The development and evaluation of a program for leg-strengthening exercises and balance assessment using Kinect

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Abstract. [Purpose] In this study, a program was developed for leg-strengthening exercises and balance assessment using Microsoft Kinect. [Subjects and Methods] The program consists of three leg-strengthening exercises (knee flexion, hip flexion, and hip extension) and the one-leg standing test (OLST). The program recognizes the correct exercise posture by comparison with the range of motion of the hip and knee joints and provides a number of correct action examples to improve training. The program measures the duration of the OLST and presents this as the balance-age. The accuracy of the program was analyzed using the data of five male adults. [Results] In terms of the motion recognition accuracy, the sensitivity and specificity were 95.3% and 100%, respectively. For the balance assessment, the time measured using the existing method with a stopwatch had an absolute error of 0.37 sec. [Conclusion] The developed program can be used to enable users to conduct leg-strengthening exercises and balance assessments at home.

Key words: Kinect, Balance assessment, Leg-strengthening exercises

INTRODUCTION

One of the problems faced by the elderly in terms of their quality of life is their reduced balance function. Balance is the ability to maintain the balance of the body while performing all actions1). Therefore, balance is essential for stability, independent living, and gait2,3). The existing balance ability assessment methods use commercial measuring equipment with a force platform or a functional assessment tool for relatively simple motions. A force platform provides precise measurements by measuring the moving path of the center of pressure during a certain motion. However, expensive measuring equipment must be used, and a specific space and data analysis method for the assessment are required. On the other hand, functional assessment tools provide ease and convenience through time measurements. Representative functional balance assessment methods include the one-leg standing test (OLST), Berg balance scale (BBS), and functional reach test (FRT). These assessment tools are widely used because they can assess balance ability in about 20 minutes without additionally expensive equipment. However, they are based on the subjective assessment of clinicians or experts regarding the score, and time measurements, which differ according to the assessor and have limitations in quantitative analysis. Elderly people who wish to conduct self-diagnoses may not be able to understand the assessment methods.

In rehabilitation exercises undertaken to recover balance ability, the correct posture must be adopted according to the principle of the exercise4), and the body functions according to the exercise effect must be quantitatively presented. Motion recognition camera technology can provide convenience in measuring the quantitative kinematic data required for rehabilita-
tion exercises for balance ability improvement and balance assessment. Kinect, developed by Microsoft for games, is a low-priced motion recognition camera that splits the body area in the image and provides information on 20 of the main human joints in three-dimensional (3D) coordinates. This information has been used to develop diverse rehabilitation programs with Kinect, such as a 3D virtual reality rehabilitation treatment system, a stretching exercise program, and functional games. Clark et al.\(^5\) and Yang et al.\(^9\) reported that the kinematic measurement method using Kinect was reasonably accurate and reliable for standing postural control, which is used for balance ability assessment, and could be a useful tool for clinical applications in hospitals and rehabilitation centers.

In this study, Kinect was used to enable users to assess their balance ability, easily and conveniently, and perform rehabilitation exercises. The program is in an early stage of development and covers three simple leg-strengthening exercises (knee flexion, hip flexion, and hip extension) for balance improvement, as well as OLST, a clinically used functional assessment tool. The program was designed to recognize the motions of the user and to conduct training and assessment. Also, the motion recognition accuracy of the leg-strengthening exercise and the time-measuring accuracy of the balance assessment were analyzed to evaluate the program under development.

**SUBJECTS AND METHODS**

This study comprised two parts. One was the development of the program for leg-strengthening exercises and balance assessment using Microsoft Kinect, and the other part was the accuracy evaluation of the developed program. For the evaluation of the accuracy of the program, five male adults (age: 24.8±2.9 years, height: 175.9±3.8 cm, weight: 68.1±9.2 kg) with no abnormality in their lower extremities were tested. Before the test, experimental procedures were explained to all of the subjects, and their written consent was received. The protocol of this study was approved by the Ethics Committee of Konkuk University. All the subjects wore tight sleeveless T-shirts and short pants.

Kinect can provide real-time depth information, RGB images, and skeleton tracking information of 20 joints, including x, y and depth coordinates, which are used to recognize the motion. The joint data were acquired using the Kinect Windows Software Development Kit (SDK). The program was implemented using Microsoft Visual Studio 2010 in the Windows 7 operating system, and C# was used as the development language. The program acquires the skeleton tracking data extracted using Kinect SDK. The joint data are used to recognize the motion of the leg-strengthening exercise and in the assessment protocol that is selected on the main screen.

The hand gesture recognition module of SDK is used to recognize the user’s hand position and to enable the operation and control of the mouse cursor. For the movement of the mouse cursor, the position value of the right or left hand is mapped using coordinates. The programming was executed so that the event would be performed when the cursor was placed in a specific position. When selecting the motion on the main screen, the user consecutively conducts three leg-strengthening exercises (knee flexion, hip flexion, and hip extension). The exercises were chosen from basic motions for leg strengthening and flexibility so that they could be conducted with only a chair and without additional tools. The user understands the motion from the description and picture of the leg-strengthening exercise and presses the ‘start’ button to conduct the exercise. The exercise start screen shows a simple description of the motion and a start button. The user’s full body skeleton extracted by Kinect provides the user with visual information of the motion. The program recognizes the correct exercise posture according to the range of motions (ROM) of the leg-strengthening exercise shown in Table 1.

The number of motions is increased according to the correctness of a user’s motion posture, and the user continues to perform the next motion after the number of exercises they were set are completed. The correct exercise posture is recognized by calculating the angles at the hip and knee joints using the position data around the joints. The angle at the knee joint is calculated by tracking the coordinates of the hip, knee, and ankle joints. The reference point for the angle calculation is set with the knee joint used as a point of contact, and the flexion angle is calculated using the inner product of the vector. The angle of the hip joint is determined by calculating the flexion and extension angles with the coordinates of the hip joint as a reference point for the angle calculation. The starting point for the one-leg standing movement is when the knee joint flexion angle is 60°–90°. From this point, the time measurement starts, and the screen shows the prompt “Started”. If the knee joint flexion angle is < 20°, it is recognized as a two-leg standing motion, and the measurement is terminated. The measured time is indicated on the result screen and converted to the balance-age, which is based on the results of a preceding study of OLST involving 549 people\(^6\). In that study, the average measured OLST durations of six groups of subjects aged 18–99 were reported. A regression equation with this data was used to calculate the balance-age according to the measured time in the following equation.

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\text{Balance-age} = 99.5 + (-1.355) \times (\text{Measure}) \quad [\text{Unit: years}]
\]
The balance-age, which is obtained from the measured time and the regression equation, is indicated on the screen to provide the user with an assessment. The developed program was used to assess the recognition of the leg-strengthening exercise motion and the time measurement accuracy of the OLST assessment tool.

For the preliminary test of the developed program, the Kinect sensor was placed in front of the subject at a distance of 2 meters. The subject consecutively performed the leg-strengthening exercises and assessment protocols designed for the program. They repeated the correct exercise postures according to the joint angle criteria of the three leg-strengthening exercises 20 times, and the motion recognition rate of the leg-strengthening exercise from the program was examined. In the balance assessment, each subject performed the OLST four times. The time measured by the program was compared with the time measured using a stopwatch.

**RESULTS**

Figure 1 shows an overview of the leg-strengthening exercise and balance assessment program.

Table 2 shows the recognition results of the number of exercises using Kinect during the leg-strengthening exercise. The specificity (the recognition rate when there is no motion) of the motion recognition accuracy of the leg-strengthening exercise from the program was 100%, and the average sensitivity (the recognition rate when there is motion) was 95.3%.

Table 3 shows the time measurements and absolute errors of the balance assessment using the conventional manual timer method and the program. The average absolute error of the time measurement of the program was 0.37 sec.

**DISCUSSION**

A decrease in balance ability is an intrinsic risk factor of falls. To recognize the decline of balance ability, periodic self-balance-ability assessment is required, and an easier and simpler assessment method must be provided, especially for the elderly. Also, rehabilitation to recover physical functions requires motivation through constant re-training and guidance in actual daily life9. Rehabilitation is more efficient when a patient is in a familiar environment10. Therefore, Kinect, a low-priced motion recognition camera, is suitable for easy-to-use self-diagnosis and periodic measurement of kinematic data for rehabilitation.

In this study, Kinect was used to enable the users to easily and conveniently assess their balance ability and perform leg-strengthening exercises. The program recognizes the correct posture from the range of motion of the three leg-strengthening motions, which are related to the balance improvement, and provides the user with a number of motions to encourage accurate motions. For the balance assessment, the duration of one-leg standing was measured, and the results were presented.
in terms of the balance age so that a user could easily understand the results. The elderly can recognize a reduction in their balance ability earlier through periodic and quantitative balance ability assessment at home. Also, the user can improve the rehabilitation efficiency with constant exercise in a familiar environment. Although the direct cause of balance loss cannot be determined from the balance age, because it is related to a combination of physical, mechanical, and sensory factors, the user can recognize the risk of reduced balance ability through periodic assessment. In recognizing the motion of the leg-strengthening exercise, the developed program had 95.3% sensitivity and 100% specificity. The developed program was compared with an existing manual method, the time of the OLST, for the balance ability assessment, and the results show that the measurement method of the program was reliable. The joint angle was used to recognize limb motion in this study, but the reliability of the joint angle measurement using Kinect was not established. In other words, the recognition accuracy was lower for knee flexion than for the other motions. This is because it involves flexion of the knee joint by as much as 90° which entails overlapping of the ankle joint by the knee joint, which produced skeleton tracking errors. Average absolute errors in the balance assessment between the time measurements of the developed program and the duration using the conventional manual method were 0.37 sec. This seemed to be due to the difference between the two time measurement methods. In the program evaluation, time is taken to move to the proper knee angle for the motion recognition, whereas in the manual method, the point when the foot leaves or touches the floor is measured.

In preceding studies, the accuracy of the joint angle measurement method using Kinect was analyzed by comparing it with the results of a conventional 3D motion analyzer. Schmitz et al. used Kinect to recognize the joint center of a testing jig of the leg model, and calculated the resulting joint angle\(^1\). They reported that it had 0.5° or less accuracy in the sagittal and frontal planes, and a 2° or less accuracy in the transverse plane, compared with the 3D motion analyzer. In addition, Fernández-Baena et al. reported that the arm and leg joint angles according to the actual arm and leg motions showed a 6–13° difference, which was accurate enough to allow clinical rehabilitation treatment to be conducted\(^2\). Apart from the accuracy of the joint angle, the reliability of Kinect in trajectory measurement of body’s segment and center of mass (COM) has been determined\(^3, 4\). These results indicate that the Kinect has the potential to be used as a reliable and valid tool for the assessment of static and dynamic balance.

In preceding studies, the motion recognition technology of Kinect for the full-body skeleton has been applied to many rehabilitation and training programs, such as arm rehabilitation training\(^5\) and physical training, as well as improvement of psychological characteristics using virtual reality games for stroke patients\(^6, 7\). For the initial stage of the balance rehabilitation exercise and assessment program development, this study examined a relatively simple leg-strengthening exercise and OLST using five adult males. Through further studies involving the elderly, it is expected that rehabilitation and assessment methods using Kinect that are more diverse can be developed to create more applications such as exercise interventions and treatments, and fall prevention.

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