Using augmented reality technology for balance training in the elderly. A feasibility study

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Sven Blomqvist
University of Gävle

Sven.blomqvist@hig.se Corresponding Author
ORCiD: https://orcid.org/0000-0002-2995-4428

Stefen Seipel
University of Gävle

Maria Engström
University of Gävle

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Abstract

Background
Impaired balance leading to falls is common in the elderly, and there is strong evidence that balance training reduces falls and increases independence. Reduced resources in health care will result in fewer people getting help with rehabilitation training. In this regard, the new technology augmented reality (AR) could be helpful. With AR the elderly can receive help with instructions and get feedback on their progression in balance training. The purpose of this study was to examine the feasibility of using AR-based visual-interactive tools in balance training of the elderly.

Methods
Seven elderly participants (66-88 years old) with impaired balance trained under supervision of a physiotherapist twice a week for six weeks using AR-based visual-interactive guidance, which was facilitated through a Microsoft HoloLens holographic display. Afterwards, participants and physiotherapists were interviewed about the new technology and their experience of the training. Also, fear of falling, balance and physical ability were measured before and after training.

Results
Most participants experienced the new technology as positive in terms of increased motivation and feedback. Experiences were mixed regarding the physical and technical aspects of the HoloLens and the design of the HoloLens application. The majority of participants perceived that they were steadier after training; this was also shown in the balance tests. Also, most participants reduced their fear of falling after the training. Participants also described issues that needed to be further improved, for example, the training program was difficult and monotonous. Further, the HoloLens hardware was felt to be heavy, the application's menu was difficult to control with different hand maneuvers, and the calibration took a long time. Suggestions for improvements were described.

Conclusions
The study showed that training with the new technology is, to some extent, feasible for the elderly, but needs further development. Also, the technology seemed to stimulate increased motivation and adherence to training. However, the new technology and training requires further development and
testing in a larger context.

Background
Impaired balance is a common cause of reduced health in the elderly. Impaired balance can lead to falls, reduced independence, and reduced daily activity that in turn can lead to illness and premature death (1). Annually, 35–45 percent of community-dwelling people over 65 years of age and 50 percent of elderly people report falls (2,3), which accounts for more than half of the injuries leading to hospital care (4). A Swedish study showed that less than half of the elderly met a physiotherapist after inpatient hospital stay. Although there was a willingness to exercise, there was uncertain about the type of exercise to perform to regain physical ability (5). There is strong evidence that balance training prevents falls and increases independence for the elderly (6). It is also known that the training should include strength, balance, flexibility, endurance and contain dynamic exercises; also, it should be done 2–3 times a week for three months to be effective (1,4,7).

Also to be effective, it is important that the elderly have adherence to training advice (8,9). Most of the elderly (79%) who train at home struggle to fully implement their prescribed balance training to reduce falls (10). New forms of exercise based on technologies such as Virtual Reality (VR) and Augmented Reality (AR) have been shown to increase adherence to training protocols, and to stimulate cognitive abilities in the elderly. Studies show that training should not only stimulate physical ability but also executive processes, and therefore should include enriched environments that provide physical activities decision-making since these are believed to facilitate development of both motor performance and brain functions; AR exercises have the ability to facilitate this (11). AR provides opportunities to create new methods for training and rehabilitation with spatially properly calibrated 3D visualizations. Hopefully, AR-glasses can provide more people the opportunity for individualized training at home, which could increase adherence and create a more controlled implementation of physical training sessions. AR in various forms has been successfully used in skill training for doctors/healthcare personnel, and is considered suitable for training that requires high motor skills and careful spatial mobility (12). Currently, studies are scarce that focus on physical training/rehabilitation for patients. An AR-training program (based on a video stream from a camera
perspective) has been used as rehabilitation after stroke (13–15), as training in Parkinson's disease (16–17), to treat phantom pain in the arms (18), for shoulder problems (19), and as balance walking training for the elderly (20–22). The few studies available indicate that AR in various forms alone or in combination with other methods may be an alternative to traditional training/rehabilitation. The latest technology in AR glasses enables the creation of properly calibrated 3D visualizations in real time, which are spatially aligned with the real environment. This way of visually combining virtual 3D content that is metrically correct with the real environment is referred to as Mixed Reality (MR), and the displays facilitating this are sometimes called holographic display. The novelty in activity training of the elderly, as described herein, is that new information technology in the form of holographic computer display (HoloLens™ glasses) is used to develop health-promoting services in the care of the elderly. More specifically, it is on the technical side of the method development to try new ways to visualize 3D instructional content spatially aligned with real (known) context to the elderly. Unlike previous applications of AR technology in healthcare (see above), which are based on the user perceiving reality as a video stream from a exocentric camera perspective, the holographic display allows the user to observe their real environment from their own perspective and thus can perceive and interact with 3D training content in a calibrated and metrically correct way.

When developing new complex interventions, the Medical Research Council (MRC) has expressed that one needs to be systematic and use the best available evidence and appropriate theory. Then it should be tested with a thorough method. In a first stage, feasibility/piloting studies are important key elements in developing the complex intervention, and an important question then is whether it works in everyday life. This first step is to optimize its design and develop the intervention before running a full-scale study (23). Furthermore, the MRC has recommended to use both qualitative and quantitative methods when evaluating the process and the outcome (23–24).

To stimulate and develop more cost-effective training for the elderly who need to improve their balance. We have developed balance training aids using AR and HoloLens that help the elderly to perform exercise correctly with both verbally and visually feedback. Exercise also automatically increases when the person performing is getting better. In this way, with the help of the training aid,
hopefully one can increase motivation and adherence to training for a better result. The balance training with the new aid is based on strong evidence of what works for the elderly, but in the present study, we only tested the new technique for six weeks since the focus was on the feasibility of the new way of training and not its effects.

The purpose of the present study was to test the feasibility of AR based on a holographic display for visual-interactive activity training for elderly persons with balance impairments. The following questions were addressed: a) how do elderly people experience the new technology as an aid in balance training? b) how are the elderly people adhering to the HoloLens/app's instructions and exercises? c) what experiences do physiotherapists have of the new technology as aids in balance training for elderly people? d) how do balance ability, fear of falls, and belief in one's own ability change over time for elderly people who use the new technology as aids in balance training?

Method

Design

This was a prospective study that used a mixed-method approach. Seven people trained their balance ability twice a week for six weeks using the HoloLens glasses with new training applications. The feasibility of the new AR-based training method was examined using both quantitative and qualitative methods. The qualitative method consisted of interviews with participants about their experiences of the new technology and training. The quantitative methods measured physical ability using both questionnaires and physical tests. Results from both the qualitative and quantitative analyses were jointly interpreted to answer the study questions.

Participants and recruitment

The study originally included eight participants with impaired balance and two physiotherapists. One person had to cancel due to illness. The remaining seven participants consisted of two men and five women between 66 and 88 years of age, and the average age was 74 years. The physiotherapists were recruited from a health center near the university. The participants were recruited and asked by the physiotherapists if they would like to be in the study to evaluate a new technique that trained the balance ability. Inclusion criteria were a) older than 65, and b) diagnosed with impaired balance.
Exclusion criteria were; a) the participants were not allowed to have any cognitive impairment e.g. developmental disorder or dementia, or b) functional impairment due to neurological causes, e.g. stroke.

Procedure
To develop the new training aid, a group was assembled that consisted of three experts in the technical application AR technology HoloLens (Microsoft), three physiotherapists with good theoretical and practical experience in balance training, and an expert on the care of the elderly. The training application was developed jointly in the group and was test run as well as improved based on what emerged at the test run. The two physiotherapists, from the health center, practiced handling the training application so that they were well versed in both the training and the technical part. The physiotherapists recruited participants for the training period through the health center where the physiotherapists were employed. Participants were informed about the study's purpose, and the training period began with participants answering questionnaires and being tested about their physical ability. Then, the participants trained under supervision of the physiotherapists twice a week for 20 minutes each time for six weeks with the new balance training aids. Afterwards, the tests were repeated, and all participants and the two physiotherapists were interviewed about their experience of the training and the new technology. Finally, data were compiled and analyses were done by the research team.

Study intervention
By using the new AR technology via HoloLens, participants can see the game-like scenario as a hologram on the lens of the glasses at the same time as they see the real world through the glasses. The developed training application consisted of two games. One was to catch a ball in a ring (training game 1) by moving the center of gravity to the side. If a participant got full points on the level of practice, the difficulty level increased by the ball going faster, being further out to the side, or by reducing the bases of support for the participant. The most difficult level was when the ball went fast and went far to the side while participants were standing on one leg. None of the participants passed this level. The second game was to follow a ball for some time (training game 2) with a virtual laser
pointer until the ball burst. Herein, the ball moved randomly in the field of view and at different speeds. At the easiest level, the ball moved slowly and mostly in the middle of the field of view. At a higher level of difficulty, there was an increased spread of movement of the ball from the center of field of view and the ball moved faster. Also here, the base of support was used to increase the difficulty of training and the participants also performed this game walking in the corridor. Each participant trained for 20 minutes with the help of the training application using the HoloLens and with support from the physiotherapist. Depending on how well the training went, the level automatically increased. The distribution between the two games was equal. This was repeated twice a week for six weeks.

Data collection
A semi-structured interview guide was used where participants and physiotherapists were interviewed about the new hologram-based methodology for visual-interactive (AR) activity training for the elderly and about its feasibility.

Before and after the training period, the Microsoft HoloLens was used to determine the balance ability by measuring the total sway of the head for 30 sec. This was accomplished by projecting the 3D position of the user’s head, as acquired from the HoloLens device, upon the horizontal plane of the floor and by evaluating deviations from the center of gravity of those measurements. The acquisition of 3D positions was done with a sampling frequency of 30 Hz. Balance was also measured with a force platform Ergopower Technology (Porsgrunn, Norway). The force platform was connected to a personal computer via an analogue/digital converter (MuscleLab Model 4000e). The software used for calculation was MuscleLab 8.0. The total sway (mm) during 30 sec. of the center of pressure was calculated. The sampling interval was 0.01 sec. (100 Hz). This procedure follows recommendations by Browne and O'Hare (25). Participants measured their balance in four different positions (shoulder width, feet together, semi-standing, and tandem standing) at 30 sec. standing on a force platform with the Hololens on the head. This was repeated twice, and an average of the two tests was calculated and used in the analysis. The instruction to the participant was to stand as still as possible and to fix the eyes at a point on the wall about two meters in front of the participant that was just
below eye level. After this, participants conducted the Berg's balance scale (BBS) (26-27). Physical ability was tested using the Short Physical Performance Battery -Swedish version (SPPB-S) (28), and finally participants estimated their fear of fall with Falls Efficacy Scale International, (FES-I) (29). One participant could not complete the intervention because of illness.

Data analysis

The first author (SB) preformed all interviews with the participants. Afterwards, the interviews were transcribed and read through several times to ensure understanding of and familiarity with the text. The text was divided into meaning-bearing units based on the study aim, and was thereafter condensed and coded. The codes were then compiled into categories. Analysis was done by the authors SB and ME. A descriptive analysis of the quantitative data was conducted and presented. To increase ‘trustworthiness’, recommendations by Graneheim et al (30) were followed. We tried to increase credibility by putting together a group of different participants, by using open questions, and by describing the method carefully. In order to meet the transferability criterion, we tried to describe the data and have cited the participants in the text. Dependability and credibility criteria we also tried to fulfill by that first author (SB) did the whole procedure of dividing into meaning-bearing unites condensed, coded and then sorted data inductively into categories. This procedure was monitored and controlled by one of the authors (ME).

Ethical approval and consent to participate

All participants were informed orally and in writing about the study purpose, about what it meant to participate, and about confidentiality. All participants stated that they understood the information and signed a written consent to participate. Participation was voluntary and the data were treated confidentially. The study was approved by the Regional Ethical Review Boards in Uppsala, Sweden (Dnr 2018/357).

Results

The reasons for why the balance was reduced varied among the participants from pain and surgery to various diseases and medicines. All participants stated that their balance reductions had led them to become less active and to cut down on some activities like chores, walking up stairs, climbing
ladders, cycling, cleaning, going out in the winter, etc. Many experienced dizziness when changing positions, e.g. getting up from bed or a chair, turning around, etc. Three participants had fallen, and one of these had fallen several times. Six out of seven experienced a fear of falling due to the balance reduction. The reasons for taking part in the study varied, but all had hoped that their balance would be better afterwards. Participants also expressed that it would be fun, interesting, and exciting to take part.

Practicality around balance training

Most participants thought that exercising 15–20 minutes was adequate and was not too long. One participant expressed that it could have been even longer. Many experienced that training twice a week at fixed times was good, and it was easier to plan. However, two participants felt that they were ‘stuck’ with the fixed training times, which made it difficult for them to do anything else like going to the summer cottage. These participants expressed that it would be better to exercise more often but not so long since this would have a better effect on the training, “….probably best to do it a little more often. This would give better results; perhaps every other day or so;” participant 2. This opinion was also shared by the physiotherapists who thought that the training could be a bit too long for some. Participants would get tired, experience pain and lose concentration. The physiotherapists felt it best that participants would train a bit less but more often, “….when you are going for such long intervals, one gets tired in the body also. Then it is not the just the balance that becomes an obstacle, but tiredness also occurs in the hip muscles and in the feet […]. It is better not to push further but instead use shorter intervals more often;” physiotherapist 2.

Experiences of the two training games

Training game 1

Many of the participants had difficulty moving the center of gravity to the side. All felt that the exercises went well in the beginning when the ball did not move so much to the side and the base of support was large. When the ball went more to the side and moved faster, many had problems moving the center of gravity to the side, and especially when the base of support got smaller. Many participants felt that the ball disappeared from the screen. They also experienced that the exercise
became static and predictable as the balls would alternately come from the right and left, “....you could catch it if you moved your feet; if you twisted your head the ball would disappear;” participant 5, or or “.... it felt like I was playing tennis and that was fun, but in the end it became a bit tedious [...]; at the same time you feel that it is useful for the hips to do that movement;” participant
The physiotherapists had similar experience of the exercise and found it was difficult to move the weight between feet without turning the head at the same time. As a result, the participants turned their heads, and the ball disappeared from the screen. This exercise was considered by the physiotherapists as a difficult motor performance. As a result, many did not manage the exercise when demands increased, which did not lead to a good balance exercise. The physiotherapists also experienced that the exercise was repetitious and boring, which led to reduced motivation among the participants, “.... it was a complicated move to do because the participant would lean in one direction making it difficult with a rotation of the neck in the other direction to keep the glasses in the same plane. It was a motor challenge that was very difficult for the participants;” physiotherapist 2.
Training game 2
Participants expressed that they had to concentrate a lot to be able to follow the ball all the way until it burst. There was no problem to follow the ball when standing still, however, it became more difficult when the base of support decreased or when participants walked in the corridor. The ball could disappear from the screen but participants were given information about where the ball was via feedback by an arrow. Many participants felt that walking was more positive than standing still and following the ball, “.... I thought walking in the corridor went well, it was fun; the only problem was that turn. I stopped and didn't know where the ball went “ participant 4, or “.... it was kind of fun walking like this; it is monotonous when you stand still in the room;” participant 6. The physiotherapists thought training to follow the ball worked well, and that the training could expand and increase in difficulty in the future. They also felt, as participants did, that it was more positive to exercise walking in the corridor than standing still.
The physiotherapist wanted more exercise program to choose from in order to increase the motivation and concentration of the participants. They also pointed out that the participants needed
to understand that they had to challenge themselves when training to get good effects. Also, clear goals for the participants with the training were needed. It was not just the figures indicating they were getting better balance during a test, but also a desire to see this in everyday life. This was a way to increase participants’ motivation, “.... some say, ‘no, but I do not dare stand like that because I get so wobbly’. But then you have to remind them again that it is a balance study, and that it is the balance we are challenging. They cannot stay in their safety zone because then they do not improve. [...]. They have to push to the point of being a bit uncomfortable, and stretch the limits in order to get better. ;” physiotherapist 2.

The increase of balance training

None of the participants experienced that the increase in the severity of the exercise was too fast, e.g. reducing the base of support, but none managed to train on one leg, “....I really thought it was fun. I didn’t really feel it increasing;” participants 5, or “.... I cannot manage with only one foot; I have to have the toes of one foot on the other [...]; otherwise it went well;” participant 1.

Feedback from the HoloLens

Most participants felt that feedback on how training went, through how many points they received, was positive, but they wanted to know more clearly what the points stood for and what points were good or bad, “....I did not really understand if it was counted all together or if it was one moment at a time;” participant 4. Many participants also thought that the feedback from the technology could be motivated to boost one to train a little more, “....it is difficult to get people to work out, but when you are doing something like catching balls, it can be justified. It's like a fun game;” participant 5, or “.... I thought several times that, now I have to start a little more with the waist like this and stretch out, and then I can take that ball [...]; this is something you get from the technology and in this way it has been very good;” participant 4.

Other feedback that participants experienced as positive was that one could see where the ball was by looking at the arrow on the screen, and also that you could see how far you had left before the ball burst by looking at the circle around the ball, “....then the ring around the ball would start growing. Then when it merged, there was an bursting [...] then one had succeeded and it was just to find the
arrow again and start with the next ball;” participant 5. There were mixed opinions about what the participants thought about audio feedback. Some felt that the sound did not really match what they experienced, while others thought it was good that they received feedback through sound when they managed to catch the ball.

The experience of the physical and technical aspects of the HoloLens and its application

Most participants felt that wearing the HoloLens was not a problem, although some thought it was heavy to wear, “....it felt a bit heavy because I have neck problems. You can feel a little wobbly and not so steady [...], otherwise there was no problem;” participant 6. All participants felt that the fit on the HoloLens was poor and it affected the training. Some got pain from the HoloLens either on the nasal root or on the forehead because you needed to tighten securely the HoloLens on the head in order for it to sit still, “…I had to tighten it quite hard for it to sit still, so I got a bit sore on the nose;” participant 5. The physiotherapists also perceived that it felt heavy and it pressed on the root of the nose and the forehead due to the tightening to make it sit still, “…many complained that it was a pain having it on their nose, and they usually had quite a hard time setting it right. You can wiggle it up and down a bit and adjust tension;” physiotherapist 1. The physiotherapists also came up with suggestions on what could improve the fit, e.g. some type of padding for the nose or some type of helmet insert so that it rests on the head and not only on the root of the nose and forehead.

Some participants felt that it would be good if even the person who helps with the training could also see what is happening on the screen in the HoloLens. This would make it easier to explain and to provide feedback to the user, which would facilitate the training, “....then you had someone to communicate with [...]; this, for example, is how it should be;” participant 1. To facilitate in the future, the physiotherapists thought it would also be helpful if the person next in line could see and hear the same thing as the person who trained with the HoloLens. This would make it easier to correct the training and to provide feedback, “....had one been able to see and control things from the side, that would be all the feedback you needed. Then it would have been optimal;” physiotherapist 2.

The HoloLens was calibrated at start-up. This was a sensitive moment that many experienced. If the HoloLens did not sit well on the head and you changed it, the calibration of the screen could also be
changed. Then there was a need to recalibrate in order to continue training. This took time and was annoying. Sometimes when a participant turned their head in certain positions, what was seen on the screen could be affected. In some cases, what was on the screen became half or disappeared completely. This made it impossible to follow or to catch the ball, which many felt was frustrating, “...sometimes I thought I would tighten it a little more, but then it would slide downwards [...]; then I would not want to change it because usually the screen itself also changed;” participant 1. The physiotherapists experienced a lot of trouble with the technique. It was difficult to get the HoloLens in the right place on the participants' heads so that they could see the entire screen. The HoloLens had difficulties calibrating the environment so it became correct, and it took a long time to calibrate. This could cause the game pitch to be slightly shifted, and the participants would have difficulty completing the training. Sometimes the game needed to be recalibrated during the game itself, which took time and created frustration. The hand and finger commands that controlled the game were difficult to execute and were sensitive to both the physiotherapists and participants. As a result, it took a long time, for example, to start the game or to change the exercise program. It was difficult to maneuver and reverse in the menus because these were not user-friendly. The physiotherapists experienced the screen as small and that the participants could not see that much of the field of view; this made it difficult to see things from the sides and upwards/downwards, “…now it is just a small part of the field of view that is affected. If the screen was bigger in the future, it would open up possibilities such as you could see things coming from the side;” physiotherapist 1. Contrast on the screen was also something they pointed out that the HoloLens was good to see bigger things but harder with smaller objects. Some suggestions came up on how to improve the technique. For example, to have some kind of sight reference so that you knew you had the HoloLens right. The calibration would be as in a ‘follow a ball’ game where the HoloLens calibrates itself continuously and not with a fixed calibration such as in the game ‘to catch a ball’. Another suggestion was to be easier to back in the menus with a back button, "... you would need some kind of sight-reference points or lines, or something like that when you put on the glasses [...]; you could put points in the corners of the screens so you could see all four points. If you did not see it, then you may have to make
changes;” physiotherapist 2.

Clarity

Clarity was a theme that emerged regularly during the interviews. This referred to everything from clear instructions to what the training was about and how to start the program. Also, clarity on how the training should be performed, about what the score stands for, and about when you are successful in the training was desired, “....At first I thought you couldn't move your head, but then you were allowed to move your head. Then where to make of the hands [...], this was something that could have been more clear;” participant 1.

Exercise at home

Most participants were positive that they would consider practicing balance exercises at home using the HoloLens, and most felt that they could recommend friends to train with the help of the HoloLens. They did not feel that the technology would be a major obstacle to training, but many thought that motivation would be, and also that the social part would disappear when exercising at home. In order to increase motivation, some participants felt that someone needed to follow-up the training, and here the technology could be helpful, for example, if you could see how much you exercised and the progress you made with the training, "....this would not be a problem for this technology [...]. If you notice improvement, then you might be more motivated;” participant 1. Both physiotherapists mentioned home exercising and they saw opportunities in the future. Technology can be helpful with clear instructions via video and sound as well as increasing and progressing training. It can also help motivate and enable compliance to training, which could lead to better training results, "....it is compliance to maintain it over time, which is the problem [...]; many say they need a little ‘carrot and stick approach’ sometimes. If you go home with the understanding that, ‘If you do not exercise they will be able to see that’; many perceive this as a strong motivation;” physiotherapist 2. The physiotherapists experienced the HoloLens as easy, convenient, relatively safe, and cost-effective to train with. It is fun and it becomes more like a game than training, which can be motivating, “....first of all, it is fun to play a game and get training as a benefit [...]; you know how to get immersed in games and you can be motivated [...]. It can be easy to have training regularly, daily in the home
environment. It is both time- and cost-effective;” physiotherapist 1.

Adherence to the new technology

Overall, the technology worked well, and the physiotherapists felt that there would be no major problems for the elderly to train with the new technology. In addition, it simplifies whether the person has an interest in technology when learning the new technology, “….for a normal person there should be no problems to learn the technology;” physiotherapist 1. However, there were some parts of the new technology that the elderly had difficulty with such as movement with their hand and fingers to control the program or being able to maneuver in the menus on the screen. The sight dot was also difficult to see.

Effects on the balance of exercise

When asked if they felt that their balance had changed after the training period, four participants replied that they felt they had become steadier, “….I feel that I have become more stable with the training, although it was an exercise that I could not have imagined since it was not possible to catch the balls anyway (with laughter);” participant 5. Two participants did not experience any change, and one participants experienced a decline, which she described that she became dizzier due to changing medication.

Balance and physical ability and fear of falling

Differences in sway before and after the training period can be seen in Figs. 1 and 2. All participants reduced their sway of the head when standing semi or tandem after the training period. This was not the case for sway measured with the force plate where three participants increased their sway after training. It is noteworthy to point out that participant eight managed to stand tandem for 30 sec. after the training period, which she did not do before the training. Participant two failed to tandem standing and participant three had to withdraw due to illness Table 1 shows that all except one participant reduced their fear of falling (FES-I) after the training period, whereas the BBS results show that five out of seven participants decreased their balance ability. In the SPPB-S, two participants improved their results and one decreased the result, whereas the others had the same result as before the training period (table 1).
Table 1. Participants’ points on the Berg Balance Scale (BBS), Performance Battery -Swedish version (SPPB-S), and the Falls Efficacy Scale International (FES-I) before and after the training period.

| Participant | BBS before | BBS after | SPPB-S before | SPPB-S after | FES-I before | FES-I after |
|-------------|------------|-----------|---------------|--------------|--------------|-------------|
| 1           | 53         | 51        | 11            | 11           | 123          | 130         |
| 2           | 50         | 49        | 8             | 9            | 122          | 128         |
| 3           | -          | -         | -             | -            | -            | -           |
| 4           | 53         | 55        | 12            | 12           | 130          | 130         |
| 5           | 56         | 55        | 9             | 11           | 86           | 104         |
| 6           | 56         | 49        | 11            | 11           | 100          | 127         |
| 7           | 52         | 51        | 10            | 10           | 62           | 77          |
| 8           | 49         | 50        | 12            | 9            | 120          | 108         |

The maximum scores are for BBS 56 points, SPPB-S 12 points and FES-I 130 points.

Discussion

The purpose of this study was to test the feasibility of a new AR-based methodology for visual-interactive activity training for the elderly with balance impairments. The results showed that most of the participants experienced the new technology as positive. This was in regard to the training programs, increasing motivation, feedback technique, and the physical, technical and design of the HoloLens and its application. Four out of seven participants experienced that they become steadier after the training period. This was also exemplified by sway measurements, especially measured by the HoloLens, and also the majority of the participants rated their fear to fall (FES-I) as lower after training. There was, however, no obvious changes on the BBS and SPPB-S. However, there was room for improvements; for example, training game 2 was difficult to perform, and when difficulty increased it was monotonous. The HoloLens was perceived as heavy, difficult to control the application with the various hand movements, and problematic to switch between the different menus in the application; also, the calibration took a long time. The physiotherapists felt that it was not a major problem for the elderly to handle the HoloLens as long as the participants have no cognitive impairment.

In a literature review, Tsertsidis et al. (31) found that when the elderly had difficulty in using the technology, this was due to technical and design problems. Our participants also had these experiences and they were not satisfied with the way the application was designed, which meant that it was difficult to control the application. Furthermore, the elderly expressed that the technology in itself created problems that could lead to frustration, e.g. calibration took a long time. Therefore, it is important to change the design of the application in the Hololens to be more user-friendly for the
elderly. One example, is by making it easier to navigate through the various menus perhaps with the help of handheld clicks so that the elderly do not have to use the various hand maneuvers that control the application. Also, the calibration of the HoloLens must be easier and more stable. The participants also experienced the benefits of the new technology such as it could increase motivation, it was fun to train with, and it could help to show participants how to train. This is consistent with Tsertsidis et al. (31) who found that the elderly saw benefits of the technology such as increased awareness of health condition, increased independence, and increased enjoyment. Although many of the participants did not experience the training as too long (15–20 minutes), some participants, as well as the physiotherapists, felt that the training time could be long and it was easy to lose motivation and concentration. Their suggestion was to train more often but for a shorter period of time to get a better focus on the training. In a systematic review and meta-analysis by Lesinski et al (32), it was recommended that the training should be between 30–45 minutes per session and the total training duration per week between 90–120 minutes to have an effect on the balance ability. The reason that the participants in our study lost motivation and concentration may be because the training consisted of only two exercises, which some experienced as static, predictable and monotonous, thereby causing them to lose concentration. Therefore, the next step in the development of the new technology will be to introduce new exercise games to avoid monotony and to increase motivation, but also to exercise different parts of the balance ability. Advantages with the new technology are that you do not need any practical preparation and it is simple to work with; this offers the opportunity to exercise for a short period of time to avoid losing motivation and concentration, but still come up with the recommended amount of exercise per week. Feedback and motivation were raised by many participants during the interview as something that was positive with the new technology. This applied both to doing the exercise right and to giving a little more effort to get an extra point or go to the next level in the game. The physiotherapists also felt that feedback from the technique stimulated participants to exercise and to try a little harder. Research has shown that in order for the training to be effective, one must follow the training advice (8,9), and a study showed that many elderly people find it difficult to fully follow the training advice
they received during home training (10). In this regard, the new technology can be helpful for the elderly who are exercising balance, not only to carry out the training but also to get help with progression and increase their motivation. This could increase the efficiency of training, but as some participants expressed feedback must be understandable, i.e. understand what a good result is, what a poorer result is, and what this means for one’s balance ability. This feedback is important to develop in the new technique to increase the understanding of those who exercise and thereby increase motivation. The technique can also be helpful for physiotherapists to make it easier to follow-up the training. The physiotherapists can see how often, how long, and at what level participants have trained, which is difficult with traditional home training program. Furthermore, this also presents more pressure on the individual because it shows how much they have exercised, and many participants expressed this as a good thing for increasing motivation, which could lead to more adherence to training.

Neither the SPPB nor BBS showed a clear change in balance ability after the training period. However, four of the participants felt that they had become steadier, and most participants had reduced their fear of falling after the six weeks. The purpose of the study was not mainly to improve balance ability of the participants, but to investigate the feasibility of training with a new technology. This approach is in accordance with recommendations for the development of complex interventions from the MRC (23). The next step in developing this training method is to improve the technique and extend the exercise games, which will then be tested in a new feasibility study. This new study design should be combined with increasing training length and frequency according to the recommendations of balance training for the elderly (1,4,7).

Research has shown that the training should also stimulate physical activities decision-making since this is believed to facilitate development of both motor performance and brain functions (11). This is what the AR technology has the opportunity to do by using the reality and at the same time building up scenarios through the hologram that participants need to consider when practicing, for example, you walk in a corridor and meet another person and at the same time you have to follow the ball. The person must be in control of several things at the same time such as going steady without losing
balance, avoiding colliding with the person in the corridor, and following the ball. In the future, more situations that are complex should be built up with the new technique that stimulate both physical ability as well as different decision-making when training. That can lead to more effective balance training (11). A clear advantage of the technology is that you can develop a variety of training situations without having to physically build these training situations into reality.

A common way to measure balance ability is to measure the postural sway. This is usually done with a force plate or inertial sensor. Studies have shown that there is a correlation between the size of the postural sway and the risk of falls in the elderly (33–35), i.e. the greater the sway one has, the greater the risk of falling. In our study, we investigated the postural sway using both a force plate and the Hololens. What was interesting about the result was that even though the postural sway did not decrease on the force plate for some participants, the sway measured with the HoloLens did decrease. This is interesting since the participants trained their balance by using the sight and the head and through the Hololens application to catch different balls while keeping the balance. This training seems to have influenced the postural sway measured with the Hololens more than that measured with the force plate. Since there is very little research regarding the sway of the head for the balance ability and the risk of falling for the elderly, it is difficult to describe the importance of the head sway for the balance ability. However, it can be stated that vision is a very important factor for the elderly's balance ability, and it appears to increase with age (36). Furthermore, it can also be stated that with the help of balance training, it is possible to reduce the postural sway for the elderly (37) and thereby reduce the risk of falling (33–35).

It is important to take into account that the study has limitations. The goal of the feasibility study was to discover the advantages and disadvantages of the study design in order to develop a better design before making major interventions according to the MRC (23). Our design was that participants trained at the health center in close cooperation and with the physiotherapists who also had been involved in the development of the new methodology for visual-interactive activity training. This may have affected participants' experiences of the new technology. The number of participants was small, and therefore, it is difficult to generalize and have sufficient statistical power to evaluate the
intervention's effectiveness; also the results are considered descriptive rather than hypothesis testing. Although the number of participants is small, it is a strength that we used a mixed-method design and validated measuring instruments, and we interviewed both the participants and the physiotherapists. The measurement of the postural sway using HoloLens is also uncertain since this measurement method is not reliability and validity tested, which must be done in order to use it in the future.

Conclusion
The study showed that the new hologram-based methodology for visual-interactive activity training for the elderly is to some extent feasible. The technology seems to be able to stimulate increased motivation and adherence to training. However, more development is needed, and after that a new feasibility study is required before undertaking a larger and longer intervention study.

Declarations

Ethics approval and consent to participate
All participants were informed orally and in writing about the study purpose, about what it meant to participate, and about confidentiality. All participants stated that they understood the information and signed a written consent to participate. Participation was voluntary and the data were treated confidentially. The study was approved by the Regional Ethical Review Boards in Uppsala, Sweden (Dnr 2018/357).

Consent for publication
Not applicable

Availability of data and materials
The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests

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Authors' contributions

SB, SS and ME have made contributions to the study design and interpretation of data. SB and ME contributed to reading and coding transcripts, and analyzing the data. SB was responsible for writing the initial draft of the manuscript but SS and ME participated regularly in the writing process. SB, SS and ME read and approved the submitted manuscript.

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Figures
Figure 1

If the point falls below the zero line, the participant has reduced his sway during the training period.
If the point falls below the zero line, the participant has reduced his sway during the training period.

**Supplementary Files**

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