An Online Balance Training Application using Pose Estimation and Augmented Reality

Amirhossein Etaat[1], Negar Haghbin[1][a] and Marta Kersten-Oertel[1,2][b]
[1] *Gina Cody School of Computer Science and Engineering, Concordia University, Montrèal, Canada*
[2] *PERFORM Centre, Concordia University, Montréal, Canada*

Keywords: Healthy Aging, Rehabilitation, Pose Estimation, Web Applications, Balance Training, Augmented Reality.

Abstract: The evolution of digitally connected devices and artificial intelligence has opened the door for novel health and fitness applications that can be used by individuals at a time and in an environment convenient to them. The purpose of our research was to develop a platform that requires no additional hardware to provide an online home balance training program. Balance exercises are often prescribed for healthy aging to keep the body active, improve balance and coordination, and prevent falls and injuries, as well as, for those doing rehabilitation after injuries or diseases such as stroke. We developed a simple web application (BaART: Balance Augmented Reality Trainer) that uses PoseNet to determine a user's location and pose for balance exercises. Furthermore, we looked at how augmented reality, and specifically adding a virtual chair, might impact a user's sense of balance. In a study of 20 participants with and without balance disorders, we found that the developed system was easy to use, however, we also found that the virtual object (i.e. chair) was not used by most people. Furthermore, those with balance issues felt they required a real chair for balance and some even felt that the virtual object was distracting from the exercise. In the future, we will explore other uses of augmented reality, such as feedback on exercise quality, gaming features, and a virtual avatar trainer.

1 INTRODUCTION

As smart mobile phones and internet connections become more accessible than ever, mobile health (mHealth) applications are becoming ever more popular with many seeking to take their health into their own hands within their own environments. This has led to growing availability of web and mobile applications for rehabilitation, virtual coaches for training and exercise, online doctor visits, and mental health, meditation, and fitness applications.

In this paper, we focus specifically on rehabilitation and balance exercises. Balance exercises which work the core muscles, lower back, and legs are often prescribed for healthy aging to keep the body active, improve balance and coordination, and prevent falls and injuries. They are also used in rehabilitation after injuries or diseases such as stroke. New sensing (e.g. wearables) and communication technologies (e.g. internet of things) are positively influencing the expansion of training and rehabilitation programs outside of standard healthcare facilities. It is now feasible to do guided online exercises ensuring that they are done correctly and even track a person's progress over time in the comfort of one's own environment without direct contact with a physiotherapist or trainer. This can be done using different motion-tracking devices such as wearable sensors, depth cameras and most recently using *pose estimation* from simple web camera feeds. Pose estimation is the task of using machine learning models to estimate the pose of a person from an image or a video by determining the spatial location of keypoints (i.e. knee, elbow, nose, etc). Pose estimation is beginning to be widely used in training robots, motion tracking for game consoles, augmented reality, animation, and health and fitness applications.

Gamification, i.e. the introduction of game elements to traditionally non-gaming situations, has also proved to be an important aspect of mhealth applications, which can encourage and motivate users to not only comply with their exercise regimes but also to help them to enjoy doing so (Haghbin and Kersten-Oertel, 2021). Augmented reality (combining virtual and real elements) can also be used both for aiding users to better understand exercises and the proper

[a] https://orcid.org/0000-0002-9598-9936
[b] https://orcid.org/0000-0002-9492-8402

Etaat, A., Haghbin, N. and Kersten-Oertel, M.
An Online Balance Training Application using Pose Estimation and Augmented Reality.
DOI: 10.5220/0010973800003188
In *Proceedings of the 8th International Conference on Information and Communication Technologies for Ageing Well and e-Health (ICT4AWE 2022)*, pages 168-176
ISBN: 978-989-758-566-1; ISSN: 2184-4984

way of doing them and/or for adding gaming elements to make exercising more enjoyable.

In this paper, we focus on delivering balance training exercises into the comfort of a user's own home using simple and low-cost technology (only a webcam and connected digital device are needed). Furthermore, we explore the use of augmented reality elements, i.e. adding a virtual chair for balance, to see if this can aid users to perform balance exercises. In order to study these questions, we developed a balance training exercise prototype system, "**Ba**lance **A**ugmented **R**eality **T**rainer" (BaART) and tested it with 20 subjects to determine the impact of the virtual elements and in general the ease of use of the system.

2 RELATED WORK

2.1 Pose Estimation Health Applications

Encouraging people to exercise by exploiting technology at home can be a strategy that may be cost-effective, particularly if consumer-level equipment is used. A number of research groups have looked at using simple applications with webcams and using pose estimation algorithms to determine the location of the user's joints in order to help guide and monitor exercises. Pose estimation specifically refers to computer vision techniques that can be used to detect human figures in images and videos. By taking a processed camera image as the input, pose estimation models outputs information about the keypoints (e.g. elbow, nose, knee, etc.) which can then further be used to determine the pose of a person.

Moreira *et al.* (Moreira et al., 2020a) systematically reviewed mobile applications proposed for analyzing human posture. Their results showed that the use of human pose estimation on mobile applications is reliable, and can assist medical clinics, and physiotherapists, especially in the case of evaluating physical treatments. Moreira *et al.* (Moreira et al., 2020b) also proposed a prototype application using PoseNet (a real-time pose detection library) and the TensorFlow library for automatic identification of Anatomical and Segment Points (ASPs). Their results show that PoseNet can be used to develop applications concerning the physical assessment process and diagnosis of disorders related to postural and movement changes. Herrera *et al.* (Herrera et al., 2020) developed a web application, using Posenet and TensorFlow, for sedentary workers to help them take *active pauses* (i.e. pausing work to do exercises) in order to reduce the risk of job-related muscular and skeletal injuries and diseases. The application accurately determined the position of the user and whether they were doing the exercise correctly.

2.2 Balance Training

A number of previous research studies have employed various technologies to help aging adults to train balance, with an aim to maintain health and reduce the likely hood of falls (Jorgensen et al., 2013). Mostajeran *et al.* (Mostajeran et al., 2019) presented an application for balance training at home using the Microsoft Kinect Sensor V2. The application has a virtual coach who gives balance training instructions and demonstrated the exercises. The authors found that adults have a more positive reaction towards using a virtual coach for balance training compared to traditional health care approaches. In a similar work, Kouris *et al.* (Kouris et al., 2018) proposed a system that uses a virtual reality avatar and wearable sensors for physiotherapy balance exercises. The wearable sensors can monitor user activity and determine the correctness of the balance exercises in real-time. Vonstad *et al.* (Vonstad et al., 2020) developed a 2D custom balance training exergame (i.e. a type of exercise that mixes exercise and video games) using a deep learning based pose estimation system to detect human body parts and estimate three-dimensional (3D) body positions. In their work, they compared three systems: a Microsoft Kinect Sensor V2, a marker-based three-dimensional motion capturing system and a deep learning system using a digital camera. In a study where participants played the balance exergame, the deep learning method had similar performance to both the Kinect and the marker-based system, demonstrating the feasibility of using less complex hardware and sensors for these types of applications.

Ogonowski *et al.* (Ogonowski et al., 2016) developed a system that used individualized physical fitness training, gamification and wearable sensors with a Microsoft Kinect and simple TV. Their work illustrated the possibility of incorporating such systems into the daily life of older adults. Hardy *et al.* (Hardy et al., 2013) also developed an exergame to motivate older adults to do balance exercises and gain training based on the adaptation and exergame analysis. Their findings suggest that elderly individuals accept multimedia training and the adaptability notion improves the system's accessibility.

Smartphones are also beginning to be tested for use for balance, rehabilitation and physiotherapy exercises. For example, Androutsou *et al.* (Androutsou et al., 2020) proposed a smartphone application for patients with balance disorders that enables users to self-evaluate their activity and progress, communicate with others using the system, and get real-time feedback about their training, activities and progress over time.

2.3 Augmented Reality in mHealth

A number of researchers have explored the use of augmented reality in the context of fitness and rehabilitation applications and specifically the use of virtual coaches or trainers (Tsiourti et al., 2014). Virtual coaches have been explored to help clinicians monitor the use of medications and seniors' adherence to specific guidelines for medication use (Félix et al., 2019) or to keep the elderly physically active (Bickmore et al., 2009; Albaina et al., 2009). For example, Felberbaum *et al.* (Felberbaum et al., 2018) explored aspects of an AR-based virtual coach that would improve older adults' mobility. Features of such a virtual coach would include virtual friends to walk with, having interactive guidance to help define and reach goals and online monitoring to determine risks such as falls. Bickmore *et al.* (Bickmore et al., 2009) demonstrated that the combination of a virtual coach and pedometer can increase the amount of walking among older adults.

Virtual training assistants or coaches do not necessarily have to take on the form of a human avatar. Albaina *et al.* (Albaina et al., 2009) proposed an animated flower that is used as a virtual trainer to boost the motivation of individuals to walk. Their study found that elderly users appreciated the flower virtual trainer and had a positive tendency to use it over a longer period of time. The results of their studies also demonstrated that the virtual flower trainer was effective in boosting the acceptance of such a system among older adults, despite its uncommon form.

Other studies have incorporated AR technology into the daily lives of older adults. Ku *et al.* (Ku et al., 2019) used the 3D-ARS (3D interactive augmented reality) system to determine its impact on people with balance disorders. A randomized controlled study with 36 people who could walk on their own and could stand on one leg was done to assess the effect of the AR technology. In comparing the control group, who did a conventional physical fitness program three times a week for 1 month, to the experimental group, who used 3D-ARS training three times a week for 4 weeks, they found that although both groups experienced improvements those who used of 3D-ARS had better results in terms of stability index, weight distribution index, fall risk index, and Fourier transformations index of posturography. Roy *et al.* (Roy et al., 2017) developed a low-cost AR system using the Microsoft Kinect. The system guides users to perform stability training and even calculates a real-time stability score.

3 SYSTEM DESCRIPTION

Using intervention and assessment tools *at home* can considerably decrease the risk of falls and enhance one's quality of life through increased mobility and in turn healthy aging (Society et al., 2001). Balance training exercises and therapies are commonly used to improve both balance and gait conditions. According to the American Geriatrics Society (Panel on Prevention of Falls in Older Persons, 2011) a proper and standard balance exercise plan can play a vital role in health and rehabilitation. However, studies have found that many patients and users do not do physiotherapy exercises or training that can help or prevent ailments due to a lack of motivation, time and/or the high cost of physiotherapy, gyms, and hiring personal trainers (Argent et al., 2018). Building on the previous works described above, our goal was to develop a prototype system that requires no specialized equipment but rather can be used in the comfort of one's desired environment by simply clicking on a url on a computer, mobile phone, tablet, Smart TV or other connected device. We also aimed to make the system easy to use by providing a simple interface that includes voice commands and instructional videos. Our developed home-based rehabilitation online app uses (1) pose estimation to determine the users pose and count the number or repetitions of a given exercise and (2) explores the ability of augmented reality to help with balance exercises. The motivation for the latter, was to determine if a stationary object added via a virtual object, which would provide a visual static reference point, can improve balance. Although this is the case for walking or balancing in the real world it is unclear if virtual objects have the same impact.

3.1 PoseNet

Our prototype uses PoseNet (Papandreou et al., 2018), a library built on top of TensorFlow, which is an open-source machine learning platform that provides an ecosystem of tools for developing machine learning applications. PoseNet is trained in the MobileNet Architecture (a convolutional neural network (CNN) developed by Google and trained on ImageNet) and has pre-trained models that detect user gestures and poses from given images. An advantage of PoseNet in comparison to other API-dependent li-

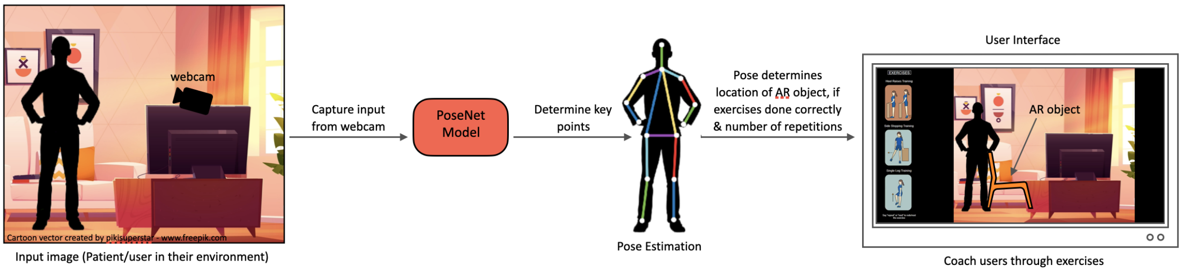

Figure 1: The user opens the application on a browser on any connected digital device. The web browser fetches data from the server (written in HTML, CSS, JavaScript codes including Posenet Library and P5js library). The keypoints are detected using the PoseNet model. The web application processes the captured inputs to determine exercises correctness and counts repetitions, as well as, displays the AR object in the correct position relative to the user.

braries for pose estimation is that the pre-trained models run in a browser thus private data (i.e. images and video stream from webcam) are protected and not sent to a server for processing. Furthermore, anyone with a webcam equipped desktop or TV, tablet or phone can use PoseNet within their web browser. Taking advantage of PoseNet allowed us to keep the system simple and highly accessible, without the need of devices such as Kinect, wearables or motion capture systems that can add complexity and may have high installation and preparation costs.

3.2 BaART: Balance AR Trainer

The BaART user interface was developed using Javascript, HTML and CSS and PoseNet and TensorFlow's models were used to recognize and estimate the human poses. Pose estimation was specifically used to count the number of repetitions that were done by the end user and check if the exercise has been done correctly. We also used p5.Speech (an extension of p5.js which is an open-source JavaScript library) for implementing speech-to-text and voice commands.

The application pipeline is shown in Figure 1. As mentioned above, the application uses a simple webcam without any further specialized equipment. After opening the application via the provided URL on a computer, laptop, or mobile device, RGBA input is captured from the web camera and the user's pose is estimated via PoseNet. After successful keypoint detection, the exercise routine begins. The keypoint data (e.g. knee, ankles, hips, shoulders, eyes, etc.) is used to determine the location of the user to both place the virtual object and determine if an exercise is being done. While exercises are being performed, the keypoints and movements are tracked so that the system can evaluate if an exercise is being executed correctly and the number of repetitions the user has done. Results are displayed to the user in real-time through the interface, which shows the count and or repetitions (either number of seconds or repetitions successfully completed). The user can interact with the application using either voice commands: "next exercises", "re-do", "refresh" or "previous" or with a mouse on a computer or gestures on a mobile device.

3.2.1 Exercises

For the first prototype of our system we selected three exercises that improve balance and prevent falls based on the clinical guidelines and recommendations of the National Institute of Clinical Excellence (NICE) and the joint American and British Geriatric Society (ABGS) for the prevention and assessment of falls in older people (National Institute for Health and Care Excellence (NICE), 2013; Panel on Prevention of Falls in Older Persons, 2011). Specifically, we chose: *heel raises*, *side stepping* and *single leg standing* exercises (see Figure 2).

Tyagi *et al.* (Tyagi et al., 2018) studied the adoption of technology-based telerehabilitation (TR) and found that although younger users preferred TR, older ones preferred daily visits to the rehabilitation center. As in person visits are not always feasible particularly for daily visits (or during a global pandemic), Tyagi *et al.* recommended using videos in TR programs for older patients. Thus for each of the exercises in the BaART application, an instructional video (taken from www.Physitrack.com) is first shown to explain how to do the exercise. After the video, the user then does the given exercise following along with both verbal and onscreen written instructions. As well as giving instructions, the voice of the "trainer" tries to motivate the user with encouraging statements and counts the repetitions the user has done. We briefly describe

Heel Raises: For heel raises, the keypoint information is used to track the position of the hips of the user while standing and uses the raising and lowering of the hips to determine the number of repetitions. Often times a chair is used for extra balance in heel raise exercises, thus we use a virtual chair to study if "resting" one's hands on a virtual chair can invoke a sense of balance. The virtual chair is placed in front of the determined location of the user. During the exercise, the user raises both of their heels off the ground to stand on their tiptoes. The user raises their heels 10 times, each time the application says "raise your heels", and then slowly lowers their heels back to the floor when the application says "release".

Side Step: For side stepping, the keypoint information of the hips and shoulders are used to ensure the user is stepping to the side correctly and to count the repetitions. Again, a virtual chair is shown in front of the user so that the user can "rest" their hands and focus on this static point for better balance. This exercise starts with the feet together and knees slightly bent, the user then moves one foot to the side and then back to join the other foot. The instructions given are "step right" to take a full right step and then "release" to step back to the centre and bring the feet back together. The exercise is repeated 10 times.

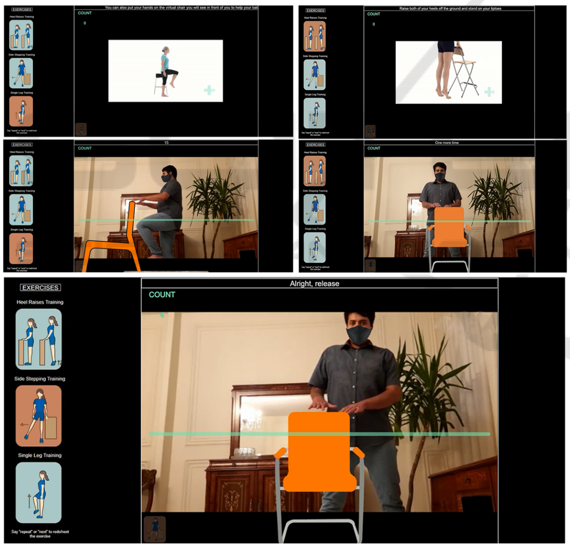

Figure 2: The instructional videos demonstrating the three exercises and user doing the exercises with the virtual chair. The green line represents the position of the hips.

Single Leg Standing: For this exercise, the most challenging of the three, keypoint information is used to determine how high the leg is raised relative to the distance to the pelvis. For this specific exercise, the user is asked to rotate the body by 90 degrees to the right or left in order to be able to best detect the knees. The user is then instructed to stand upright with their feet together, and try to slowly lift their foot off the ground so their thigh is perpendicular to the floor. The virtual chair is provided and the user is instructed to do single leg standing for 15 seconds for the left and then right leg.

3.2.2 User Interface

A simple user interface (UI) was developed so that users of all ages can easily interact with BaART. For instance, verbal communication and images were used to convey information to the user. For those with hearing problems, the words and sentences are transcribed and displayed at the top of the interface. Also, we tried to encourage and motivate the user after each correct set using motivational and prompting words and phrases, e.g. "good job!", similar to a real trainer.

4 BaART EVALUATION

The BaART application was evaluated with 20 participants aged 18 to 73 with 14 males and 6 females (see Figure 3). Participants used the application online at their convenience. Those who agreed to participate were first sent a consent form, a description of the application, instructions on how to use the BaART application and a link to the application that they could run on the device of their choice at their convenience.

4.1 Questionnaire

After the study, participants filled out a questionnaire with both background questions and questions about their experience with the application. Note that the pre-test and post-test questionnaires were combined to facilitate navigation between instructions, application and questionnaires. The summary of the analysis of the questionnaire are presented in the following sections.

4.1.1 Technology Use

To determine comfort with new technologies, participants were questioned on how they felt about their

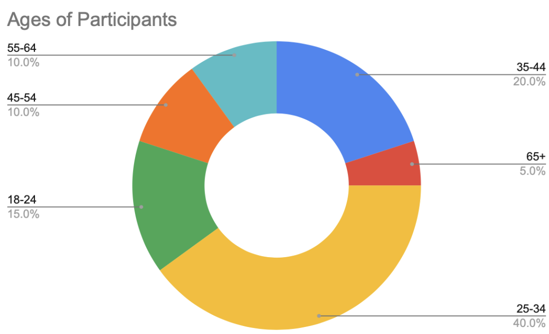

Figure 3: The BaART application was evaluated with 20 participants aged 18 to 73 with 14 males and 6 females.

practical knowledge of technology, and how often they used a smartphone, tablet, or computer. The majority of participants (75%) use some form of digital device daily, whereas 25% use a device only weekly. In terms of their practical knowledge of technology, which was answered on a scale from 1 (I don't know anything about technology) to 5 (I'm very technologically savvy), the majority of participants rated their knowledge as 4 or 5, thus our sample participants were technologically savvy.

We also asked how keen the participants are on trying out new technologies from 1 (Not at all) and 5 (Yes I'm usually very keen) and found that 35% were very keen, 40% were quite keen, 10% were neither keen or not keen and 15% were not keen. Lastly, we asked participants about the degree to which it was easy and simple for them to use new technologies such as mobile apps and found that the majority find it either very easy or somewhat easy.

4.1.2 Sport and Health Activities

The second part of the questionnaire queried users about health and fitness activities. Specifically, participants were asked if they considered themselves physically active as well as how often they participated in fitness activities such as sports, aerobics, training, etc. In a range of 1 (Not at all physically active) to 5 (Yes I'm very physically active), only 1 person (5%) considered themselves very active, 30% considered themselves somewhat active and 40% considered themselves neither very active or inactive. Lastly, 25% of participants considered themselves somewhat inactive. In terms of how often participants exercised 40% said 1-2 times a week, 40% 3-4 times a week, and 20% answered that they hardly ever exercise. None of our participants exercised 5-6 times per week or everyday. In terms of users ideal location for exercising, 30% prefer exercising at home, 35% at the gym, 30% prefer exercising outside and 5% said they didn't have a preference.

We also questioned participants about the main factors that lead them to exercise less frequently than they would like to. Here participants could select multiple answers. Of our population, 95% (19 people) answered "I don't have time", 6 answered "I forget to exercise", one person answered "I don't like exercising", one other said "I don't feel I need to exercise", and one person answered that they did not exercise because they did not have someone else to exercise with.

We also asked participants about their use of online exercise training (e.g. Apple Fit+, Wii, YouTube online class) and found that most participants (70%) had not previously done online fitness classes or exercises whereas as 30% had. Lastly, participants were asked if they have ever done any rehabilitation, physiotherapy or balance training. For rehabilitation and/or physiotherapy 20% had done this, whereas 80% had not. For balance training which included balance exercises within yoga and rehabilitation/physiotherapy routines, we had 25% who had done balance training in yoga or uni-cycling routines and 75% who previously had not done any balance exercises and one person (5%) who was not sure.

4.1.3 Balance Disorders

As our application concerns balance exercises, we queried the participants about their experience of dizziness, falls and loss of balance. Specifically, we asked if participants had experienced a loss of balance or had a balance problem leading to falls or near falls in the last six months. The majority of participants (65%) did not have any balance problems. More than one-third of participants reported that they suffered from dizziness and loss of balance. Specifically, 10% had experienced a fall and 20% had nearly fallen. One person had experienced both a near fall and had fallen in the last six months.

4.1.4 Ease of Use

Participants were asked to rate the application on a scale of 1 (Hard to understand) to 5 (Easy to understand), for the video instructions and auditory coaching instructions. We found that 60% found the video instructions easy to understand (rated with 5), 35% found the video instructions somewhat easy to understand and 5% found them neither hard or easy. For the spoken instructions, 55% found them easy to understand, 40% found them somewhat easy to understand and 5% found them difficult to understand. We also asked if the subjects used the voice commands (next, repeat, previous) while doing the study. Most of the participants, 80% used voice commands, 15% did not and one person (5%) answered maybe. Of those that used the voice commands, 11.5% found them very easy to use, 47% found them somewhat easy to use, 11.5% found them difficult to use, and 30% found them very difficult to use.

In terms of the overall system ease of use 50% of the participants found it very easy, 35% found it somewhat easy to use, 10% found it neither hard or easy and one participant (5%) found it difficult to use. The majority (80%) tested the application on laptops, 15% tested on workstation computers and 5% (1 person) used a mobile device.

4.1.5 Augmented Reality

As one of our goals was to determine if augmented reality (provided by virtual objects introduced into the video images) could aid in improving a sense of balance, we specifically asked users about their impression of this. First users were asked if they tried using the virtual chair for the different exercises, we found that 60% of participants did use the virtual chair, 20% did not, and 20% answered maybe. Of those that used the virtual object, we asked if it gave them an impression of helping them with their balance as they performed their exercises. On a scale of 1 (It didn't help at all) to 5 (It helped me to balance), we found that 21% found it did not help at all, 10.5% found it did not help, 32% were not sure, 26% thought it helped a little to balance and 10.5% found it helped them to balance. Furthermore, we asked participants if they had any comments about the use of the virtual objects for exercises, most of the participants didn't have any issue with using virtual objects, but we received some comments including *"I do not know how to use a virtual object to maintain my balance"*, *"The virtual objects didn't improve my performance"*, as well as, *"It did not help much and sometimes made me lose my focus on the exercise itself just because I wanted to keep my hands on it"*.

4.1.6 System Usability Scale

Finally, we provided participants with a version of the System Usability Scale (SUS) (Brooke, 1996). The questionnaire has ten questions positive and negative questions relating to a system's usability. The questions are answered on a scale of 1 to 5, with 1 representing Strongly Disagree and 5 representing Strongly Agree with the question's statement. The BaART application received a SUS score of 80. The average SUS score is 68, and given that a SUS value of 75 is considered good, and over 85 is excellent, our system was rated very highly with participants finding who found it easy to use, easy to learn, and felt confident using it. The results of the individual SUS questions are represented in Table 1.

4.1.7 Using BaART in the Longer Term

We asked participants to answer on a scale from 1 (very unlikely) to 5 (very unlikely) if they would use BaART if the prototype was extended with more exercises and features. Thirty percent of participants were not sure if they would use such a system, 20% percent and 50% said they would very likely use it.

We also queried specifically if the participants felt that such an application can motivate them to exercise whenever they did not feel like it or were busy, by sending notifications to their phone, on a scale of 1 (No would not help at all) to 5 (Yes it would very much help). We found that 5% said it would not help at all and another 5% said it would not help and 15% said they were not sure. However, 35% thought it would help and 40% thought it would help very much.

Lastly, we had an open question to gather the participant's overall opinions about the prototype system. Some commented on the exercises, e.g. "Increase exercises", "I think the second exercise which was step siding could be replaced to be a more effective exercise". A few users had difficulties with some aspects of the app such as their pose not being recognized although they mentioned they were able to resolve the issues by moving the camera or their position relative to the camera but this made them rate the usability lower. We also had the following comments in terms of the platform in general: *"It was good for me because I'm 77 years old and it's hard for me to go to the gym. But I needed a real chair or someone to help me with doing exercises."* and *"Since I am a housewife and I am usually at home, I think it is a good idea if I can do exercises at home with this app"*. In general, we found that it was are older participants, who tend to spend more time at home, who were more excited about using such a system.

5 DISCUSSION AND FUTURE WORK

The results of our work suggest that online home exercise routines for balance training may be desirable for some users, though it may not be the ideal platform for all. Specifically, we were happy to see that our older population was excited about such a platform. Although our participant pool was very tech savvy, surprisingly 70% had not used online training applications before, but did rate the BaART application as easy and convenient to use.

In terms of the augmented reality visualization, although our sample population did not have a significant portion of users with balance disorders, those that had them, believed that they would require a real object to help them for balance rather than a virtual object. Furthermore, only 60% used the virtual object and one person even mentioned it was distracting from the exercises. We believe this still may be an interesting avenue of future research, however, it might require a better synchronization between verbal instructions and the visualization. For example, asking the users to imagine having their hands on a real chair while they step to the side. In future work, we plan to

Table 1: System Usability Scale (SUS) average scores from 1 (strongly disagree) to 5 (strongly agree).

System Usability Scale Questions	**Average**
I think that I would like to use this system frequently	3.65
I found the system unnecessarily complex	1.85
I thought the system was easy to use	4.3
I think that I would need the support of a technical person to be able to use this system	1.55
I found the various functions in this system were well integrated	4.55
I thought there was too much inconsistency in this system	1.6
I would imagine that most people would learn to use this system very quickly	4.25
I found the system very cumbersome to use	1.85
I felt very confident using the system	4.2
I needed to learn a lot of things before I could get going with this system	2.05

add more AR elements not necessarily for balancing but to guide the exercises and add gaming elements. One such example is an apple to pick from a tree when raising on ones tiptoes. Adding gamification elements such as this may make the application more engaging. Furthermore, a virtual trainer or avatar that does the exercises with you and adjusts their pace to the end user may also be interesting.

Given this was a first prototype, we only had three exercises and found users would be interested in having more. In the future, we plan to extend the platform to have more exercises and include other features as suggested by the participants. Additional features including: being able to either watch the tutorials again or skip them, improving the voice commands which some users had issues with (perhaps due to microphone issues or accents) and into different languages to accommodate non-native English speakers, enlarge the text instructions, and send notifications to the user to ensure they perform the exercises regularly.

Lastly, although we capture the pose and determine that the user is doing the exercise correctly in order to count the repetition, the user does not receive any visual or auditory feedback on the quality of the exercise and how to improve it if they are doing it wrong. In future work, we plan to relay this information to the user. In general, collecting, analyzing, and delivering performance-related data of users in charts could motivate users further by showing them the progress they have made.

As well as, the future directions described above it will be important to do a longer term study with more participants to look at not only how we can encourage these healthy habits in the short term but change user habits for sustained use.

6 CONCLUSION

In this paper, we describe a developed prototype for doing balancing exercises at home based on the National Institute of Clinical Excellence (NICE) guidelines for fall prevention and British Geriatric Society (ABGS) set of clinical instructions to prevent and evaluate older adults falls. We conducted a study with 20 users, both younger and older, and with and without balance disorders. The results of our study indicate that the participants liked the concept in general and found the application easy to use. Furthermore, they are interested in using this application, especially if it were extended to have more exercises and features such as notifications.

In terms of the augmented reality aspect, most users found the virtual object did not help them to balance. Although this is the case, we posit that there are additional possibilities to be explored for using AR in such a system, including adding visual feedback on the quality and correctness of the exercise, adding a virtual coach, and adding gaming elements. The participants of the study also felt that they do not exercise as much as they like because it is time-consuming and costly. Online fitness and health applications are helping to mitigate these issues by allowing users to have personal trainers to work with them whenever and wherever they are.

REFERENCES

Albaina, I. M., Visser, T., Van Der Mast, C. A., and Vastenburg, M. H. (2009). Flowie: A persuasive virtual coach to motivate elderly individuals to walk. In *International Conference on Pervasive Computing Technologies for Healthcare*, pages 1–7.

Androutsou, T., Kouris, I., Anastasiou, A., Pavlopoulos, S., Mostajeran, F., Bamiou, D.-E., Genna, G. J., Costafreda, S. G., and Koutsouris, D. (2020). A smartphone application designed to engage the elderly in home-based rehabilitation. *Frontiers in Digital Health*, 2.

Argent, R., Daly, A., Caulfield, B., et al. (2018). Patient involvement with home-based exercise programs: can connected health interventions influence adherence? *JMIR mHealth and uHealth*, 6(3):e8518.

Bickmore, T., Silliman, R., Nelson, K., Cheng, D., Winter, M., Henault, L., and Paasche-Orlow, M. K. (2009). A randomized controlled trial of an automated exercise coach for older adults. *Journal of the American Geriatrics Society*.

Brooke, J. (1996). SUS: A "quick and dirty" usability scale. *Usability evaluation in industry*, 189(3).

Felberbaum, Y., Lanir, J., and Weiss, P. L. (2018). Challenges and requirements for technology to support mobility of older adults. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–6.

Félix, I. B., Guerreiro, M. P., Cavaco, A., Cláudio, A. P., Mendes, A., Balsa, J., Carmo, M. B., Pimenta, N., and Henriques, A. (2019). Development of a complex intervention to improve adherence to antidiabetic medication in older people using an anthropomorphic virtual assistant software. *Frontiers in Pharmacology*, 10.

Haghbin, N. and Kersten-Oertel, M. (2021). Multimodal cueing in gamified physiotherapy: A preliminary study. In *Proceedings of the 7th International Conference on Information and Communication Technologies for Ageing Well and e-Health (ICT4AWE)*, pages 137–145. INSTICC, SciTePress.

Hardy, S., Göbel, S., and Steinmetz, R. (2013). Adaptable and personalized game-based training system for fall prevention. In *Proceedings of the 21st ACM international conference on Multimedia*, pages 431–432.

Herrera, F., Niño, R., Montenegro-Marín, C. E., Gaona-García, P. A., de Mendívil, I. S. M., and Crespo, R. G. (2020). Computational method for monitoring pauses exercises in office workers through a vision model. *Journal of Ambient Intelligence and Humanized Computing*, pages 1–9.

Jorgensen, M. G., Laessoe, U., Hendriksen, C., Nielsen, O. B. F., and Aagaard, P. (2013). Efficacy of nintendo wii training on mechanical leg muscle function and postural balance in community-dwelling older adults: a randomized controlled trial. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, 68(7):845–852.

Kouris, I., Sarafidis, M., Androutsou, T., and Koutsouris, D. (2018). Holobalance: an augmented reality virtual trainer solution forbalance training and fall prevention. In *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pages 4233–4236. IEEE.

Ku, J., Kim, Y. J., Cho, S., Lim, T., Lee, H. S., and Kang, Y. J. (2019). Three-dimensional augmented reality system for balance and mobility rehabilitation in the elderly: A randomized controlled trial. *Cyberpsychology, Behavior, and Social Networking*, 22(2):132–141.

Moreira, R., Teles, A., Fialho, R., Baluz, R., Santos, T. C., Goulart-Filho, R., Rocha, L., Silva, F. J., Gupta, N., Bastos, V. H., et al. (2020a). Mobile applications for assessing human posture: A systematic literature review. *Electronics*, 9(8):1196.

Moreira, R., Teles, A., Fialho, R., Dos Santos, T. C. P., Vasconcelos, S. S., de Sá, I. C., Bastos, V. H., Silva, F., and Teixeira, S. (2020b). Can human posture and range of motion be measured automatically by smart mobile applications? *Medical hypotheses*, 142:109741.

Mostajeran, F., Katzakis, N., Ariza, O., Freiwald, J. P., and Steinicke, F. (2019). Welcoming a holographic virtual coach for balance training at home: two focus groups with older adults. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1465–1470. IEEE.

National Institute for Health and Care Excellence (NICE) (2013). Falls: Assessment and prevention of falls in older people.

Ogonowski, C., Aal, K., Vaziri, D., Rekowski, T. V., Randall, D., Schreiber, D., Wieching, R., and Wulf, V. (2016). Ict-based fall prevention system for older adults: qualitative results from a long-term field study. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 23(5):1–33.

Panel on Prevention of Falls in Older Persons (2011). Summary of the updated american geriatrics society/british geriatrics society clinical practice guideline for prevention of falls in older persons. *Journal of the American Geriatrics Society*, 59(1):148–157.

Papandreou, G., Zhu, T., Chen, L.-C., Gidaris, S., Tompson, J., and Murphy, K. (2018). Personlab: Person pose estimation and instance segmentation with a bottom-up, part-based, geometric embedding model. In *Proceedings of the European conference on computer vision (ECCV)*, pages 269–286.

Roy, S., Mazumder, O., Chatterjee, D., Chakravarty, K., and Sinha, A. (2017). Quantification of postural balance using augmented reality based environment: A pilot study. In *2017 IEEE SENSORS*, pages 1–3. IEEE.

Society, A. G., Society, G., Of, A. A., and On Falls Prevention, O. S. P. (2001). Guideline for the prevention of falls in older persons. *Journal of the American Geriatrics Society*, 49(5):664–672.

Tsiourti, C., Joly, E., Wings, C., Moussa, M. B., and Wac, K. (2014). Virtual assistive companions for older adults: qualitative field study and design implications. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, pages 57–64.

Tyagi, S., Lim, D. S., Ho, W. H., Koh, Y. Q., Cai, V., Koh, G. C., and Legido-Quigley, H. (2018). Acceptance of tele-rehabilitation by stroke patients: perceived barriers and facilitators. *Archives of physical medicine and rehabilitation*, 99(12):2472–2477.

Vonstad, E. K., Su, X., Vereijken, B., Bach, K., and Nilsen, J. H. (2020). Comparison of a deep learning-based pose estimation system to marker-based and kinect systems in exergaming for balance training. *Sensors*, 20(23):6940.