Ring a Bell? Adaptive Auditory Game Feedback to Sustain Performance in Stroke Rehabilitation

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Abstract. This paper investigates the effect of adaptive auditory feedback on continued player performance for stroke patients in a reaction time tablet game. The feedback sound pitch followed a saw-tooth shape that cumulatively increased for fast reaction times and flying back to the base pitch after a single slow reaction time. The analysis was based on data obtained in a field trial with lesion patients during their regular rehabilitation. The auditory feedback events were categorized by feedback type (positive/negative) and the associated pitch change of either high or low magnitude. Both feedback type and magnitude significantly affected on players performance. Negative feedback improved patients reaction times in subsequent hits by 0.42 s and positive feedback impaired their performance by 0.15 s.

Keywords: Stroke patients · Rehabilitation · Attention · Hemi-spatial neglect · Serious games · Adaptive difficulty · Non-speech audio · Adaptive audio feedback · Sonification

1 Introduction

Self-rehabilitation initiatives place emphasis on the growing responsibility that patients have for improving their own well-being and progress. Stroke rehabilitation is a lengthy and expensive process. However, it leaves time for patients to improve their situation on their own time, even while in rehabilitation centers. Games are now being sought as a means to tap into the intrinsic motivation they promote and research has started investigating to what degree, for example, causal games train cognitive abilities [1]. We believe that purpose-built games that provide more feedback and are simple for patients to understand are better suited for rehabilitation. But the literature is scant on how to challenge players adequately and give in-game feedback on performance for individual interactions and how negative or positive feedback influences patient performance. We focus on brain lesion patients who suffer from hemi-spatial neglect or other types of attention deficiency disorders.

Inspired by the Whack-a-Mole arcade game, we designed a tablet game that adapted target positions to the player's performance to sustain engagement [11]

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and emphasized how they excelled [16] through incremental auditory feedback. The auditory feedback adapted by increasing pitch by 10% on each consecutive quick hit while resetting the pitch on slower hits. We evaluated the game in a field study with patients at a neuro-rehabilitation center whom we encouraged to play the games three time a day while undergoing regular therapy. The results showed that negative feedback yield faster subsequent hits while hit time increases after positive feedback.

2 Background and Related Work

Patients suffering from hemi-spatial neglect, as a result of a stroke or lesion, fail to respond to stimuli on the contra-lateral side of their lesion, despite having the motor and sensory capacity to do so. Most common, persistent, and severe after right hemisphere lesions, neglect affects visual sensory input, resulting in left-side visual neglect affecting daily living [3]. Patients may for example only groom or dress the right side of their body, or only eat from the right half of a plate. In addition to ignoring sensory input, patients can be expected to have a lowered capacity for sustained attention according to feedback from rehabilitation center staff.

Cognitive training has been proven to be effective, but research has yet to determine, which regimen and conditions result in the best transfer effect [7]. Video games for rehabilitation and cognitive training based on standardized tests have been implemented [6,9] and positively received by users [5,12]. The methods used to engage and intrinsicly motivate players may address the problem of the intensive and repetitive rehabilitation activities [2].

Malone distinguished between two types of user interfaces: toys and tool. People use toys or games for their own sake whereas they use tools as a means to pursue external goals [13]. Good toy should be easy to learn and hard to master while a tool should be easy to both use and master. However, in cases where the external goal is not motivating enough on its own, tools can benefit from having toy-like features. In our case, the game constitutes the tool with the toy-like qualities to help the patient overcome the repetitive nature of rehabilitation.

However, despite the novelty of the game format patients need different challenge levels to remain engaged [11], which research in dynamic difficulty adjustment (DDA), both within and outside the subject and rehabilitation, has started addressing [10]. Mainetti et al. designed a home-based motion-controlled game for rehabilitation of hemi-spatial neglect with increasing difficulty levels by removing visual and auditory cues and hints [12] and found continued engagement and positive responses from one patient using the game in half hour sessions on weekdays for a month.

Non-speech auditory feedback have previously been used in the context of rehabilitation systems. Masiero et al. [14] utilized auditory feedback in a robotic-assisted motor rehabilitation system, which kept patients' attention throughout a training session. In stroke rehabilitation, Wallis et al. [18] used musical sonification of movement as well as discrete sounds for positive feedback and sustained audio indicating poor performance. Similarly, Newbold et al. [15] investigated musically-informed movement sonification and found that harmonic stability useful in a physical rehabilitation context, as stable and unstable cadences encouraged either ending or continuing stretching movements. Cockburn and Brewster [4] researched feedback modalities in the context of acquisition of small targets and discovered that auditory feedback reduces targeting time significantly.

Rabbitt conducted a study on how positive or negative feedback impact performance focusing on error correction in a continuous-performance choice-response task involving signal lamps as feedback. On correct responses the lit lamp would turn off and another lit up delivering positive feedback. Errors yielded negative feedback through the lack of changes. Response times before negative feedback were not different from the mean response times of all correct responses. However, errors as well as subsequent responses to correct errors after negative feedback were significantly faster (∼500 ms) than equivalent correct responses either before or after the error and correction (∼600 ms) [17].

3 Game Design

Drawing on the eponymous arcade game, our Whack-a-Mole (WAM) game focused on hemi-spatial neglect patients. Following clinical staff recommendations, a game lasted for 8 min to maintain on-task attention. In WAM, the player presses a large center sphere, upon which one or several six millimeter targets (with 12 mm touch collision area) appear around it (see Fig. 1). The player has to hit targets before they disappear again. After such timeouts or successful hits another center sphere hit makes new targets appear. The distance at which new targets appear depends on player performance. Expired targets reduce while hit targets increase the distance. We used the delay between tapping the center and hitting the targets as a reaction time performance measure to evaluate the effect of feedback.

A chime sound plays upon pressing the center sphere and coincides with target appearance. Target hits provide audio-visual feedback in the form of a bell sound paired with an animation. Hits targets fly with a visual trail in a direct line into the center, which responds with a bouncing animation, a small particle explosion, and turning green again. All cues aim at grabbing attention and guiding to press the center sphere for new targets. Auditory feedback upon target expiration played at most twice within 20 s to reduce potential frustration in case of poor performance. An initially low pitched bell like sound plays upon successful hits. Hits below one second reaction time increase the current feedback pitch by 10% resulting in no pitch ceiling for consecutive fast hits. The audio feedback on center sphere taps remains unchanged, providing an audible baseline with increasing contrast between center and fast target hits. This adaptive positive feedback aimed at providing motivational feedback for sustained high performance. WAM gave negative feedback for slow target hits by resetting the feedback pitch to the starting pitch. This resulted in high contrasts to what the players hear before, especially in cases of long streaks of fast hits. We categorized

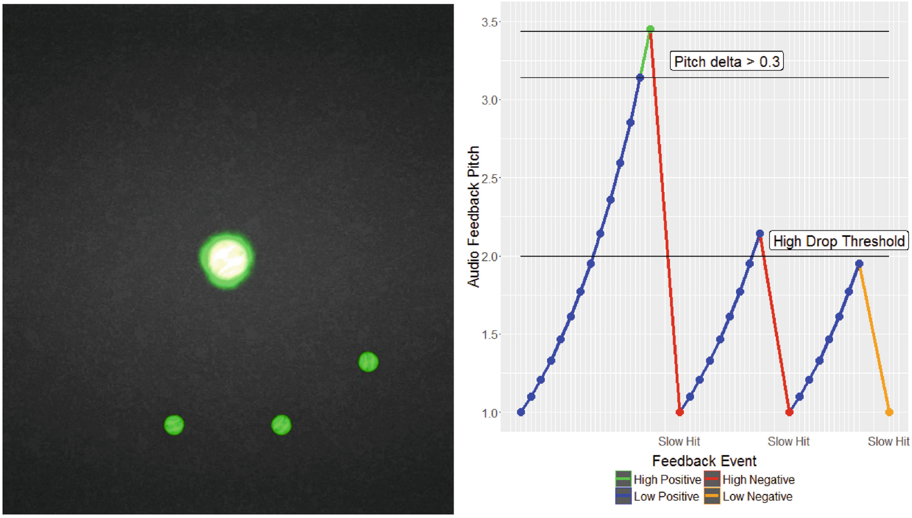

Fig. 1. Left: Cropped 16/10 landscape screenshots of multi-target events requiring hitting all three before tapping the center. Right: Illustration of the accumulating pitch on fast hits and drops in pitch on slow hits. (Color figure online)

audio feedback based on the magnitude of pitch changes (see Fig. 1, right). We categorized increases to pitches higher than 30% from the baseline pitch as high, drops in pitch of at least 100% of the baseline pitch as a high negative feedback event. The asymmetry in the thresholds is due to the nature of the patients participating in the study: because each participant needs to contribute samples to each of the four feedback event, the thresholds are set as to include as many participants as possible.

4 Study

The participants were volunteers from Brønderslev Neurorehabilitation Center recruited by the therapist supervising the experiment. Inclusion criteria for participating were suffering from a form of acquired attention deficit disorder as a results of a brain lesion, being able to use the tablets, and giving informed consent. Forty-two out of fifty-two patients completed the trial. Some patients dropped out early due to moving to a different facility. Regardless, we considered all logged data in the analysis. Thirty-three men and eleven women (63 years on average, SD: 14.5) contributed data. Based on Jehkonen et al's test suite (line bisection, line cancellation and letter cancellation [8]) and their cut-offs from the literature, four participants suffered from neglect. Seven participants had above cut-off scores on both the left and right hand side of the paper tests and the health care professional in charge of conducting all tests classified them as attention deficit cases. During the trial period, participants continued regular rehabilitation in addition to being encouraged to play the game three time a day.

The metric for evaluating the effects of adaptive audio feedback was the change in reaction time directly before and after an audio feedback event. In cases of drops in pitch the task tied to the feedback event would be associated with a lapse in concentration or an interruption in the form of a mistake or a target not perceived due to neglect, and the feedback is there to sustain continued performance.

4.1 Results

On average, the test participants played WAM for 5.6 min per day (SD 1.8). Usage varied hugely between participants. We categorized adaptive audio feedback events into four categories based on two attributes pitch change direction (positive/negative) and its magnitude (high/low). In our analysis we arbitrarily split the positive feedback pitch rises into high (marked green in Fig. 1, right) or low (marked blue) depending on whether the rise yielded an increase of 30% or more than the base pitch. High positive feedback occurred after twelve successive fast hits. The pitch drops of at least half the pitch, or 100% of the base pitch we defined as high (marked red) others as low (orange). High negative feedback drops could occur after at least eight successive fast hits, as illustrated in Fig. 1, right. In order for each participant to contribute their average change in reaction time to each of the four event categories, we excluded thirteen patients, eight men and five women, who did not receive high positive or negative feedback from the analysis. Four suffered from attention deficiency and one suffered from neglect. The subsequent analysis is based on 170 thousand feedback events.

We used a within subjects analysis of variance (ANOVA) to test the effect of *feedbacktype* (positive or negative), *magnitude* (high or low) on the change in reaction time performance surrounding a feedback event. In terms of the reaction time at the feedback events themselves only *feedbacktype* ($F_{1,120} = 929.60$, $p < 0.001$) was a significant factor, meaning that the prior performance and accumulated pitch had no effect on the reaction time at the event. The average reaction time was 1.31 at a negative feedback event and 0.66 s for a positive event. Both *feedbacktype* ($F_{1,120} = 7.95$, $p < 0.01$) and *magnitude* ($F_{1,120} = 6.97$, $p < 0.01$) had a significant albeit small effect on reaction time after a feedback event: The average reaction time after negative feedback was slower (0.89 s) than for positive feedback (0.81 s). Large magnitudes in feedback made people go faster (0.81 s) than low (0.89).

However, if we compare the changes in reaction time between the feedback event hit and the subsequent hit As for the change in reaction time going from the feedback event to the hit directly after, both *feedbacktype* ($F_{1,120} = 762.95$, $p < 0.001$) and *magnitude* ($F_{1,120} = 6.41$, $p < 0.05$) were significant factors, negative feedback improved reaction time on the subsequent hit by 0.42 s and positive feedback impaired performance by 0.15 s.

Another way of looking at performance changes is the comparison between reaction times before and after feedback, similarly to [17]. Both *Feedbacktype* ($F_{1,120} = 88.78$, $p < 0.001$) and *magnitude* ($F_{1,120} = 27.93$, $p < 0.001$) and the interaction between the two ($F_{1,120} = 10.46$, $p < 0.01$) were significant factors in

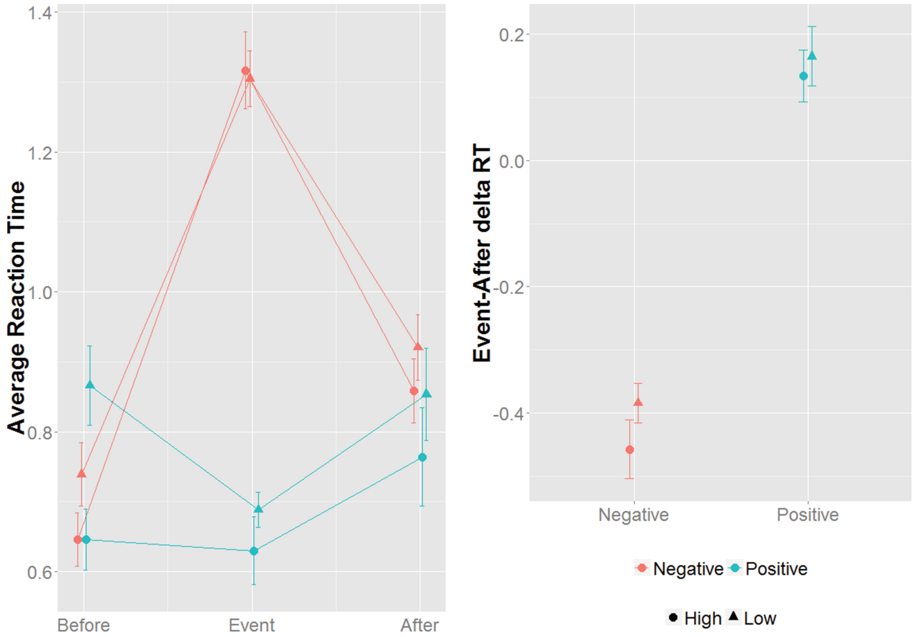

Fig. 2. Left: Average reaction times before, during and after an audio feedback event, including error bars at 95% confidence intervals from per participant averages. Right: The average delta reaction time between an audio feedback event and the next task split between *feedbacktypes* and change *magnitude*, including error bars at 95% confidence intervals from per participant averages.

the delta reaction time between the hits prior to and after the feedback event. However, the reaction time prior to a feedback event was significantly different depending on *magnitude* ($F_{1,120} = 47.83$, $p < 0.001$) in addition to *feedbacktype* and factor interaction, meaning that the base reaction time was not comparable within the *feedbacktypes*. Figure 2 illustrates this in the differences in average reaction times for the low feedback groups (triangles). This difference stems from the order in which feedback could occur in the game: Negative feedback must have been preceded by a quick hit, while a (low) positive feedback event can be preceded by either a quick or a slow hit. In contrast, high magnitude feedback events have to preceded by several positive feedback events, and we can see that the *before* averages of these groups are the same. To remove this difference we averaged the low magnitude feedback groups and reran the analysis on delta reaction time before and after a feedback events. Both *feedbacktype* ($F_{1,120} = 1.040$, $p < 0.01$) and *magnitude* ($F_{1,120} = 11.080$, $p < 0.01$) were significant factors - negative feedback increased reaction time by 0.17 s and positive feedback by 0.085 s compared to average performance before the feedback event.

5 Discussion

Results show that negative feedback lead to faster reaction time immediately after while positive feedback showed to lead to slower reaction times. It is unclear whether the changes in reaction time were caused by players' prior performance: Increases in reaction time could be caused by the player slowing down do to a long streak of hits due to fatigue or lapses in concentration. However, we can rule out fatigue given that the average reaction time prior to a high positive feedback event was the same as for high negative feedback events. If fatigue were a contributing factor we would expect these two to be different, as a slow hit would be preceded by hits of a higher reaction time, but within the one-second margin. Our field study setup did not verify whether all players in all sessions heard the feedback, e.g. by muting sound or putting in headphones and not using them. However, we saw clear differences in response to audio feedback indicative of patients hearing and responding to it, seeing as patients would react faster after high magnitude feedback.

Decreases in reaction time following negative feedback may have been caused by the player continuing at same pace as previous, wanting to recover from their mistake regardless of the audio feedback. Still, what we see from Fig. 2 is that after negative feedback the average reaction time recovers to the speed of a fast hit, but not to the speed prior to the slow hit. This indicates that the negative feedback may contribute to a performance as a reminder in cases of lapses in concentration or other causes for slowing down. The increases in reaction time after both low and high magnitude positive feedback events suggested that continuous positive feedback did not contribute to sustained performance, even though average reaction times remained within the limit of a fast hit. It may, however, serve to motivate to work up the fast pace in the first place.

Whether the recovery time for reaching previous speed after an negative feedback is comparable to [17], where response time after errors were significantly faster than prior or subsequent responses, is inconclusive. This is because reaction time prior to a feedback event varies significantly independently of the subsequent audio feedback. The condition for the reaction time before a feedback event is a mix successful hits, motivated recovery from past mistakes and warming up at the beginning of a session, creating varying baseline performances. Negative feedback does lead to faster reaction time immediately after, but it is not significantly faster than at other events.

6 Conclusion

We created a Whack-a-Mole style game for assessment and rehabilitation of stroke patients suffering from hemi-spatial neglect that patients with attention deficiency disorder found enjoyable, too. Our analysis of the adaptive incremental audio feedback for showed that negative feedback was followed by an improvement in reaction time while positive feedback increased.

References

1. Baniqued, P.L., Kranz, M.B., Voss, M.W., Lee, H., Cosman, J.D., Severson, J., Kramer, A.F.: Cognitive training with casual video games: points to consider. Front. Psychol. **4** (2013)
2. Burke, J.W., McNeill, M.D.J., Charles, D.K., Morrow, P.J., Crosbie, J.H., McDonough, S.M.: Optimising engagement for stroke rehabilitation using serious games. Vis. Comput. **25**, 1085–1099 (2009). Springer
3. Cherney, L.R.: Unilateral neglect: a disorder of attention. Semin. Speech Lang. **23**, 117–128 (2002). Thieme Medical, New York
4. Cockburn, A., Brewster, S.: Multimodal feedback for the acquisition of small targets. Ergonomics **48**, 1129–1150 (2005). Taylor & Francis
5. Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., Boyle, J.M.: A systematic literature review of empirical evidence on computer games and serious games. Comput. Educ. **59**, 661–686 (2012). Elsevier
6. Dalmaijer, E.S., Van der Stigchel, S., Nijboer, T.C.W., Cornelissen, T.H.W., Husain, M.: CancellationTools: all-in-one software for administration and analysis of cancellation tasks. Behav. Res. Meth. **47**, 1065–1075 (2014). Springer
7. Jaeggi, S.M., Buschkuehl, M., Jonides, J., Shah, P.: Short- and long-term benefits of cognitive training. In: PNAS 2011, vol. 108, pp. 10081–10086 (2011)
8. Jehkonen, M., Ahonen, J., Dastidar, P., Koivisto, A., Laippala, P., Vilkki, J.: How to detect visual neglect in acute stroke. Lancet **351**, 727–728 (1998)
9. Knoche, H., Hald, K., Jørgensen, H.R.M., Richter, D.: Playing to (self-)rehabilitate: a month-long randomized control trial with brain lesion patients and a tablet game. In: PervasiveHealth 2016. IEEE (2016)
10. Liu, C., Agraval, P., Sarkar, N., Chen, S.: Dynamic difficulty adjustment in computer games through real-time anxiety-based affective feedback. Int. J. HCI **25**(6), 506–529 (2009). Taylor & Francis
11. Lopez-Samaniego, L., Garcia-Zapirain, B., Ozaita-Araico, A., Mendez-Zorrilla, A.: Cognitive rehabilitation based on working brain reflexes using computer games over iPad. In: Proceedings of CGAMES 2014, pp. 1–4. IEEE (2014)
12. Mainetti, R., Sedda, A., Ronchetti, M., Bottini, G., Borghese, N.A.: Duckneglect: video-games based neglect rehabilitation. Technol. Health Care J. **21**, 97–111 (2013). IOS Press
13. Malone, T.W.: Heuristics for Designing Enjoyable User Interfaces: Lessons from Computer Games. ACM (1981)
14. Masiero, S., Celia, A., Rosati, G., Armani, M.: Robotic-assisted rehabilitation of the upper limb after acute stroke. Arch. Phys. Med. Rehab. **88**(2), 142–149 (2007). Elsevier
15. Newbold, J.W., Bianca-Berthouze, N., Gold, N.E., Tajadura-Jiménez, A., Williams, A.: Musically Informed Sonification for Chronic Pain Rehabilitation: Facilitating Progress & Avoiding Over-doing. In: Proceedings of CHI 2016, pp. 5698–5703. ACM (2016)
16. Przybylski, A.K., Scott, C., Ryan, R.M.: A motivational model of video game engagement. Res. General Psychol. **14**, 154–166 (2010). APA
17. Rabbit, P.M.A.: Errors and error correction in choice-response tasks. J. Exp. Psychol. **71**(2), 264–272 (1966). APA
18. Wallis, I., Ingalls, T., Rikakis, T., Olsen, L., Chen, Y., Xu, W., Sundaran, H.: Real-time sonification of movement for an immersive stroke rehabilitation environment. In: Proceedings of Auditory Display 2007, pp. 26–29 (2007)