Universal balance?

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Abstract. In the ActivAbles and STARR projects we are developing interactive training tools for stroke survivors. As our initial user studies pointed to balance being a key ability, one of the developed tools is an interactive balance mat. While balance equipment is common, interactive balancing equipment for persons with poor balance is less common. Equipment exists for persons with good balance (eg. Wii), but most games and exercises are less suited for many stroke survivors. The development process has been done in close collaboration with stroke survivors. We have used both creative workshops and individual iterative testing in the development, and have currently a prototype that is being tested in the home of 12 stroke survivors. This prototype is based on a foam mat which incorporates pressure sensing, and which allows you to see the pressure distribution as you exercise, but also allows you to play music or play different games. The feedback is designed to be inclusive - designs are multimodal (visual and auditory), and the setup is flexible and can easily be adapted. Initial test results show that the overall design is promising and works well (is robust, motivating and used). Problems identified are connected to the fact that we use main stream tablets for feedback, which adds complexity for the user both with interaction and charging. We are currently working on solving these problems, and expect to end up with a balance mat well suited for a wide range of users - not only stroke survivors.

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

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].

The present paper presents different interactive prototypes designed to support the continuation of balance rehabilitation at home. The goal is to provide a more enjoyable experience when performing balance rehabilitation exercises. We present early results from the testing of our prototypes.

2. Design Process

In both the ActivABLES project and the STARR project, development started with user studies in order to get design requirements for our designs. These studies included interviews, focus groups and co-design workshops. Results from the studies in ActivABLES has been published in [11], while a STARR co-design workshop is reported in [12]. Initial design recommendations for the developments were [11]:

- Support the user in keeping a good balance between activity and rest.
- Exercises need to have a purpose/meaning, and should be embedded in activities.
- Safety & security needs to be considered
- The system should provide reminders, and support the user remembering and getting started.
- Activity goals should preferably be broken down into sub goals, to allow the stroke survivor to “win many small victories”.
- Feedback and awareness on activity and progress should be provided.
- Provide a sense of accomplishment and empowerment.
- Designs should be easy to use, but not childish.
- Social use and the social context should be considered.
- The technology should support patient – family - professional communication
- Motivation is key; designs need to be either useful and/or fun
- Indoor and outdoor use should be considered.
- Designs need to support different speeds and should be adjustable, personalizable and multimodal to allow use by persons with different sensory abilities.
- Avoid excluding users with aphasia.

- Designs should be flexible, easy to move and allow users to re-appropriate the technology.
- To support different skill levels, it needs to be possible to adjust a suitable level of challenge.

A part of these initial studies was to find out what kind of activities to target in our developments. We found that activities involving balancing, standing up/sitting down, walking and activating the weak or paralyzed side of the body would allow us to reach a wide range of stroke survivors. Balance is particularly important, since balance is a pre-requisite for walking, and walking is important both for health (physical activity) and for the ability to participate in different activities (social inclusion). Thus, it was decided that one of the developments in the projects should be an interactive device for balance training. A series of prototypes were developed and tested. We started off with an interactive BOSU ball (figure 1 left), but quickly realized a BOSU ball was very challenging for many of our users, especially for persons with poor balance.

Figure 1. Left: Stroke survivor using the interactive bosu ball, leaning slightly to the right. Therefore the right hand lights are lit up. Right: The pedals. These pedals are linked together with a rubber sheet, and the same safety handle bars as in figure 1 were used.

In order to design a device that was slightly easier to use, we explored a pedal like design, which limits the range of movement of the platform tilt (figure 1 right), but this design turned out to be harder, instead of easier to use, because each foot tilted separately. Our final, successful, prototype (ActivFOAM) was an interactive balance foam which provides a soft standing surface that challenges balance but does not tilt (figure 2) [13]. ActivFOAM comes with a selection of interactive activities; you can play music from a music player, you can play a couple of music pieces and soundscapes interactively, you can play games (an audio game, pong and a game where you avoid obstacles on a course, figure 4) and you can also use only the visual pressure feedback to see the pressure distribution and center of balance (figure 3). Both the pressure sensitivity, and how sensitive the mat is to changes in balance can be adjusted. The volume of the sounds is controlled via a slider on the screen.

The mat is connected to feedback lamps via a local server that can display the progress. 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. ActivFOAM registers when it has been stepped onto and stepped off, and counts a use session that way.

Figure 2. The balance foam, together with the feedback devices – a tablet for the visual presentation, and loudspeakers for sounds.

A first version of this prototype was pilot tested 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.

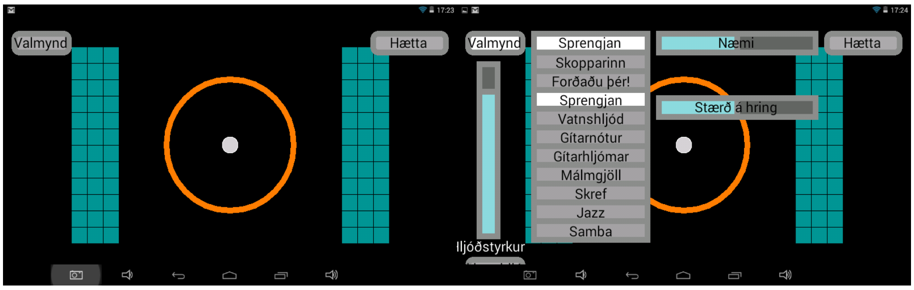

Figure 3. Left: The basic interface where you see the pressure on the mat (blue) and the center of balance (white circle). The orange circle shows the goal area for the center of balance. Right: The menu interface. Volume to the right, the different activities in a drop down menu. Additionally you can adjust the size of the orange ring, and the balance and pressure sensitivity.

The pilot testing led to the identification of a few 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 mat was connected to the tablet via USB port, which is also used for charging. E.g., users forgot to disconnect the mat and connect the charger to charge the device and when they wanted to use it, it was out of power. There were 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. The new setup was also connected to a music player that unlocks 5 new songs per day (a functionality which could unlock other things like TV shows in the future).

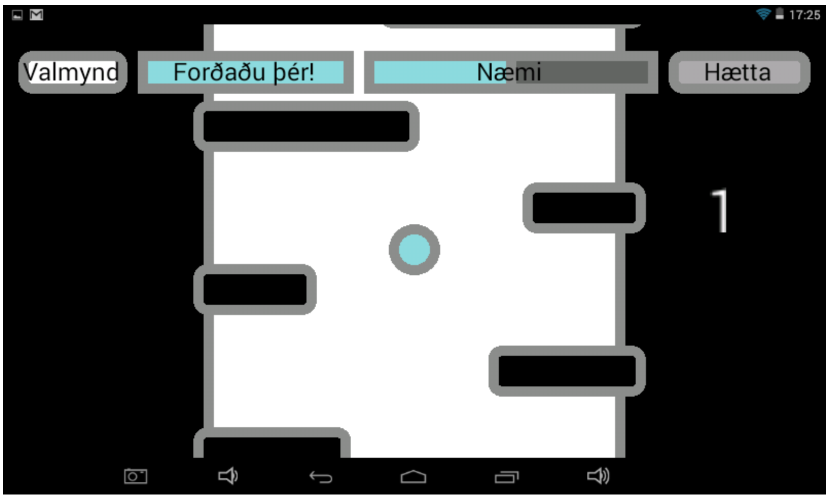

Figure 4. The “race course” game. The goal is to control the centre of balance (blue circle) so that you avoid hitting the blocks.

This second setup is currently being tested in Iceland at stroke survivors’ homes for a period of four weeks of daily usage, and preliminary results are promising. All testers have problems with balance and some have other additional problems eg. hand spasticity, aphasia. Our tests so far have confirmed the design, the setup works, is being used, and has been reported to be motivating. 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 prototype lacks more elaborate game & feedback designs (leveling, activity feedback etc). The feedback to date, indicates that the different design ideas are all appreciated (users prefer different ones, but there is no obvious failure – no game/activity that no-one likes), but that more elaborate feedback eg. time spent training, high score in games, qualitative feedback on balance as well as level support is needed. The pong game is currently silent, and we have had requests on adding sound. One problem we discovered was that it was hard/tiring to operate the tablet when you are sitting in a wheelchair and are using the balance mat (the current design assumes you are standing when using the mat and the tablet). This could potentially be solved by using a different stand for the tablet, and it is something we will consider in future re-design.

3. Discussion & Future Work

One guiding principle for our design has been that the interaction should be flexible to allow users with different perceptual and cognitive abilities to use the mat. Thus, we have included activities using both sounds and visual feedback in our design. It is possible to use the mat with only sound feedback, with only visual feedback as well as with a combination of sound and visual feedback. 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 (Figure 3).

The mat itself is quite flexible. One can stand on it, but it is also possible to sit on it. A problem has been the stand for the tablet – for a person in a wheelchair, the stand needs to be lower to allow interaction with the tablet.

The development of the feedback lights showed the importance of testing in the home, cf. [14]. 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.

As has already been stated, our tests so far appear to confirm our basic design. In the pilot tests, persons who were not stroke survivors (eg neighbour, spouse), but who wanted to train their balance also tried out the mat, and the positive feedback from these persons indicate our design would work for quite a wide audience. Although we need to complete and analyse our current tests, preliminary results indicate the ActivFOAM itself has a design that is stable and quite robust. What remains to be developed is the interaction and feedback – more games and activities, better game mechanics and improved overview of long term results.

4. Acknowledgements

The reported work has been funded by NordForsk (project ActivAbles) and EU Horizon 2020 (project STARR, grant agreement 689947). The authors also gratefully acknowledge the help from all test participants, and in particular we want to thank Strokeföreningen Malmö, Sweden and Heilahell, Iceland.

References

[1] C.D. Wolfe, The impact of stroke, *Br. Med. Bull.* **56** (2000) 275–286. doi:10.1258/0007142001903120.

[2] Stroke.org.uk, Balance problems after stroke, (n.d.). https://www.stroke.org.uk/resources/balance-problems-after-stroke (accessed May 24, 2018).

[3] B.J. Lutz, M.E. Young, K.J. Cox, C. Martz, and K.R. Creasy, The crisis of stroke: experiences of patients and their family caregivers, *Top. Stroke Rehabil.* **18** (2011) 786–797. doi:10.1310/tsr1806-786; 10.1310/tsr1806-786.

[4] H.K. Kristensen, C. Ytterberg, D.L. Jones, and H. Lund, Research-based evidence in stroke rehabilitation: an investigation of its implementation by physiotherapists and occupational therapists, *Disabil. Rehabil.* **38** (2016) 2564–2574. doi:10.3109/09638288.2016.1138550.

[5] V. Donker, P. Markopoulos, and B. Bongers, REHAP Balance Tiles: a modular system supporting balance rehabilitation, in: Proc. 9th Int. Conf. Pervasive Comput. Technol. Healthc., 2015. doi:10.4108/icst.pervasivehealth.2015.259278.

[6] A.O. Effenberg, Movement Sonification: Motion perception, behavioral effects and functional data, in: Proc. 2nd Int. Work. Interact. Sonification, 2007.

[7] J. Stienstra, K.C.J. Overbeeke, and S. Wensveen, Embodying Complexity Through Movement Sonification: Case Study on Empowering the Speed-skater, in: Proc. 9th ACM SIGCHI Ital. Chapter Int. Conf. Comput. Interact. Facing Complex., 2011: pp. 39–44. doi:10.1145/2037296.2037310.

[8] F. Feltham, and L. Loke, The slow floor: increasing creative agency while walking on an interactive surface, *Proc. 8th Int. Conf. Tangible, Embed. Embodied Interact.* (2014) 105–112. doi:10.1145/2540930.2540934.

[9] P. Srinivasan, D. Birchfield, G. Qian, and A. Kidané, A pressure sensing floor for interactive media applications, *ACE '05 Proc. 2005 ACM SIGCHI Int. Conf. Adv. Comput. Entertain. Technol.* **265** (2005) 278–281. doi:http://doi.acm.org/10.1145/1178477.1178526.

[10] K. Thornberg, S. Josephsson, and I. Lindquist, Experiences of participation in rhythm and movement therapy after stroke, *Disabil. Rehabil.* **36** (2014) 1869–1874. doi:10.3109/09638288.2013.876107.

[11] C. Magnusson, H.A. Caltenco, D. McGookin, M. Kytö, I. Hjaltadóttir, T.B. Hafsteinsdóttir, H. Jónsdóttir, and I. Bjartmarz, Tangible interaction for stroke survivors: Design recommendations, in: TEI 2017 - Proc. 11th Int. Conf. Tangible, Embed. Embodied Interact., 2017. doi:10.1145/3024969.3025073.

[12] K. Rassmus-Gröhn, C. Magnusson, B. Rydeman, G. Randall, and S. Belson, Conjuring up New Technology-Using Magic Objects in Co-Ideation with Stroke Survivors, 2017. doi:10.3233/978-1-61499-798-6-429.

[13] H.A. Caltenco, A. Olsson, A. Aliyari, C. Magnusson, D. McGookin, M. Kytö, I. Hjaltadóttir, T.B. Hafsteinsdóttir, H. Jónsdóttir, and I. Bjartmarz, Designing interactive systems for balance rehabilitation after stroke, in: TEI 2017 - Proc. 11th Int. Conf. Tangible, Embed. Embodied Interact., 2017. doi:10.1145/3024969.3025084.

[14] M. Balaam, S. Rennick Egglestone, G. Fitzpatrick, T. Rodden, A.-M. Hughes, A. Wilkinson, T. Nind, L. Axelrod, E. Harris, and I. Ricketts, Motivating mobility: designing for lived motivation in stroke rehabilitation, *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.* (2011) 3073–3082. doi:10.1145/1978942.1979397.