to use this system for LBP rehabilitation in the future.

Keywords: Wireless sensor IMU · Virtual reality · Low back pain

M. Antona and C. Stephanidis (Eds.): UAHCI 2015, Part III, LNCS 9177, pp. 374–382, 2015.
DOI: 10.1007/978-3-319-20684-4_37

1 Introduction

Low Back Pain (LBP) poses an impact on any affected individual's muscle strength, flexibility and endurance and may be accompanied by many associated diseases such as depression, anxiety, and low self-efficacy [1, 2]. As a result, medication costs and other tangible burdens are increased and witnessed in our society [3]. The main LBP type is Non-Specific Low Back Pain (NSLBP) which is induced in the cases when individuals have poor posture, overburden the pertinent muscles or injure themselves in sports [4]. However, traditional programs of LBP rehabilitation usually are laborious and tedious for patients and require the full attention of physiotherapists to monitor, to record and to correct inappropriate motions of patients. This leads to a lack of objective assessments as well as unsatisfactory rehabilitation progress. In spite of this, those suffering LBP most numerously are middle-aged individuals who provide economic support to their families; they work industriously and need physical exercise in their daily activities to reduce recurrence of LBP [3]. Through understanding the limitations of current approaches and how and when such fail to meet the needs of LBP suffers, LBP prevention and administration have to align principles to achieve: (1) Reduction of pain, (2) Prevention of disability and (3) Maintenance of work capacity [5] as design guidelines and further use in the application of therapeutic development.

Recently, this VR-based therapy has been used to administer LBP intervention in various populations, for example, Kim et al. [6] assigned thirty middle-aged female patients to either a physical therapy program or a VR-based yoga program for a period of four weeks. The results indicate that the VR-based yoga program can be employed as a therapeutic medium to prevent and to cure LBP. Park et al. [2] investigated the effects of different exercise programs on chronic work-related LBP. They randomly assigned factory workers to either a lumbar stabilization exercise group or a Nintendo Wii exercise group. After an eight week intervention, they found that the Nintendo Wii exercise program demonstrated influences on mental health due to its gaming components. In sum, the need for a comprehensive and interdisciplinary rehabilitation program with a combination of treatments, education, strengthening exercises and fitness training are suggested in these studies.

In a LBP rehabilitation study, the researcher McGill points out that a fixed and unchangeable intervention program could not achieve expected treatment outcomes and also finds that the creation of spine stability should be a first priority. Once pain stability is established and the pain is resolved, many patients find that their mobility returns without further intervention [5]. Therefore, McGill develops the three training stages for back health and includes associated exercises found effective for the treatment of LBP sufferers. However, it can be readily observed that some individuals are not very "body aware" to successfully perform motion suggestions upon command. An example of this difficulty is for instance when a physiotherapist must place a straight bar along a patient's spine while asking the patient to maintain contact with it for separating hip rotation from lumbar motion in rehabilitation sessions [5]. Additionally, physiotherapists need to prepare various training tools and facilities, and that requires their physical presence all of the time. As a result, additional efforts at rehabilitation assistance and performance measurements are carried out by other medical staff. Additionally, the present VR system should offer the capacity for patients to blend learning patterns into daily activities due to the fact that the recurrence rate of LBP is more than sixty percent [7]. Consequently, people can easily relate to the circumstances targeted by LBP rehabilitation tasks with which they are familiar in their workplace or home to prevent a recurrence of LBP, e.g. rising from a chair and sitting, carrying heavy objects, etc. However, such familiar tasks are rarely found in current LBP intervention studies. Thus, these requirements enable us to develop and configure an interactive and flexible VR-based therapeutic approach alleviating deficit to provide immediate visual and auditory feedback to users, and allowing physiotherapists to monitor movements of patient and use statistical information tracked and analyzed for further treatment support and medical decision making. Through building the aforementioned mechanisms, the benefits to the mental and physical health of patients can be improved by this work.

The objective of this paper is two-fold: (1) present the design and development of a VR-based LBP rehabilitation system to measure joint flexion angle via a self-built wireless sensor modules and provide visual and auditory feedback to the user which is based on reestablishment and analysis of human postures in the training session; and (2) understand the technology acceptance of system users and summarize their feedback as per future work.

This essay is organized as follows: In Sect. 2, the system design requirements, IMU measurement system, strategies of rehabilitation and the methods used for analysis and evaluation are presented. Section 3 presents the experiment design, setup and analytical results obtained in this present study. Section 4 summarizes the contributions of this work and highlights future research directions.

2 Materials and Methods

2.1 System Design Requirements

The system requirements are collected and summarized from a research literature review and discussions with physiotherapists and attending hospital physicians via multiple interviews and meeting discussions. Subsequently, a VR system using Unity 3D engine as the development platform and accompanying with revised therapeutic guidance in [5, 8] is proposed. The three training stages for back health are: (1) Motion correction (2) Exercises for LBP (3) Increase muscle endurance and strength. In each stage, the rehabilitation tasks of a patient are measured by an inertial measurement unit (IMU) measurement system in real time and patients can see themselves as a projected avatar on the screen with information about training frequency, measuring angle, time remaining, etc. This offers consistent assistance to patients performing the exercises as defined by medical staff. Accordingly, if the result is correct then the system communicates this to the patient; if not, the system provides specific visual and auditory advice to encourage the patient to complete the rehabilitation tasks in the correct way. Furthermore, all patient training histories and outcomes are recorded in the system for further analysis of the patients' rehabilitation progress by physiotherapists.

2.2 IMU Measurement System

The primary hardware sensor for measuring the joint flexion angle and motion trail is a 9DOF Razor IMU (SparkFun Electronicstems Inc., USA), which includes a gyroscope, a magnetometer and an accelerometer for differentiating between when the subject is stationary versus walking. Furthermore, it integrates a Xbee wireless module (Digi International Inc., USA) to transmit the patient's rehabilitation information to a personal computer. We adopt it as a transmission medium due to its low cost designs, low energy consumption and support of reliable and short distance wireless transmission. In conclusion, the integration of these computing devices is very suitable for us to implement a highly flexible measuring mechanism and use it in various LBP rehabilitation scenarios (Fig. 1).

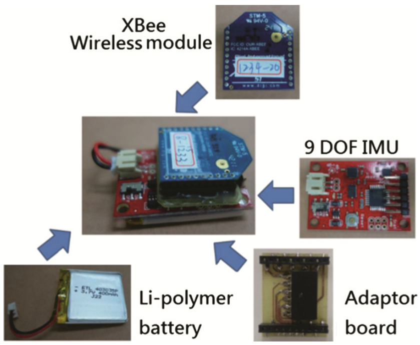

Fig. 1. Overview of own-built wireless IMU measurement system

2.3 Three Training Stages for Back Health

The used therapeutic guidance is amended from [5, 8] and a summary of three training stages is depicted in Fig. 2.

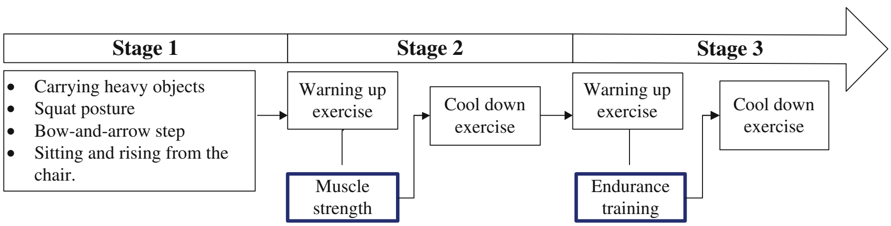

Fig. 2. Overview of three training stages for back health

Fig. 3. Overview of VR-based LBP rehabilitation system

2.4 Technology Acceptance Questionnaire

In order to understand the perceptions of the VR system users, we invite all patients to complete the technology acceptance questionnaire after experiments. The content of questionnaire is designed with five constructs according to a combination of technology acceptance model (TAM) and flow theory [9, 10], and their definitions are:

1. Presence: Does understanding the presentation, setup environment and given information of the VR system help users to complete the tasks assigned or not.
2. Usefulness: Can the resources (i.e., physiotherapist and VR system) effectively guide the users to complete the task assigned or not.
3. Playfulness: While using this VR system for rehabilitation training, do patients will feel interested or not.
4. Intention to use: Would the patients recommend the proposed VR system to friends or use it themselves for LBP rehabilitation in the future.
5. Perspectives of flow theory: Do the patients feel that they can integrate use of the training scenarios and feel satisfied while using the VR system.

There are in total 31 questions designed and these can be scored with a Likert 7 point scale, for instance, 1 = "Strongly Disagree" and 7 = "Strongly Agree." The outcomes of this study can assist us to understand users' satisfaction and the limitations of this VR system allowing their subsequent use as a base for future improvements.

3 Results and Discussions

3.1 System Overview

In Fig. 3, recruited participants fasten wireless IMUs on their upper back and/or left thigh with elastic Velcro straps depending on different assigned tasks. Afterwards IMUs will transmit angle information from the affected side to personal computer and a mounted projector will project an avatar on a display screen with analyzed information immediately. Simultaneously, physiotherapists can work with patients to adjust training targets, provide customized support and reduce the burden incurred by traditional training sessions.

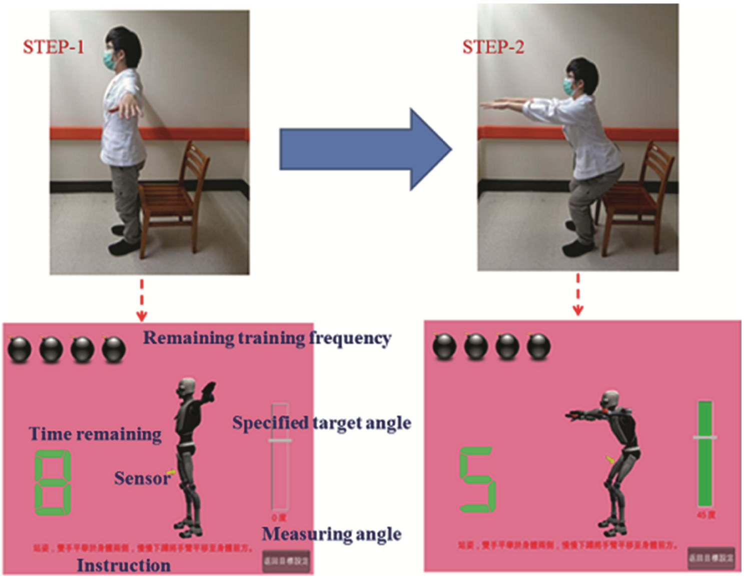

Fig. 4. Overview of rehabilitation information tracked and analyzed

3.2 System Functions

The patient has to maintain a specified angle for a particular target angle for a pre-defined period. Further, after completing one repetition, a virtual bomb will explode on the screen to reward the user for task completion. However, if the user fails to finish their assignments, the VR system will encourage them with auditory feedback, i.e., “You have almost done it!”, “You can do it!” and “Keep trying!” The description of each item of information tracked is depicted in Fig. 4. In addition, the physiotherapist and patient can access rehabilitation performance and training histories stored in the system, for example, rehabilitation motion, completion date, training frequency, etc. A physiotherapist may utilize this information as a basis to define a new round of training if necessary. The essential concepts are demonstrated in Fig. 5.

3.3 Experiment Outcomes

In this interventional study, participants invited meet inclusion criteria and agree to sign consent forms. An understand has been sought as to whether this VR-based rehabilitation system is acceptable to LBP patients with regards to constructs of presence, usefulness, playfulness, intention to use and perspectives of flow theory. Therefore, in total twenty participants for experimental treatments are studied. Their average age is 65 years old and the average LBP period of duration is 14 months. An exit survey was distributed and collected from eighty percent of participants and indicates that most participants are satisfied with this VR system. Specifically, the feedback from visual, auditory responses by the system and information on the screen are a useful resource to guide the system users to complete their tasks. Furthermore, patients also feel that they are interested in

Fig. 5. Rehabilitation course setup and demonstrated performance record

the design of the avatar and projected information on the screen and this also encourages them to step into a new form of training. To that end, participants have readiness to recommend this system to their friends and relatives when these individuals do have similar rehabilitation requirements. In the meantime, participants also look forward to the addition of a serious game design to be added and implemented within these rehabilitation exercises. To sum up, it is creditable to conclude that the proposed VR-based system for assisting rehabilitation of LBP sufferers of this study has a potential to be accepted by the target LBP rehabilitations population (Table 1).

Table 1. Descriptive statistics and reliabiltiy analysis (N = 16)

Construct	Mean†	SD	Cronbach's α value
Presence	5.94	0.92	.933
Usefulness	5.97	0.81	.798
Playfulness	5.31	1.27	.836
Intention to use	5.63	1.36	.924
Perspectives of flow theory	5.84	1.04	.814

† Rating categories from (1) strongly disagree to (7) strongly agree.

3.4 Discussions

In this study, there are twenty male LBP patients effectively treated with the proposed VR-based LBP rehabilitation programs. The recent studies by Park et al. [2] and Kim et al. [6] also recruited LBP patients to participate in Wii-based rehabilitation programs. By comparison this innovative VR-based system considers varied LBP training exercises and attempts integration of the training into a patient's daily routines. Consequently, it offers a better, customized and individualized rehabilitation program which is not easily achieved by commercial exercise programs. The researchers in [3] found daily work will cause cumulative LBP, thus, physical therapy is insufficient for LBP rehabilitation. In the outcomes of this study, proposed learning patterns are fundamental to re-align living behaviors, posing an impact on different scenarios, i.e., general living activities and (vigorous) exercises to improve muscle strength and endurance. Therefore, in this work, a therapeutic and preventive approach is considered as an innovative point. In addition, this study uses technology acceptance questionnaires to understand the effectiveness and satisfaction of the proposed VR-based system and assists in taking advantage of the findings of the current study vis-à-vis future developments.

4 Conclusions and Future Works

This study integrates wearable wireless IMU sensors and virtual reality technologies to successfully develop and configure a VR-based LBP rehabilitation system. In addition, the questionnaire survey results also confirm the evidence that the system users recognize that this system will motivate them to engage in a therapy and further receive the benefits of muscle strength and endurance enhancements.

In the near future, the researchers plan to enhance this system with more precisely joint angle measurements. For instance, suggestions have been proposed and discussed in [11], whose researchers suggest two sensors can be deployed on the lumbar spine and thoracic spine and incorporate motion analysis algorithms to prompt the angle detection precision. In addition, in order to augment entertainment factors of this system, a serious game design with multiple interactive stories and functions is necessary. To that end, and thereby, the LBP population may likely be further encouraged to participate in rehabilitation programs through the use of this enhancement to the proposed system.

References

1. Licciardone, J.C., Gatchel, R.J., Kearns, C.M., Minotti, D.E.: Depression, somatization, and somatic dysfunction in patients with nonspecific chronic low back pain: results from the osteopathic trial. JAOA: J. Am. Osteopath. Assoc. **112**, 783–791 (2012)
2. Park, J.-H., Lee, S.-H., Ko, D.-S.: The effects of the Nintendo Wii exercise program on chronic work-related low back pain in industrial workers. J. Phys. Ther. Sci. **25**, 985 (2013)
3. Hoy, D., Bain, C., Williams, G., March, L., Brooks, P., Blyth, F., Woolf, A., Vos, T., Buchbinder, R.: A systematic review of the global prevalence of low back pain. Arthritis Rheum. **64**, 2028–2037 (2012)
4. Krismer, M., van Tulder, M.: Low back pain (non-specific). Best Pract. Res. Clin. Rheumatol. **21**, 77–91 (2007)
5. McGill, S.: Low Back Disorders: Evidence-Based Prevention and Rehabilitation. Human Kinetics, Champaign (2007)

6. Kim, S.-S., Min, W.-K., Kim, J.-H., Lee, B.-H.: The effects of vr-based wii fit yoga on physical function in middle-aged female lbp patients. J. Phys. Ther. Sci. **26**, 549 (2014)
7. Sterud, T., Tynes, T.: Work-related psychosocial and mechanical risk factors for low back pain: a 3-year follow-up study of the general working population in Norway. Occup. Environ. Med. **70**, 296–302 (2013)
8. McGill, S.M.: Low back exercises: evidence for improving exercise regimens. Phys. Ther. **78**, 754–765 (1998)
9. Davis, F.D., Bagozzi, R.P., Warshaw, P.R.: User acceptance of computer technology: a comparison of two theoretical models. Manage. Sci. **35**, 982–1003 (1989)
10. Koufaris, M.: Applying the technology acceptance model and flow theory to online consumer behavior. Inf. Syst. Res. **13**, 205–223 (2002)
11. Lee, J.K., Park, E.J.: 3D spinal motion analysis during staircase walking using an ambulatory inertial and magnetic sensing system. Med. Biol. Eng. Compu. **49**, 755–764 (2011)