Improving Lives: Using Microsoft Kinect to Predict the Loss of Balance for Elderly Users under Cognitive Load

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ABSTRACT

Among older adults, falling down while doing everyday tasks is the leading cause for injuries, disabilities and can even result in death. Furthermore, even when no injury has occurred the fear of falling can result in loss of confidence and independence. The two major factors in the loss of balance is weakening of the muscles and reduced cognitive skills. While exercise programmes can reduce the risk of falling by 40%, patient compliance with these programmes is low. We present the Microsoft-Kinect based step training program system that we have developed specifically for elderly patients. The program measures physical health and cognitive abilities and incorporates an individualized adaptive program for improvements. The real-time data obtained from the program is similar to clinical evaluations typically conducted by doctors and the game-like exercises result in increased adherence to the exercise regimes

1. INTRODUCTION

Physical functioning is defined as the set of basic activities that are considered essential for maintaining independence. Decline of physical function with age leads to multiple health problems including postural instability and falls [1]. Falls in turn are linked to increased mortality, disability, fractures and fear of falling [2-4]. When balance has been lost, in order to prevent a fall, one can take a proactive or reactive step to regain balance. Physical exercise has been shown to be the most effective intervention to improve balance, stepping behaviour and reduce fall risk on older people [5-7]. However, these exercise programmes are often perceived as boring and compliance is often poor [8].

The use of video games in phypsical training (exergames) has shown a positive impact on delivering exercise programs with higher levels of enjoyment and motivation for the elderly [9]. Moreover, the use of modern input devices could allow the determination of a person's physical performance. Yet, some problems are inherent to the use of video games due to the limitation of available commercial video games which have not been designed for the purpose of providing therapeutical support for the aged cohort [10-12]. The potential of using this video game technology to accurately perform clinical testing as a tool to assess the effectiveness of an intervention has just started to being explored [13].

We present the Microsoft-Kinect based step training program system that we have developed specifically for elderly patients. This system delivers individually adaptable stepping exercises for older adults and simultaneously measures step performance. While the system has some similarities to physical games, the design differs significantly as our primary goal is to predict the likelihood of users falling and through exercises reduce their chance of falling. Furthermore, we incorporate specific cognitive tasks to help detect changes in physical ability when users are multitasking. Entertainment is a distant third goal for the system.

Next section presents a summary of related work in the field of exergames. Section 3, describes our methodology to match clinical tests used by doctors. Section 4, describes the cognitive load tests that we have developed, namely the Simplified Stroop Test, the Stroop Test and the Maths Workout to present increasing cognitive load to patients while performing exercises. The final section includes a discussion of our results and future work.

2. RELATED WORK

Modern input devices, such as the Nintendo Wii Balance Board, Nintendo Wii Motes, and Webcams among others, are now commonly used to enable older adults without much or any computer experience to interact with games as well as to evaluate user performance. For instance, Doyle et al [14] utilised a series of motion trackers and a webcam to deliver balance and strength exercises. The aim of this work was to improve the motor function of the lower limbs, which is essential to avoid falls. In this project, five exercises from the Otago Exercise Programme [15] were delivered and the user performance was remotely monitored by the instructor. This feature allowed the instructor to validate the correct completion of each exercise despite being remotely located from the participant.

In the work done by Gerling et al [16], the Nintendo Wii balance board was used for balance training. The game consisted of obstacle avoidance by weight shifting. In this game, the needs and capabilities of the elderly players were taken into consideration resulting in a game with a simplistic interface and adaptive difficulty. One of the problems with this approach is that the use of the Wii balance board still

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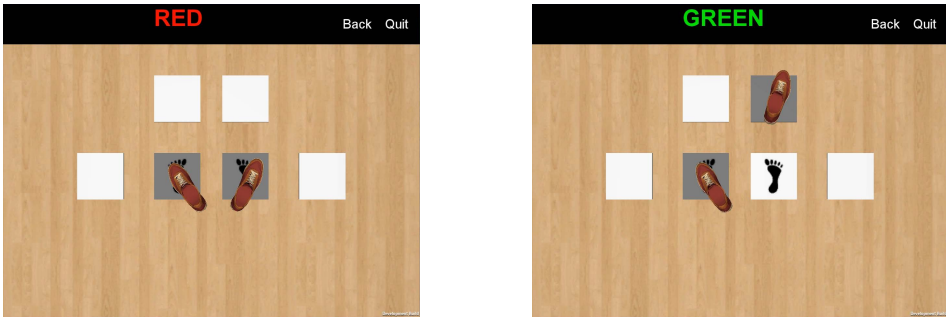

Fig 1. Screenshot of the simplified Stroop Test

imposes an obstacle on the degree of freedom to be able to perform a wider range of balance exercises suitable for the elderly. In addition to this, the board potentially exposes the older person to an increased risk of falling. To counter the fall risk inherent in a raised platform, Smith et al [17] used a flat dance pad paired with a modified version of the game Dance Dance Revolution. Its main purpose was to provide a tool to exercise the stepping abilities of older adults. Unlike the commercial game, this version has been adapted to a range of stepping speeds including slow responses. More importantly, this work has shown that a custom-made dance pad can be used as a measurement tool to obtain valid step data that discriminate between the groups of recurrent fallers and non-fallers [18].

The work presented in this paper utilises one of the most recent camera-based input devices, the Microsoft Kinect. This input device is capable of capturing video and sound without requiring user to wear any sensors. Having both sensors allows us to create dual-task tests which was not possible with previous hardware.

Furthermore, the proposed system incorporates mechanisms that can resemble clinical tests of motor and cognitive skills for the elderly. This is accomplished by Stroop test where users have to read the color while competing the stepping task as quickly as possible processing relatively accurate information of the positioning of the user's body in real-time captured with the Kinect. A full body avatar that mirrors the user movements is also displayed as part of user feedback.

Bakkes et al [19] define personalised games that utilise player models for the purpose of tailoring the game experience to the individual player. The personalization in our system is limited to adjusting the step test and varying the cognitive tasks. Garcia et al [20] describe in detail our efforts in matching the performance of the system to diagnostic tools typically used by doctors for similar evaluations.

3. METHODOLOGY

We have examined the large range of clinical tests that are used to measure physical function and chose the Choice Stepping Reaction Time task (CSRT) [21] as most appropriate for our purposes; see [20] for further discussion on types of tests and considerations. CSRT has been validated for older populations including large prospective cohort studies with falls follow-up [22]. CSRT task involves the person standing on the two central step panels of a wooden board. One of four surrounding panels (front left, front right, left, right) lights up randomly and the person has to step on this panel as quickly as possible and then return to the centre. The mean reaction time of 20 trials is measured [19] and the performance in this test is found to correlate with fall risk [18].

Our system uses Kinect as the main sensor and is implemented using Unity3D engine. The user stands in front of the TV with the Kinect placed above the TV and an avatar mirroring the person's movements appears on the TV. A circle with 6 distributed sectors is then drawn on the screen surrounding the player's avatar. Once the colour of one of the sector changes to green on the screen, the user must move their leg to take a step onto the highlighted square and back to the centre as quickly as possible. As soon as the player returns to the initial position the process starts over with a randomly selected square.

The current version of the system uses a single view, but we have also tested multiple camera views and their impact on cognitive load for the user when performing the task to create diverse cognitive conditions.

Based on the requirements of the CSRT test, the following measurements were incorporated to the Kinect-based system:

- Decision time (ms): Time elapsed between the sector turning green and one of he legs initiating a movement.
- Movement time (ms): Time elapsed between the leg initiating a movement and the foot touching the green coloured sector.

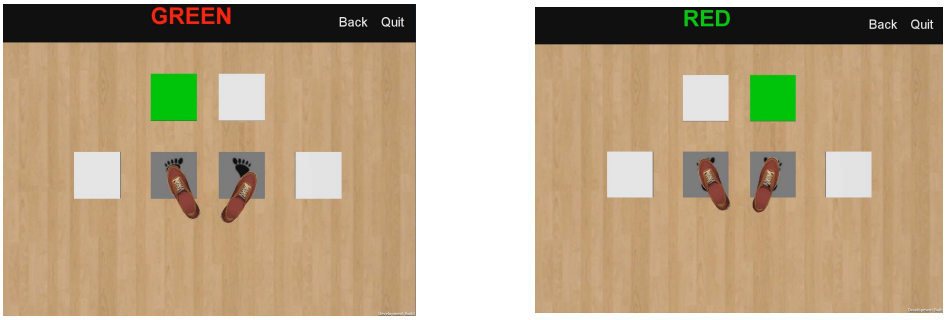

Fig 2. Screenshot of the simplified Stroop test where users have to read the color while competing the stepping task as quickly as possible.

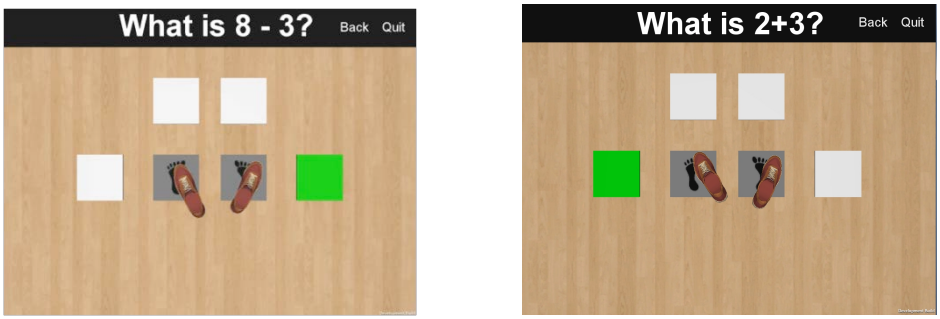

Fig 3. Screenshot of the Maths Workout where users have to answer basic math questions while competing the stepping task as quickly as possible.

- Response time (ms): Decision Time + Movement Time
- Validation of 'Go / No Go' Activity: A 'Go/No Go' activity is successful when the user meets the 'Go' condition (green) and inhibits his/her response during 'No Go' trials (red).

4. COGNITIVE LOAD

Assessing the disability and decline in elderly is often difficult. Physical performance tests are often used in conjunction with self-reports from patients to reach a determination. In some cases, cognitive state is assessed using the Mini-Mental State Examination [23], immediate and delayed recall of brief stories, which measures episodic memory [24]; and the Symbol Digit Modalities Test, which measures the domains of perceptual speed and executive function [25]. The results of the cognitive tests are evaluated as a contributing factor to decline in physical function, but there is currently no good model of the interplay between cognitive and physical functions in leading to falls. In a recent study [26] showed that the risk of multiple falls increased with poorer function in Stroop test. However, in all of these tests the physical test and cognitive test are separate. Physical test is based on timings in a step test combined with counting the number of falls over a 12-month period. The cognitive test is performed independently in an office setting.

We have incorporated three cognitive tasks with the physical step test: the Simplified Stroop test, the Stroop Test and the Maths Workout. These tests increase the cognitive load on the user resulting in noticably slower reaction time for users that are likely to fall.

The Simplified Stroop Test (Fig 1) task requires the user to say the colour out loud while performing the step test. As the colour of the word and its semantic meaning are identical, this task creates a minimal increased cognitive load for the user.

For the Stroop Test (Fig 2) task the semantic meaning of the word and the color of the word do not match. Once again the user has to say the colour out loud, but in this case there is interference between the meaning and colour of the word. While the mind automatically determines the meaning of the word and then must consciously check itself to identify instead the color the word is written in. This interference results in a delay and the extra processing required results in slowing down during the stepping test.

The Maths Workout requires the user to answer a math question that is read by the system. While there is no interference effect as with the Stroop test, it does require the user to interpret what they have heard to answer the question. The accuracy of the answer is automatically processed by the voice recognition system.

5. RESULTS AND FUTURE WORK

We first tested the system in a laboratory setting with 57 elderly patients followed by tests at a retirement village. The preliminary results indicate that users find the system engaging, prefer doing exercises with this system and the cognitive load tasks result in slower step testing results as expected. For users who are at risk of falling, the slowing down in reaction time due to cognitive load is much larger than for users who are not at risk of falling. We are currently deploying the system to be installed at 40 homes as part of a controlled trial to gather long-term data on compliance to exercise programme rates and how the system is used when there is no supervision.

6. REFERENCES

[1] Stuck, A.E., J.M. Walthert, T. Nikolaus, C.J. Büla, C. Hohmann, and J.C. Beck, *Risk factors for functional status decline in community-living elderly people: a systematic literature review*. Social Science & Medicine, 1999. **48**(4): p. 445-469.

[2] Aschkenasy, M.T. and T.C. Rothenhaus, *Trauma and Falls in the Elderly*. Emergency Medicine Clinics of North America, 2006. **24**(2): p. 413-432.

[3] Donald, I.P. and C.J. Bulpitt, *The prognosis of falls in elderly people living at home*. Age and Ageing, 1999. **28**(2): p. 121-125.

[4] Zijlstra, G.A.R., J.C.M. van Haastregt, J.T.M. van Eijk, E. van Rossum, P.A. Stalenhoef, and G.I.J.M. Kempen, *Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people*. Age and Ageing, 2007. **36**(3): p. 304-309.

[5] Gillespie, L.D., M.C. Robertson, W.J. Gillespie, S.E. Lamb, S. Gates, R.G. Cumming, and B.H. Rowe, *Interventions for preventing falls in older people living in the community*. Cochrane Database Syst Rev., 2009(2): p. CD007146.

[6] Howe, T., L. Rochester, F. Neil, D. Skelton, and C. Ballinger, *Exercise for improving balance in older people*. Cochrane Database of Systematic Reviews, 2011. **11**.

[7] Sherrington, C., J.C. Whitney, S.R. Lord, R.D. Herbert, R.G. Cumming, and J.C.T. Close, *Effective Exercise for the Prevention of Falls: A Systematic Review and Meta-Analysis*. Journal of the American Geriatrics Society, 2008. **56**(12): p. 2234-2243.

[8] Schneider, J.K.J.K., A.A. Eveker, D.R.D.R. Bronder, S.E.S.E. Meiner, and E.F.E.F. Binder, *Exercise training program for older adults. Incentives and disincentives for participation*. Journal of gerontological nursing, 2003. **29**(9): p. 21-31.

[9] Burke, J., M. McNeill, D. Charles, P. Morrow, J. Crosbie, and S. McDonough, *Optimising engagement for stroke rehabilitation using serious games*. The Visual Computer, 2009. **25**(12): p. 1085-1099.

[10] Cornelius, N., *Wii play with elderly people*. International Reports on Socio-Informatics, 2009. **9**.

[11] Ijsselsteijn, W., H.H. Nap, Y.d. Kort, and K. Poels, *Digital game design for elderly users*, in *Proceedings of the 2007 conference on Future Play*. 2007, ACM: Toronto, Canada. p. 17-22.

[12] Garcia Marin, J., E. Lawrence, K. Felix Navarro, and C. Sax, *Heuristic Evaluation for Interactive Games within Elderly Users*, in *Conference on eHealth, Telemedicine, and Social Medicine (eTELEMED 2011)*. 2011: Gosier, Guadeloupe, France. p. 130-133.

[13] Garcia Marin, J., K. Felix Navarro, and E. Lawrence, *Serious Games to Improve the Physical Health of the Elderly: A Categorization Scheme*, in *The Fourth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services (CENTRIC 2011)*. 2011: Barcelona, Spain. p. 64-71.

[14] Doyle, J., C. Bailey, B. Dromey, and C.N. Scanaill. *BASE - An interactive technology solution to deliver balance and strength exercises to older adults*. in *4th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2010* 2010.

[15] Gardner, M.M., D.M. Buchner, M.C. Robertson, and A.J. Campbell, *Practical implementation of an exercise-based falls prevention programme*. Age and Ageing, 2001. **30**(1): p. 77-83.

[16] Gerling, K.M., J. Schild, and M. Masuch, *Exergame design for elderly users: the case study of SilverBalance*, in *Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology*. 2010, ACM: Taipei, Taiwan. p. 66-69.

[17] Smith, S.T., A. Talaei-Khoei, M. Ray, and P. Ray. *Electronic Games for Aged Care and Rehabilitation*. in *11th International Conference on e-Health Networking, Applications and Services, 2009. Healthcom 2009*. 2009.

[18] Schoene, D., S.R. Lord, P. Verhoef, and S.T. Smith, *A Novel Video Game–Based Device for Measuring Stepping Performance and Fall Risk in Older People*. Archives of physical medicine and rehabilitation, 2011. **92**(6): p. 947-953.

[19] Bakkes, S., Tan, C. T., & Pisan, Y. (2012). Personalised Gaming. Journal of Creative Technologies, 1(3). Retrieved from http://journal.colab.org.nz/article/24

[20] Garcia, J. A., Felix Navarro, K., Schoene, D., Smith, S. T., & Pisan, Y. (2012). Exergames for the elderly: Towards an embedded Kinect-based clinical test of falls risk. Studies in health technology and informatics, 178, 51–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22797019

[21] Lord, S.R. and R.C. Fitzpatrick, *Choice Stepping Reaction Time: A Composite Measure of Falls Risk in Older People*. Journals of Gerontology Series A: Biological Sciences & Medical Sciences, 2001. **56A**(10): p. M627.

[22] Pijnappels, M., K. Delbaere, D.L. Sturnieks, and S.R. Lord, *The association between choice stepping reaction time and falls in older adults—a path analysis model*. Age & Ageing, 2010. **39**(1): p. 99-104.

[23] Folstein MF, Folstein SE, McHugh PR. 'Mini-Mental State': a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12:189–198. [PubMed]

[24] Albert M, Smith LA, Scherr PA, et al. Use of brief cognitive tests to identify individuals in the community with clinically diagnosed Alzheimer's disease. Int J Neurosci. 1991;57:167–178. [PubMed]

[25] Smith A. Symbol Digit Modalities Test Manual-Revised. Los Angeles: Western Psychological; 1984.

[26] Martin KL, Blizzard L, Srikanth VK, Wood A, Thomson R, Sanders LM, Callisaya ML. Cognitive Function Modifies the Effect of Physiological Function on the Risk of Multiple Falls--A Population-Based Study. J Gerontol A Biol Sci Med Sci. 2013 Feb 14. [Epub ahead of print] PubMed PMID: 23410920.