Designing Motivating Interactive Balance and Walking Training for Stroke Survivors

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ABSTRACT

In the ActivAbles and STARR projects we are developing interactive training tools for stroke survivors. Our initial user studies pointed to balance being a key ability, therefore one of the developed tools is an interactive balance pad. Equipment exists for persons with good balance (eg. Wii), but most consumer games and exercises are less suited for many stroke survivors. The development process has been done in close collaboration with stroke survivors, and we have currently a prototype system that has been tested by 10 stroke survivors for a longer period in the home during a feasibility study. The system includes an interactive balance foam pad, feedback lamps and a step counting game app which all connect to a central server. The feedback is designed to be inclusive - designs are multimodal (visual and auditory), and the setup is flexible and can easily be adapted. In this paper we report and discuss the design of the system, pilot test results and the results from a feasibility study in the home.

CCS CONCEPTS

• Human-centered computing • Interaction design • Empirical studies in interaction design

KEYWORDS

Stroke, balance training, interactive, rehabilitation, inclusive, multimodal

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1 Introduction

Stroke is the leading cause of long-term disability in western countries [1] resulting in life-altering changes for both the stoke survivor and their closest family. Loss of balance is common among stroke-survivors [2]. Difficulties with posture and balance make it difficult for persons to walk, and thus to leave the home to socialize or perform other outdoor tasks. After intensive rehabilitation in a dedicated rehabilitation setting, the majority of stroke survivors with residual impairments are discharged and then rely on informal caregivers (frequently close family members) [3]. Effective rehabilitation of stroke survivors is required to help them accomplish daily activities (cooking, washing, etc.) and lead an independent life. After discharge, most of this rehabilitation occurs at home, through performing different types of exercises and activities, such as training in activities of daily living, strength training, cardio-vascular training, balance training, gait training and postural control [4].

However, training exercises can be difficult to integrate into the existing lives of stroke survivors. Exercises can be repetitive and difficult to perform correctly, and may also be considered boring. This leads to stroke survivors losing confidence and giving up on rehabilitation, and losing the benefits it could provide. Thus, it is important to investigate how to better support the continuation of rehabilitation at home. Donker et. al. [5] used interactive tiles for balance training during stroke rehabilitation sessions. They showed that providing real time visual feedback improved motivation and was helpful for balance rehabilitation. Auditory feedback via sonification is also helpful for improving motoric skills [6]. Stienstra et. al. [7] studied how movement sonification improves proprioception during speedskating, if it is latency-free, and the richness of data details generated by the movement are preserved in the richness of sound parameters, such as dynamics, loudness, tempo, pitch and timbre. Other relevant work has proven the benefits of movement sonification on proprioception and awareness [8], [9]. Moreover, music and rhythm therapy are proven to help stroke survivors increase the feeling of being connected to their own body. A study by Thornberg et. al. [10] shows that music and rhythm exercises were considered positively challenging for stroke survivors, while facilitating motor planning and coordination. Music is also a significant motivation factor while training which can give emotional pleasure [10]. Pleasant sounds tend to persuade the user into behavioural change [7].

2 Design Process

The overall guiding principle for the design process has been "co-design". Current work on co-design has largely focused fully able-bodied people, and it can be difficult to involve persons who are disabled and/or elderly in this process. Björkquist, Ramsdal et al. [11] found that it can be difficult to involve older senior users in focus groups due to lack of information about different services. There is also the challenge of adapting activities to suit the prospective users. A person with memory problems or aphasia will find the use of scenarios, a common technique in co-design, hard to use, since these are stories that must be remembered by the participant during the discussion. The physical and cognitive ailments of ageing can add even more challenges to a co-design process [12]. Technology to be tested needs to be either very robust – or the activity well supported by persons able to cover up technology prototype imperfections [13].

Hendriks et. al. [14] identified seven challenges in doing co-design with people with dementia. These challenges seem to come down to 3 fundamental concerns that can apply also to co-design with stroke survivors: 1) the lack of approach for co-designing with these users – the number of works involving stroke survivors in co-designing is limited and few go beyond single case studies; 2) the over appreciation of the visual and the verbal – stroke survivors might lack the ability to communicate well verbally, or have a hard time to work in a visual manner; and 3) the perception of participatory design/co-design – which normally assumes that partners of (relatively) equal cognitive and physical abilities participate in the design process. Although persons with dementia are a different user group, these points are worth consideration also when designing for stroke survivors.

An example from the NavMem AAL project illustrates how one can adapt a common design technique, the scenario, to work better for stroke survivors. In this project comic like strips were seen to be useful in focus groups with persons who had had a stroke [15], and physical objects and props have been found to be a useful tool when involving persons with speech impairments in a design process [16].

One solution when designing for persons with stroke, is to engage for longer periods, in-situ, with stroke survivors [17]. Such an approach does not scale easily, and in order to make it practical, [17] suggest a toolkit approach.

2.1 Initial Studies and Prototype Development

Initial explorative user studies were performed in both the ActivAbles and the STARR projects. Studies in the ActivABLES project [18], made use of a video prototype to illustrate unfamiliar technology to participants. The requirements obtained were refined, extended and elaborated in the STARR project where the initial user studies involved 116 stroke survivors [19] as well as health care professionals and carers. The overall recommendations emerging from these studies are presented in [19].

In [18] we also investigated which activities our designs should target. We found that activities involving balancing, standing up/sitting down, walking and activating the less good side of the body would allow us to reach a wide range of stroke survivors. Balance in particular is a key ability, which impacts walking and is connected to the risk of falling, and we decided to start our technology explorations by implementing prototypes that supported balance training and walking.

A series of prototypes were then developed. As is described in [20], several balance boards/balance pads were developed ending up in a final version based on a pressure sensitive foam pad. To complement the balance pad with walking activities, an activity game based on step counting, intended for both indoor and outdoor use, was developed. The initial app design is described in [21], with a game design was built on short mini games which appear in a semi-random fashion during a walk. To provide progress feedback, different progress lamps were developed. The final versions of our prototypes are described below.

Foam pad, ActiveFoam. ActivFOAM is based on a standard foam pad used for balance rehabilitation, which was made pressure sensitive by the addition of conductive and resistive materials. The pad was covered with a sandwich design of pressure-sensing fabric material (FlexTiles [22], Figure 1). ActivFOAM connects to an android tablet USB port, and it is the android tablet that shows the visual feedback and connects via WiFi to a local OpenHab server running on a Raspberry Pi (Figure 2, left). Sounds are currently not played by the tablet, but by the server. ActivFOAM comes with a selection of interactive activities; you can play music from a music player, you can play a couple of PureData music pieces and soundscapes interactively, you can play games (an audio game, pong and a game where you avoid obstacles on a course) and you can also use only the visual pressure feedback to see the pressure distribution and center of balance.

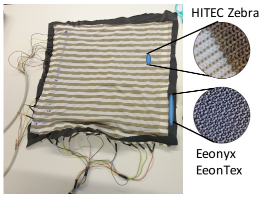

Figure 1: Pressure sensor matrix cover for ActivFOAM.

Figure 2: The final ActiveFOAM setup.

Both the pressure sensitivity, and how sensitive the interactive foam pad is to changes in balance can be adjusted. The volume of the sounds is controlled via a slider on the screen (figure 2, right). ActiveFoam is connected to feedback lamps that can display the progress (see below) via the local server. This server can be used to set a daily goal for balance training, e.g. 10 or 20 minutes per day. Training can be divided into several sessions per day. To count a use session, ActivFOAM registers when someone steps on and off the balance pad.

Feedback lights. For progress monitoring, we developed several different prototype progress lamps (figure 3). Depending on the use case, you may want to monitor progress on one or several activities, and lamps with a single row of LED-lamps, as well as a lamp with branches for three activities were developed. The tree-shaped lamp (figure 3, right) can monitor a single activity (the whole tree fills up gradually), or up to three different activities where each branch reflects a different activity.

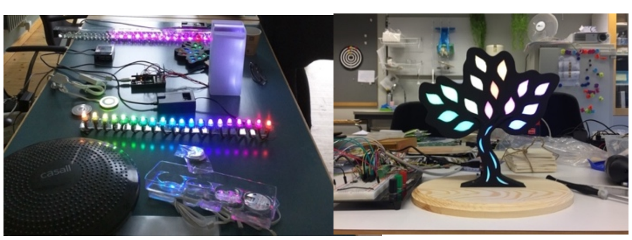

Figure 3: Different versions of the feedback lamps.

Step counting game. The design of this game is built on short mini games which appear in a semi-random fashion during a walk. The game has settings that allow customization – games can increase in difficulty, or stay the same, and it is also possible to completely remove the games leaving only the step progress screen (Figure 4, left). The app has two different graphical themes, stars (figure 4, middle) or dog (figure 4, right).

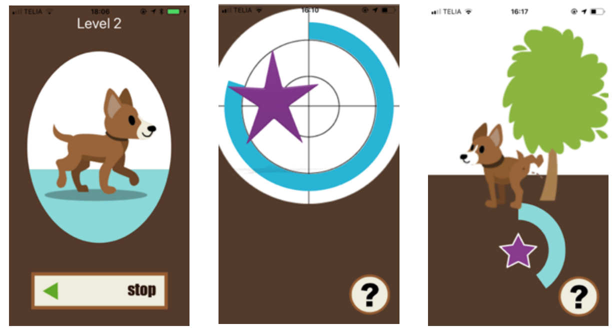

Figure 4: Three screens from the game.

The mini games are physical in nature, you are challenged to walk a little faster, to turn around and point the phone to a specified direction to catch a star or help the dog pee (Figure 4, middle and right), to tilt or shake the phone etc. The game can connect to the feedback lamps through the local server. The user can specify both game goals (how long should a walk be), and day goals (how much you walk during a whole day). These goals can be specified either as steps, distance or active time. The game connects to the server vis Bluetooth LE and the progress towards the goals is also shown on the lamps. The app can be used indoors and outdoors, although some of the mini games work better outdoors.

2.2 Pilot tests

Initial tests of the balance pad prototypes are reported in [20]. The balance pad and the lamps were pilot tested as a system in Sweden by 7 testers (4 women, 3 men, age range between 68 and 81). Of these 4 persons had had a stroke (2 men and 2 women, age range 68 - 81). The stroke survivors all had problems with balance. Additional problems were: right side of the body affected, brain fatigue, lack of stamina, tinnitus, aphasia, difficulty understanding the need for training. The persons who had not had a stroke had arthritis and scoliosis, and one of these persons uses a walker.

After the initial app beta testing described in [21], four more game testers were recruited from the stroke organization in Malmö (three men and one woman, ages between 43 and 68). Our first tester also kept using the app. All the pilot test persons had some remaining problems after their stroke, with walking, with balance and with brain fatigue. We visited each of the new testers in their home, installed the app and made initial settings and provided a written getting started guide and a paper manual. We also did a demo walk together with the user, to ensure he or she was able to use the app (all of them were).

2.3 Feasibility study

The feasibility study of ActivABLES (balance pad, lamps, activity game app) was conducted in Iceland in the spring of 2018 using mixed methods. We had 10 stroke survivors with slight to moderate disability after stroke (Modified Rankin Scale 2-3) using

ActivABLES for four weeks in their own home with support from their caregivers. All the stroke survivors tested ActivFOAM with the balance exercises and four used the Walking STARR application. Before the test, participants were given pedometers, to get a baseline of how physically active they were. Before and after the 4-week use, we performed some quantitative functional measures, including Berg Balance Scale (BBS) on balance. BBS consist of 14 static and dynamic activities of varying difficulty [23]. Wilcoxon signed rank test was used to analyze changes between pre- and post-measures with the significance level of $p<0.05$ After the 4-week use we took individual qualitative interviews with each stroke survivor and each caregiver. Feasibility had the predetermined codes of acceptability, demand, implementation and practicality [24] and subcategories were analysed for each code.

3 Results and Discussion

3.1 Pilot test results

The pilot tests generally confirmed the foam pad system design; the setup worked, was used, and was reported to be motivating. As expected, the pilot testing also led to the identification of problems; the initial setup used commercial devices (tablets, loudspeakers, a mobile phone as a remote control) that all needed to be charged, and charging turned out to be a problem for our users since the interactive foam pad was connected to the tablet via the USB port, which is also used for charging. E.g., users forgot to disconnect the ActiveFoam and connect the charger to charge the device, and when they wanted to use it, it was out of power. There was also smaller user interface (UI) problems (font sizes, colours, contrast, placements and text used). This led to a second version of the prototype with an updated UI, and with a setup where all devices involved are constantly connected to a power outlet. Additionally, the remote control interface to the server (previously on a mobile phone) was moved to the tablet, to reduce the number of devices. Pilot testing of the lamps showed that the light in the initial design was too strong – light that was looking good in the lab, was way too strong in the home, and when the light feedback was coloured, it would affect the light temperature of the whole room. Light animations (colour cycles, blinking, etc) were acceptable as temporary feedback, but quickly got annoying. For the next version of the prototype, light strengths were reduced significantly, and inappropriate light-animations were removed.

The situation for the game was different. While our initial user was quite positive and thought the game was fun and also used it for several months [21], the additional test users were less positive. The feedback we got, led us to believe reminders were needed (one user stated he forgot to use the app) but we also had a few comments that indicated that the stars maybe were a bit boring and impersonal. This led us to a redesign that resulted in the dog theme version (figure 4). Taken together, the feedback from the beta testing of the game varied - the initial beta tester kept using the game and thought it was fun, while later pilot test persons have been more sceptical. One person, who had not previously played mobile games, felt stupid doing the mini games in public. Two users also report the game element being "too much", while still potentially finding games like this interesting.

Table 1. Feasibility study participants and balance measures

gender	age	time since stroke	side of hemiparesis	pre-BBS	post-BBS
f	63	23 years	left	42	43
f	55	9 months	right	49	54
m	71	15 months	left	33	39
m	79	5 months	right	48	49
m	66	26 months	right	31	X*
m	74	19 months	left	45	46
m	67	8 months	left	48	48
f	73	30 years	left	38	42
f	78	4 years, 3 months	left	43	44
f	72	14 months	right	44	48

*was not able to take part in the post-testing

	pre-test*	post-test*	p
BBS (0-56)	43.5 (39-47.3)	46.0 (43.0-48.0)	0.013

*median (1st and 3rd quartile)

3.2 Feasibility study results

In general, the participants were impressed with ActivFOAM and reported interest in further use for themselves as well as for future stroke survivors. The stroke survivors did significantly better on the balance measures after the 4-week use (see Table 1) and both stroke survivors and their caregivers reported noticed functional improvements, especially on the balance. They also said they were more stable while walking and relied less on their assistive devices. Both stroke survivors and caregivers described the importance of instant feedback while doing exercises and a majority of participants thought the feedback in forms of light were encouraging. The stroke survivors reported the excitement of collecting scores while exercising. At the same time, they express the need for more variety of exercises/games. About half of the stroke survivors did use the possibilities for progression of the exercises (by making the paddle and the circle smaller) and they thought that was a good option. The stroke survivors were mostly independent in using ActivFOAM and did not get a lot of support from their caregivers.

The four stroke survivors that tested the step counting game, were most delighted with the step counts and thought it was encouraging to see the steps taken and what to aim for. They had problems with the games and were not very interested in trying them out. One stroke survivor said the activities with the dog were too childish. Depending on the participant, the app has been used for short walks indoors (4-8 min) or longer, outdoor, activity.

3.4 Discussion

It is encouraging to see that already such a short home intervention as four weeks can generate significant results. It has been shown that four weeks of supervised balance training for 20 minutes a day at a rehab center will generate significant results also in the chronic phase of stroke [25]. The difference in our case is that the training was unsupervised, on a comparatively low cost device and done in the home - thus having to be integrated in the daily activities of the participants. The pedometer use before the intervention generally indicated quite a low activity level, something which shows the importance of developing these kinds of designs and interventions – also quite limited efforts like using an interactive balance pad and/or an app, can generate measurable improvements.

Compared to the Wii balance board, our balance pad is soft, potentially safer since you are not standing on a raised hard platform and can also show the pressure distribution over the surface. The REHAP balance tiles [5], which are designed for supervised training allow the creation of different step exercises, respond to pressure at specific points. Our setup is designed for unsupervised training, and the games and other feedback are also designed for our user group; for stroke survivors it is important to limit the amount of information the user has to process. Additionally, our pad is part of a system – through the server it is possible to link additional devices, apps and potentially also embedded sensors to feedback lamps or other feedback devices as well as to games.

At the same time, we also see that there is more to do. In the project, focus has been on building the hardware, and the software was implemented to test different design ideas for the interaction. Thus, the current balance pad prototype lacks more elaborate game & feedback designs (leveling, activity feedback etc, cf [26]). The feedback to date, indicates that the different design ideas are all appreciated (different users prefer different ones, but there is no obvious failure – no game/activity that no-one likes), in fact the variety is stated as something positive; it is important to have a wide variety of different games and activities. More elaborate feedback is still needed eg. time spent training, high score in games, qualitative feedback on balance as well as level support. The pong and obstacle course games are currently silent, and we have had requests on adding sound.

The lamps have been generally well appreciated and seeing the lights change has been felt to be encouraging. Still, the lamps as they are now, are a proof of concept and future developments should involve artists/designers to create designs that are both aesthetically pleasing and useful. A potential advantage of the step counting game connecting to the lamps, is that you can see your progress without constantly having to monitor your phone. Currently, you still need to run the app in the foreground to get the connection to the lamps (the app connects to apple health so once you connect you see all your activity for the day), but with an app running in the background it would be possible to keep track of your activity continuously. The development of the feedback lights showed the importance of testing in the home, cf.[17]. Our first prototypes, which looked ok in our lab environment, turned out to give too strong light to work in a home environment, and we had to dim them substantially.

Having a server allows the creation of a flexible system, but it is also potentially a security/privacy risk. In our system, we decided to have the server local and unconnected to the internet to avoid having to deal with extensive security measures. This came with two immediate disadvantages: firstly the server can no longer get the time from the network and we had to add a real time clock to our design, and secondly tablets (or phones) connecting to the server wifi will not be connected to the internet. Thus, any device which needs internet connection cannot use wifi, but instead has to connect to the server via Bluetooth LE (this is what the step counting game does). In future designs we will consider allowing internet connections – something which would allow the user to send information to, and receive information from, their physician, physiotherapist or other relevant person. Another limitation of the current design is that the balance pad connects via USB. Most tablets have a single USB port, which is used when charging the device, and connecting via Bluetooth would allow it to be used with any tablet, regardless of what USB ports are available (currently our design requires tablets where the ActiveFoam can be connected via USB while the device is charging).

Currently the music is played by the server. This design choice allows different input devices to interact with the same soundscape, but in a more stand-alone system, the tablet could be made responsible for providing both visual and auditory feedback.

It is interesting to note, that although it is a challenge to develop novel technology, a major challenge in our case turned out to be the charging of devices. Our current solution is to keep the system connected to a power outlet, but since we use existing standard technology when possible (eg tablets) designed for charging, this isn't an ideal solution. Although products aimed at facilitating charging are beginning to reach the market, charging is still a challenge that needs to be considered in any system intended for use in the home by our user group.

While the ActiveFoam setup has been generally successful, it is clear from the test results that the step counting game requires re-design. The varying feedback of the step counting game reflect a wide variation of both user abilities (our initial test user had walking difficulties, but nothing major) and preferences. All the Swedish test users were able to play the games during the introductory demo that was given at the start of the test period, although two users thought the game was "too much" to use during a longer period. Generally, the mini games appear to have been too demanding for the Icelandic test users. One of our Icelandic test users also experienced the games as childish. As was stated under the pilot test results, the reason for introducing the dog theme, was feedback that said the original star theme was boring, but this change was made without actual comparisons of the two designs – and we have brought the, potentially less childish, star theme back as a possible selection in our latest version of the app. Taken together, the feedback we have indicates that either the mini games need to be re-designed, or more alternative game designs are needed. Since we have users who think the mini-games are fun (especially our first test user used the app extensively), we have decided to start with the second alternative and have implemented a version of the app which includes two completely new games: one game where you don't have to do anything actively while you are walking – you automatically pick up keys and chests with treasure which can later be unlocked once you are home again; and one version which is less of a game – each completed exercise moves you forward in a journey through a landscape. This new version of the app will be tested during 2019.

Looking more at the audio-haptic interaction design of the app, a challenge in the mini games has been to reflect the effects of gesture interaction in audio. While this could potentially have been done with musical mappings, we had design requirements pointing to a need for simplicity [18]. Thus we tried to keep our feedback simple and have limited it to distance mappings combined with success and failure information. Following [27], distance or closeness to a goal was mapped either to pitch or to volume. Although not formally tested, it is our impression is that in our designs pitch generally worked better since it provides audible information also when the distance to the target is longer. An observation based on the received feedback, is that even the limited multimodal feedback used, appears to have been too much for some of our test users.

Another specific design challenge has been that persons with walking difficulties need to focus on the environment and not on the screen. Not looking at the screen is important for many users in many situations [28], but for our user group it is crucial. Thus the app needs to be designed so that it can be kept in the pocket, or in the hand without the user looking at it, for all use that involves walking. All our mini-games except one, are designed to be played while standing still. Even so, the rotation involved in the pointing turned out to be challenging for a person with balance problems. This could be beneficial since it implies playing the game will train your balance, but it could also be a problem for persons with significant balance difficulties. The walking faster game, the game which involves walking, is designed so that all information needed to play the game is presented through sound and vibration to allow the user to know what is happening without looking at the screen.

A problem with pocket use, has turned out to be accidental touch events (particularly in damp weather). Since the app relies mostly on gestures, and less on touch, the main effect of this has been that the app sometimes can turn off in the pocket without the user realising this has happened. To prevent such accidental closing of the game, the app currently notifies the user through sound and vibration and also requests extra confirmation before exiting.

An interesting observation from the app design process, is that while one can come up with a wide range of gesture based challenges, it can be a pedagogical challenge to come up with an explanation of what the user needs to do in order to succeed in the game. As an example: While the jerking gesture in itself is not complicated, providing appropriate feedback supporting the learning of the gesture, together with an appropriate mental model for the user of what you should do, required several iterations in the early game versions.

Finally: a guiding principle for all our designs has been that the interaction should be flexible to allow users with different perceptual and cognitive abilities to use the developed technology. Thus, we have included activities using both sounds and visual feedback in our design. It is possible to use the balance pad with only sound feedback, with only visual feedback as well as with a combination of sound and visual feedback. Also the step counting game uses multimodal feedback – visual, auditory and haptic (vibration). This comes with two issues: 1) too much simultaneous information may overwhelm the user. It is common for stroke survivors to have brain fatigue, which makes multimodality a potential problem. 2) to avoid overwhelming the user, one could use settings. But settings in themselves run the risk of overwhelming the user. So far, we have opted for multimodality as our basic approach, but added a limited number of settings.

4 Conclusion

Our test results confirm our designs with regards to the interactive balance pad and the feedback lamps. The participants in the four week feasibility test significantly improve their balance, and also generally appreciate the pad and the lamps. What remains to be developed is the interaction and feedback – more games and activities, better game mechanics and improved overview of long term results. We have confirmed that ActivFOAM has a design that is stable and quite robust. The foam pad itself is also quite flexible. One can stand on it, but it is also possible to sit on it. The direct activity feedback provided by the lamps has been appreciated, but also the lamps need further development with regards to both functionality and aesthetics. For the step counting game, the picture is less clear. Although some elements of the design got positive feedback for some of our users, clearly further development and testing is needed.

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