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CONTRAST: Gamification of Arm-Hand Training for Stroke Survivors

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Abstract

This paper describes the design of a serious game that supports arm-hand training for stroke survivors aiming to render rehabilitation training enjoyable and sustainable. The design of this game was based on combining well-known game-design principles and principles of task-oriented training. Most importantly the game involves the manipulation of every day physical objects and the game's difficulty is dynamically adapted to the patient's performance. The game was evaluated in actual training with two stroke patients for a period of a week. Their feedback shows the promise of this approach; the study motivates the further development of game content and further extension of adaptability features.

Author Keywords

Tangible Embodied Interaction, Rehabilitation Technology, Arm-Hand Training, Stroke, Serious Game

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design, Human Factors

Introduction

Stroke, or cerebrovascular accident, is the second most common cause of death and major cause of disability worldwide [5]. About 40% of stroke survivors have a diminished ability to control an upper extremity with severe consequences for their perceived quality of life and their social integration [8]. After the acute stage of a stroke where patients are hospitalized, they enter the sub-acute stage where they will continue recovery through extensive training. Depending on the severity of their impairment, training can take up as much time as a full time job for several months. Rehabilitation training is very demanding on therapist time and is very difficult to pursue unsupervised. After discharge, patients enter the chronic stage after stroke and return home where they train less and often regress, failing to fulfill their potential and to sustain skill levels they had formerly achieved during their rehabilitation. The two main causes for this are lack of available resources to sustain training for longer periods, and diminishing motivation as training is tedious and patients lose confidence regarding their potential to improve.

These observations motivate the development of rehabilitation technologies that help patients train without supervision and sustain training for longer periods. For example, the Us'em system [10] is an experimental wearable device that measures and provides feedback on the use of the affected versus the unaffected arm, aiming to motivate stroke survivors to use their affected arm through the day. The Philips Stroke Rehabilitation Exerciser, relies on sensor technology to model patients' movements and provide relevant feedback, while an interactive tabletop supports interactive exercises; this system was evaluated in a small scale clinical trial [16], even leading to clinically relevant improvements for chronic stage patients who are conventionally assumed to have reached the upper limit of their recovery. [12] found improvements in several measures of movement skill, e.g., movement accuracy and efficiency, bimanual dexterity, etc. based on training with an interactive tabletop with a tangible user interface.

One way to motivate patients to train more is to improve the training exercises offered: the TEC [7] system has been created to encourage variability and personalization of exercises. Another approach is gamification: to embed arm-hand training into games making the exercise itself less dull. E.g., Beursgens et al [1] and Delbressine et al [3] support rehabilitation training by playing a game on interactive tabletop display by manipulating every day objects. These games were positively received by patients and therapists alike, but they could yet not support and encourage sustained play. An important reason for this was the limited exercise variability and exercise challenge provided. We present CONTRAST, which was designed to address this limitation. In the next sections we describe the overall design principles followed that originate from the fields of physiotherapy and game design. We then describe the game and its evaluation with patients as part of their actual training.

Design principles for CONTRAST

The design of CONTRAST is based on two diverse sets of principles: (a) Principles of task-oriented training for stroke rehabilitation [17], according to which training should involve meaningful daily tasks of the patient's choice, and (b) game design principles, e.g., see Burke [2], regarding challenge and feedback to encourage sustained play. Crucially, CONTRAST aims to increase motivation for sustained play by dynamically adapting game difficulty, and by providing feedback on progression, in order to shift the patient's focus from full recovery (a remote final goal) towards focus on emerging progression (increased game performance observable by the minute).

Following the task-oriented training approach [17], training with CONTRAST involves physical manipulation of everyday objects. These can be chosen depending on the patient's training needs and capabilities. Playing the game involves typical daily tasks, like lifting a glass and shifting it, which are motivated by the game action, e.g., to avoid an on-screen obstacle or hit an on-screen target (Figure 1). This is paramount in task oriented stroke rehabilitation as patients' motor learning and motivation largely increases when training includes activities comparable to everyday contexts using everyday objects [16]. Exercise variability, one of the principles of task-oriented training for stroke rehabilitation is important for improving retention of training effects and keeping the patient engaged in cognitive processes required by the task [9, 15]. Multiple exercises that are slight variations of each other reinforce the physical strength and generalization of learning. Variability is ensured by the different game tasks, but also by allowing the game to be played with different objects of the patient's choice, supporting openness and personalized exercise.

Meaningful play emerges from the relationship between the player's interactions with the game and the effect that these interactions have on how a game evolves or progresses [13]. Meaningful play can only emerge if players receive feedback on how they perform and progress throughout the game, enabling them to

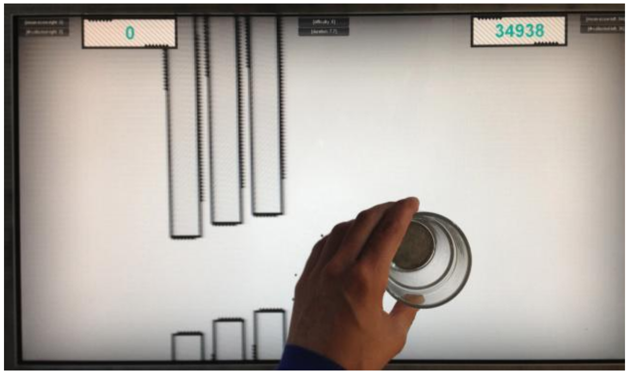

Figure 1: CONTRAST game played with a cup.

identify the relation between their actions and the resulting positive or negative feedback, and to plan sequential movements accordingly. The information the game provides dramatically affects what the player will do next. Therefore, feedback is designed to be intuitive in order to avoid misplaced or wrong behavior. Based on flow theory [14], CONTRAST provides challenges that adapt to the patient's skill; in order to keep the patient engaged. If challenge proves to be too difficult for the patient's present understanding of the game and his ability to act accordingly, the patient will get frustrated and decreased motivation to continue training is the result. Comparably, when the challenge proves to be too easy, the patient will get bored.

The CONTRAST game

The game was implemented on Unity [18] and runs on a personal computer connected to a 27' multi-touch screen to support object detection. A small felt pad is attached below to the everyday objects, to ensure good registration of touch and protect the screen from damage.

Participant	1	2
Age	79	65
Months since stroke	4	6
BF-M	49/66	53/66
ARAT	23/57	34/57
Affected Side	Right	Left
Cognitive level	5	6

Table 1: Participant profiles

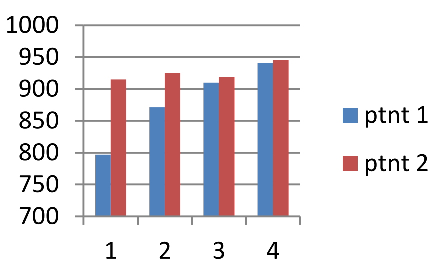

Figure 3: Score for the affected arm over the last four trials displaying gradual progression over time spent on training with CONTRAST.

Figure 2: CONTRAST start scene; choosing object size.

The game consists in three main scenes. In the start scene where patients are able to select the footprint size of the everyday object that patients will be manipulating to play the game and the orientation of the hand (left or right) with which the object will be held. In the second scene, the game consecutively displays a number of obstacles in the form of bars moving through the scene from right to left or vice versa. The patient navigates around the obstacles where possible and skips over them where necessary, by dragging and lifting the object over the screen. In order to motivate patients to place the objects back on the screen after lifting them, collectible items are added that can only be collected when the physical object actively touches the screen. Points are added for each collectible collected and points are deducted when obstacles are touched or when the patient lifts the physical object off the screen for more than one second. After each trial of thirty seconds, performance scores are displayed and logged into a database for statistical reference. The difficulty of the game is designed to be adaptive to the patients' performance over each trial. The obstacles are categorized according to the difficulty of the arm-hand movements involved in approaching them. The better a patient performs, the faster the game objects will move across the screen and more difficult types of obstacles will appear. To minimize cognitive demand, elements like obstacles and collectibles are styled in high contrast to the background, comprising thick black edges on a light background. In order to be understood as obstacles, they are shaped rectangular and jagged, as opposed to the round shape of the collectibles. In addition, animations are added to the interactions to clarify desired versus undesired manipulations. Furthermore, distinct audible effects are added to enforce the animated visual feedback. Typical elements of games, like continuous music, rich graphics and decorative animations, were consciously left out to avoid cognitive overload. The third scene displays the achieved score and asks the player to switch hands and to play again, generating two scores to be compared for evaluation of performance between affected and unaffected arm-hand.

Evaluation of CONTRAST

An initial evaluation of the game has been carried out with two stroke survivors at Jessa Hospital Rehabilitation Campus Sint-Ursula at Herk-de-Stad,

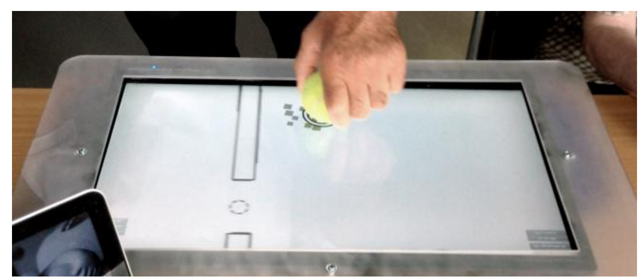

Figure 4: CONTRAST game played with a tennis ball.

Sub-scale	Ptnt 1	Ptnt 2
Interest / Enjoyment	6.43	7.00
Perceived competence	5.33	6.20
Effort	6.33	7.00
Value / Usefulness	5.86	6.43
Relatedness	6.00	6.80

Table 2: Results on IMI on CONTRAST, scale: 1-7.

Sub-scale	Mean scores CONTRAST	Mean scores regular therapy
Credibility	8.44	8,25
Expectancy	8.63	8,63

Table 4: CEQ scores for CONTRAST and regular therapy.

Belgium. The overall goal of the evaluation was to assess if the designed game could provide a positive effect on motivation for rehabilitation training. The participants were asked to play the game for one hour per day for one week, as part of their regular training. At the end of this period, they were asked to evaluate the game in terms of motivation and engagement, using the Intrinsic Motivation Inventory (IMI) [11], and expected credibility of the game using the Credibility/Expectancy Questionnaire (CEQ) [4]. Both participants were male and had suffered from a stroke that had severely affected their arm-hand functionality at different sides of their body. Between them they cover a reasonable range of arm-hand functioning as measured by the widely used ARAT [19] and BF-M [6] tests. Both participants have no noticeable cognitive limitations (Table 1).

The two participants could play and enjoy CONTRAST, and showed a clear progression in the game (Figure 3). The IMI returned a minimum mean score of 5.80 over all sub-scales (Table 2), implying a positive result on enjoyment, perceived competence, effort, usefulness and relatedness. Also, the CEQ returned similar results on CONTRAST and on regular therapy (Table 4). Both participants mentioned that the provided game approach was a pleasurable variation on the regular therapy. Further, they confirmed the importance of exercise variability, and were able to imagine that a game could improve this. However, they both argued that the game should not be seen as a substitute of-, but as an addition to existing therapy.

Over the course of the week, participant 1 decreased the erroneous response (uncontrolled supination) of his sensory disturbed hand (right hand) while sliding an object. Besides the fact that this outcome motivated him, it suggests that the exercise may be a useful and valuable addition to the existing therapy. This view was echoed by therapists at the clinic who also suggested that still more games are needed to address different function synergies. Therapists were positive about the type-randomness of appearing obstacles within the game, as it requires approaching targets from different angles, supporting exercise variability and generalization of skills. Regarding the game's difficulty levels, they mentioned that a feature that allows players to adjust the difficulty level at the start of a game would be a valuable improvement for custom training. Combined with the own choice of objects to play the game with, this would increase challenge variability and allow for improved self-regulation and autonomy.

Conclusion

CONTRAST is a serious game designed to support arm-hand training for stroke survivors. It applies principles of task-oriented skill training, in that training with everyday objects is involved in the exercise. Well-known game mechanics are applied to encourage sustained play: adapting level of challenge and providing meaningful feedback. Finally, the game design addresses the physical and cognitive capabilities of stroke survivors. The evaluation showed that the game provided meaningful exercise. And that at least for these two patients, the game was motivational and found credible as a therapy aid for improving their arm-hand functionality. Future work will extend this evaluation and test especially whether these game design principles do meet their objective of engaging the patient in training for longer periods in real life.

References

[1] Beursgens, L., Timmermans, A.A.A. Markopoulos, P. Playful Arm Hand Training after Stroke. CHI 2012 *Ext. Abstracts,* 2399-2404.

[2] Burke, J.W., McNeill, M.D.J., Charles, D.K., Morrow, P.J. Optimising engagement for stroke rehabilitation using serious games, *Visual Computing* 25, (2009), 1085–1099.

[3] Delbressine, F., Timmermans, A.A.A., Beursgens, L., de Jong, M., van Dam, A., Verweij, D., Janssen, M., and Markopoulos, P. Motivating arm-hand use for stroke patients by serious games, 2012, Proceedings EBMS 2012, IEEE, 3564-3567.

[4] Devilly, G.J.B. Devilly, G.J.B. and Brokovic, T.D. Psychometric properties of the credibility/expectancy questionnaire, Journal of Behavior Therapy and Experimental Psychiatry, 31, (2000) 73-86.

[5] Donnan, G.A., Fisher, M., Macleod, M., Davis, S.M., Lancet 2008, 371(9624):1612-23.

[6] Gladstone, D.J., Danells, C.J., Black, S.E. The Fugl-Meyer assessment of motor recovery after stroke: A critical review of its measurement properties, *Neurorehabil. Neural Repair 16*, 232-240, 2002.

[7] Hochstenbach-Waelen, A., Timmermans, A.A.A., Seelen, H., Tetteroo, D., and Markopoulos, P.. 2012. Tag-exercise creator: towards end-user development for tangible interaction in rehabilitation training. *In Proc. EICS 2012*, 293-298.

[8] Johansson, A., Mishina, E., Ivanov, A., Bjorklund, A. Activities of daily living among St Petersburg women after mild stroke. *Occupational Therapy International 14*, 3 (2007), 170-182.

[9] Magill, R. Motor learning and control, concepts and applications. New York: McGraw-Hill, 2007.

[10] Markopoulos, P.,Timmermans, A.A.A., Beursgens, L., van Donselaar, R., Seelen, H.A.M. (2011) The User-Centered Design of a Device for Motivating Stroke Patients to Use Their Impaired Arm-Hand in Daily Life Activities, *Proceedings EMBS 2011*, IEEE, 5182-5187

[11] McAuley, E., Duncan, T., & Tammen, V. V. Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport 60*, (1989), 48-58.

[12] Mumford, N., Duckworth, J., Thomas, P. R., Shum, D., Williams, G., & Wilson, P. H. (2010). Upper limb virtual rehabilitation for traumatic brain injury: Initial evaluation of the elements system. Brain Injury, 24(5), 780-791

[13] Salen, K., Zimmerman, E. Rules of Play: Game Design Fundamentals. *MIT Press*, (2003), Cambridge, MA, USA.

[14] Schell, J. The Art of Game Design, (2008).

[15] Shea, C.H., Kohl, R., Indermill, C. Contextual interference: Contributions of practice. *Acta Psychologica 73*, 1990.

[16] Timmermans, A.A.A., Seelen, H.A.M., Geers, R.P.J., Saini, P.K., Winter, S., Te Vrugt, J., Kingma, H. Sensor-based skill training in chronic stroke patients: results on treatment outcome, patient motivation and system usability, *IEEE Transactions on Neural Systems and Rehabilitation Engineering 18*, (2010), 284-292.

[17] Timmermans, A.A.A., Seelen, H.A., Willmann, R.D., Kingma, H. Technology-assisted training of arm-hand skills in stroke: Concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design. *Journal of Neuroengineering and Rehabilitation 6*, 1 (2009).

[18] Unity. http://unity3d.com/unity/

[19] Van der Lee, J.H., De Groot, V., Beckerman, H., Wagenaar, R.C., Lankhorst, G.J., Bouter, L.M. The intra- and interrater reliability of the action research arm test: A practical test of upper extremity function in patients with stroke. *Arch. Phys. Med. Rehabil. 82*, 14-19, 2001.