A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults

S T Smith,[1] C Sherrington,[1,2] S Studenski,[3] D Schoene,[1] S R Lord[1]

[1]Falls and Balance Research Group, Prince of Wales Medical Research Institute, Sydney, Australia
[2]George Institute for International Health, University of Sydney, Sydney, Australia
[3]Division of Geriatric Medicine, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

Correspondence to
Dr Stuart T Smith, Prince of Wales Medical Research Institute, Barker Street, Randwick, NSW 2031, Australia; s.smith@powmri.edu.au

Accepted 4 November 2009
Published Online First 29 November 2009

ABSTRACT

Objective This series of studies was conducted to develop and establish characteristics of exercise videogame play in older adults. The videogame was a modified version of the popular Dance Dance Revolution (DDR; Konomi).

Methods Participants aged ≥70 were asked to make simple step movements in response to vertically drifting arrows presented on a video screen. Step responses were detected by a modified USB DDR mat, and characteristics of stepping performance such as step timing, percentage of missed target steps and percentage of correct steps were recorded by purpose-built software. Drift speed and step rate of visual stimuli were modified to increase task difficulty.

Results Significant linear relationships between stepping performance and stimulus characteristics were observed. Performance of older adults decreased as stimulus speed and step rate were increased. Optimal step performance occurred for a stimulus speed of 17° of visual angle per second and a step rate of one step every 2 s. At fast drift speeds (up to 35°/s), participants were more than 200 ms too slow in coordinating their steps with the visual stimulus. Younger adults were better able to perform the stepping task across a wider range of drift speeds than older adults.

Conclusion The findings suggest that older adults are able to interact with video games based upon DDR but that stepping performance is determined by characteristics of game play such as arrow drift speed and step rate. These novel "exergames" suggest a low-cost method by which older adults can be engaged in exercises that challenge balance and which can be conducted in their own homes.

The ability to make well-timed, appropriately directed steps underpins our ability to maintain our balance and move unaided through our environment.[1] There is evidence to suggest that the timing of volitional stepping[2 3] and execution of successful steps for recovery of balance following an induced slip[4] can be significantly improved in older adults following repetitive training of stepping responses. Randomised control trials that include muscle strengthening and balance training also show that the risk of falls can be significantly reduced;[5] however, compliance with fall prevention interventions is often disappointing,[6 7] suggesting some reluctance on the part of older adults to take part in such programs.

One possible method by which compliance with exercise programs could be improved involves the use of interactive exercise videogames (exergames) that combine player movement, engaging recreation, immediate performance feedback and social connectivity via competition.[8–13] Dance Dance Revolution (DDR; Konami) is an example of an exergame that involves participants making rapid step responses from either leg to a target location in response to a randomly presented visual stimulus. Such games involve controlled body weight transfers that are similar to the step responses required to avoid many falls. We have developed a novel step training system for use by older adults based on DDR and present here a series of studies that establish parameters of system use in adults aged ≥70.

METHODS

Study participants

Participants were recruited from a pool of 44 older adults aged >70 (mean age 78.9) who were living independently in the community and were participating in ongoing studies at the Prince of Wales Medical Research Institute or were volunteers from local older adult community groups. All participants were without cognitive impairment (ie, mini-mental state examination scores of ≥24) or visual impairment not correctable with glasses and were capable of stepping unaided.

DDR step training system

The system consists of a modified Universal Serial Bus (USB) video game dance mat (fig 1A), which measures approximately 1 m^2 and has four step-sensitive target panels, two leftward and two rightward pointing. Each step panel measured 30 cm and was positioned 20 cm away from the nearest foot. Players stand at the centre of the mat at all times and make left or right step responses onto one of the four target locations. The mat and a liquid crystal display (LCD) monitor (display resolution 1280×1024 pixels, 60 Hz refresh rate) were connected to an Apple PowerMac running OS X 10.5, with the mat positioned approximately 1 m away from the display screen. Presentation of a customised DDR game on the LCD screen and recording of participant step responses was controlled by custom software written in MATLAB using the Psychophysics Toolbox extensions.[14 15]

In DDR games, players are required to respond to a sequence of step instructions that are presented as drifting arrows that rise slowly from the bottom to the top of the screen. As each arrow drifts upward, it intersected the location of one of four corresponding target arrows arranged in a linear configuration at the top of the presentation screen (fig 1B). When the drifting arrow crosses a target arrow, the player must coordinate an appropriate step onto the corresponding dance mat target.

Quantification of step performance and player feedback

Performance in the game was quantified by monitoring whether steps were made or not and whether they were correctly directed in response to the drifting arrow. A measure of step timing error was also derived (fig 1C) and perfect performance on the task, where steps onto arrows on the mat coincided in time with the collocation of drifting and target arrows on the screen, resulted in a step timing value of 0 ms. It is important to note that step timing is not a measure of step reaction time; it is rather a measure of how well participants can coordinate their steps in time with a visual cue.

Study 1: step performance as a function of arrow drift speed

In this study, we investigated the effect of increasing drift speeds on stepping performance in a group of 26 older adults (mean age 78.9 years, 17 women, 9 men). Five equally separated drift speeds between 11.5 and 34.5°/s were used. At a viewing distance of 1 m, the LCD screen subtended 13.4° of visual angle; therefore, at the slowest of the drift speeds, each arrow took just over 1 s to drift from bottom to top of the screen; at the fastest speed, each arrow took just under 400 ms. Five repeats of each drift speed at each of four target arrow locations were randomly presented to the participants. Each trial was separated by a 2-s interval. The time taken for all 20 drifting arrow stimuli to be displayed was 4 min.

A pilot study suggested that performance could be influenced by how well participants were able to predict the speed and location of drifting arrows. A presentation type factor was therefore included in this study with two levels, randomised (unpredictable) versus blocked (predictable) presentation. In the blocked trials, arrow drift speeds were systematically increased from the slowest to fastest speed following five repeats of each new drift speed. Blocks of all drift speeds were repeated at each of the four target arrow locations, systematically from leftward, front left, front right and finally rightward. Half the participants received the blocked before randomised trials. Participants received a short (1 min) familiarisation trial before exposure to either randomised or blocked trials.

Study 2: the effect of practice on step timing and percentage of missed targets

As data from study 1 was collected after only a very short period of familiarisation, it was reasoned that stepping performance might be influenced by practice. In this study, the effect on step performance of five practice trials within an hour was therefore investigated. Using the same range of arrow drift speeds in the random versus block study (11.5–34.5°/s), stepping performance of 20 older adults (mean age 79.6, 12 women, 8 men) was quantified by step timing and the percentage of missed targets as a function of arrow drift speed. Presentation of drifting arrows was the same as for the randomised condition of study 1. Following each practice trial, participants were given up to a 5-min break before the next trial with the entire set of practice trials taking between 45 and 60 min. To investigate stepping performance differences between older and younger adults in DDR tasks, 20 younger adults (mean age 28.4, 13 women, 7 men) also participated in this study.

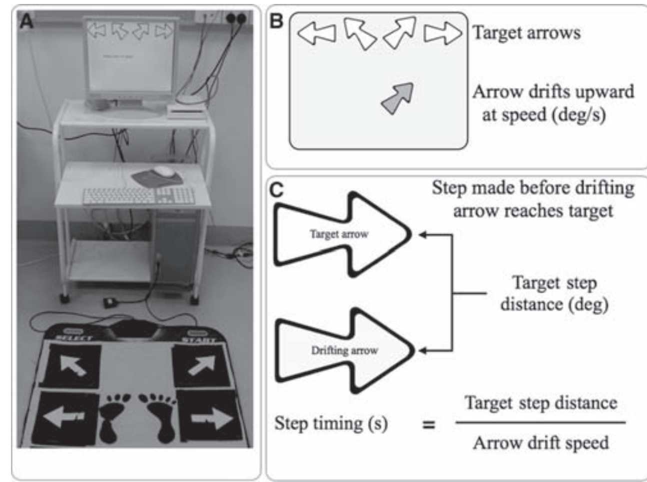

Figure 1 (A) The modified Dance Dance Revolution system showing USB dancemat connected to computer and display screen; (B) screenshot from a typical game with stationary target arrows (white) and drifting arrow (grey) indicating the response step required. During all trials, the image was replaced with a blank white background, and drifting arrows were filled white and change colour once a response was made; (C) schematic showing calculation of step timing parameter of quantification of performance.

Study 3: step performance as a function of step rate

In the final study, the percentage of missed targets as well as the percentage of correctly made steps as a function of step rate were investigated. In studies 1 and 2, a single drifting arrow was presented on screen at any one time with at least a 2-s interval before a new arrow appeared at the bottom of the screen. By manipulating the timing of arrow appearance in study 3, it was possible to introduce one, two or more drifting arrows on screen at once, thus matching more closely the kinds of stimuli typical of standard DDR games.

The number of steps per second was systematically increased from 1 step every 2 s (0.5 steps/s) to 1.5 steps/s in equal increments of 0.25 steps/s. A relatively slow arrow drift rate of 4.2°/s was chosen as a trade-off between the speed at which older adults could optimally coordinate their step timing and the greatest number of drifting arrows that could be placed onscreen at the same time. Trials were terminated if participants were unable to continue successful interaction with the game. Unsuccessful interaction was defined as average step timing scores >200 ms after the drifting arrow had passed the target arrow location or a decrease in the percentage of correct steps below 50%.

Statistical analyses

Average step timing, percentage of missed targets or percentage correctly made steps (mean (SEM) reported throughout) were computed as outcome measures of stepping performance for the different studies. These parameters of step performance were analysed using SPSS Statistics 17.0 in an analysis of variance with arrow drift speed, presentation type, practice trial number or step rate as within-subjects factors. Where Mauchley's test indicated that the assumption of sphericity of variance had been violated, degrees of freedom for *F* tests were corrected using Greenhouse–Geisser estimates of degrees of freedom. Linear trend and Helmert contrasts were used to examine any significant main effect or interactions.

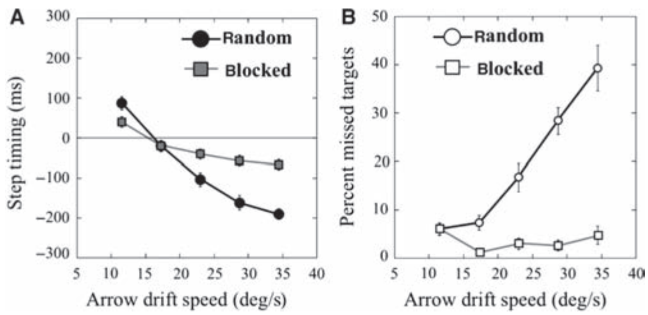

Figure 2 (A) Average step timing (closed symbols) and (B) percentage of missed targets (open symbols) as a function of arrow drift speed and presentation type (circles, randomised; squares, blocked).

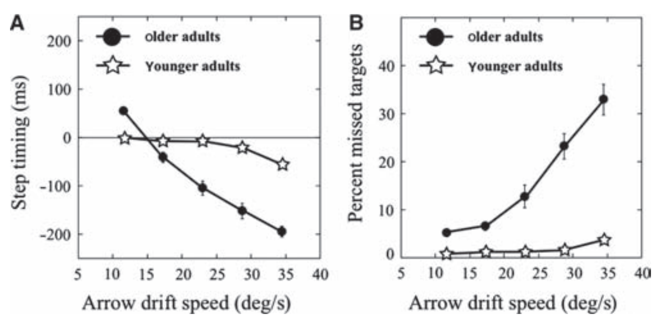

Figure 3 Average step timing (3A, closed symbols) and percentage of missed targets (3B, open symbols) as a function of arrow drift speed and practice trials.

RESULTS

Study 1: stepping performance as a function of drift speed

Mean step timing (fig 2A) and percentage missed targets (fig 2B) as a function of arrow drift speed and presentation type are shown in fig 2. There was a significant interaction (F(2.4,52.9)=46.1, p<0.05) between presentation type and arrow drift speed. The linear relationship between step timing and drift speed was greater for the randomised presentation condition than in response to blocked presentation conditions (F(1,22)=97.9, p<0.0001). For the slowest drift speed, an early step response in blocked trials (40.0 (14.1) ms) was half that of randomised trials (86.6 (17.5) ms). At the fastest drift speed, the magnitude of step timing in response to the blocked trials (−66.4 (13) ms) was nearly one-third the value obtained in response to randomised trials (−190.3 (13.7) ms), with all steps occurring after the drifting arrow had passed beyond target arrow location. Optimal timing of steps for both conditions occurred at a drift speed of 17.25°/s.

A significant interaction between stimulus type and arrow drift speed was also observed for percent missed targets (F(2.1,46.2)=35.7, p<0.05), with the percentage of missed targets increasing linearly from 7% to 40% as drift speed increased for randomised trials. For blocked trials, however, the percentage of missed targets did not significantly increase as drift speed increased. In the randomised condition, the percentage of missed targets increased rapidly for drift speeds >17.25°/s.

Study 2: DDR performance as a function of practice

Mean step timing (fig 3A) and percentage missed targets (fig 3B) as a function of arrow drift speed and practice are shown in fig 3. A significant linear relationship between step timing and drift speed (F(1,19)=127.7, p<0.0001) and step timing and percentage missed targets (F(1,19)=34.3, p<0.001) was observed (as for study 1). Helmert contrast analysis on the significant main effect of practice trial on step timing (F(1.46,27.8)=5.59, p<0.02) and percentage missed targets (F(2.3,44.3)=7.3, p<0.005) revealed a significant difference between the first practice trial and the remaining for both step timing (F(1,19)=6.7, p=0.018) and percentage missed targets (F(1,19)=13.5, p=0.002). Mean step timing on the first practice trial was −126.3 (5.7) ms, while the average for the remaining four practice trails was nearly half (−77.4 (2.9) ms). At the fastest drift speed, 45.5 (5.9)% of targets were missed on the first practice trial, while 30.3 (5.4)% of targets were missed on practice trial 5.

Younger adults perform better (smaller step timing scores, lower percentage missed targets) on the DDR task across a wider range of drift speeds than do older adults. Figure 4 shows average step timing (fig 4A) and percentage missed targets (fig 4B) collapsed across all five practice trials as a function of arrow drift speed for younger and older participants.

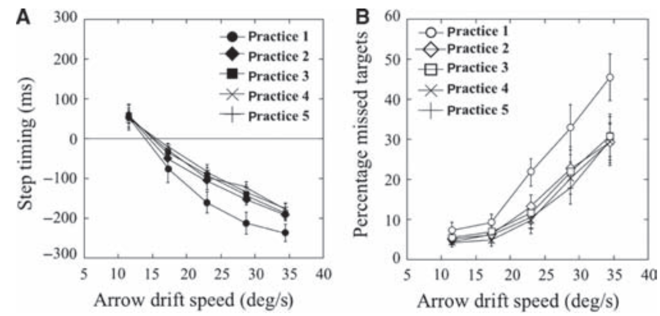

Figure 4 Average step timing (4A, closed symbols) and percentage of missed targets (4B, open symbols) collapsed across all 5 practice trials as a function of arrow drift speed and age.

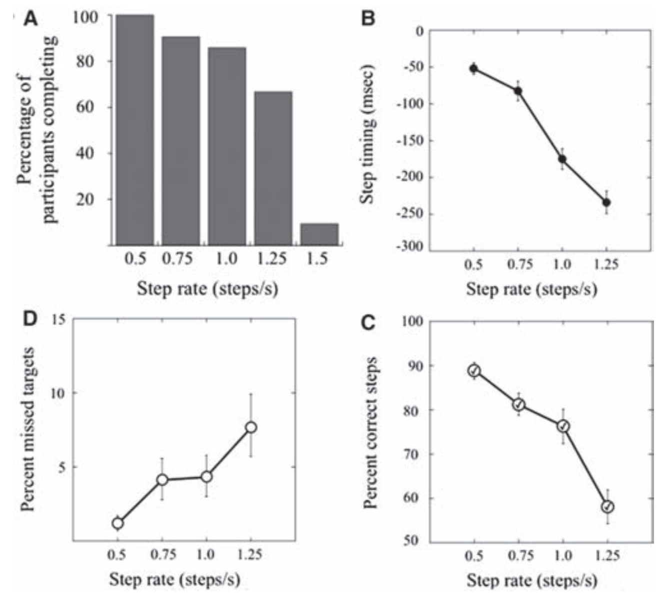

Figure 5 Older adult performance on the Dance Dance Revolution task as a function of step rate. (A) Percentage of participants completing each level of step rate; (B) step timing (closed circles); (C) percentage missed targets (open circles); (D) percent correct steps (circle tick) for the 14 participants who completed up to 1.25 steps/s.

Study 3: effect of step rate

The percentage of participants able to successfully interact with the step training system was significantly affected by increasing the step rate $\chi^2(5, n=21)=20.0$, $p>0.05$. Only two were able to complete all five levels of the step rate variable, and only 14 were able to complete up to 1.25 step/s (fig 5A). Subsequent analysis was therefore restricted to those participants who completed all step rates up to 1.25 steps/s. Mean step timing (fig 5B), percentage missed targets (fig 5C) and the percentage of correctly made steps (fig 5D) as a function of step rate are shown in fig 5. There was a significant linear relationship between step timing and step rate ($F(1,13)=115.5$, $p<0.05$) such that older adults became significantly slower in their timing of step responses as step rate increased. The percentage of missed targets (trials on which no step response was made) also increased linearly as step rate increased ($F(1,13)=9.33$, $p=0.009$) from 1 (0.5)% to 8 (2)%. At the slowest step rate, 89 (2)% of all steps were correct, and performance decreased linearly ($F(1,13)=61.3$, $p<0.005$) as step rate increased such that at 1.25 steps/s, the mean percentage of correct steps dropped to 58 (4)%.

DISCUSSION

This is the first study to systematically quantify and evaluate DDR performance by people aged ≥70. Performance, as quantified by step timing, percentage missed targets and percentage correct steps, has been shown to be systematically related to arrow drift speed and the rate at which new arrows appear on the display screen. Optimal timing of stepping appears to occur for arrow drift speeds around 17°/s. Arrow drift speeds greater than that and step rates >1 step every 1.3 s (0.75 steps/s) result in stepping performance that is >100 ms and up to 200 ms too late for successful (well-timed and correctly directed steps) interaction with the game. Older adults were also unable to successfully interact with the DDR system for step rates >1.25 steps/s. The results from our studies also suggest that stepping performance can be modified through practice over short periods of time and that older adults perform significantly worse than younger adults on the DDR task.

The results obtained in study 1 reveal that stepping performance is a significant function of arrow drift speed with poorer performance at higher drift speeds. It was also observed that a significant difference in the way step responses were made depended upon the predictability of drift arrow location and speed. When the sequence of steps required was predictable (blocked conditions), older adults were significantly better at coordinating their step responses across the entire range of arrow drift speeds. Mean step timing for blocked trials was between one-half and one-third the magnitude of step timing response to unpredictable (randomised) trials, indicating that participants were able to time execution of their steps more precisely when they could predict the speed and location of the next drifting arrow.

The relatively longer delay in stepping response observed in randomised over blocked trials is consistent with results observed in a posture perturbation experiment[16] where younger adults were asked to make corrective steps in response to unpredictable versus predictable conditions. In their study, Jacobs and Horak[16] observed that the onset of a compensatory step was significantly longer in the unpredictable condition, and it was reasoned that this delay resulted from additional online processing of updated environmental information which may or may not have been consistent with a preselected stepping response. In our studies, feedback from many participants indicated that they frequently tried to guess the next speed and location of drifting arrows in the randomised trial, often in an attempt to "beat the system". If a preselected stepping limb was inconsistent with the updated visual cue, additional online processing to correct and re-select an appropriate stepping response could lead to an increased delay in coordinating step responses with the visual target.

One additional observation related to the effect of arrow drift speed on step timing, regardless of whether the drift arrow sequence was predictable or not, is that older adults tend to step too early in response to the slowest of the drift speeds. In learning how to play the DDR game, older adults may have adopted a strategy to respond as quickly as they could once they made a decision about which leg they would use to step. A recent report on obstacle avoidance strategies adopted by older women[17] suggests that reliance upon anticipatory visuo-motor responses can be significantly reduced by visual feedback training. Data from our practice trial study, however, indicate that, at least over the short term, practice on the randomised version of our DDR system does not significantly reduce anticipatory stepping responses at the slowest drift speed. We did find, however, a significant difference in performance between the first and all remaining practice trials for both step timing and the number of targets missed. Older adults appear to learn how to use the system after a single 3–5-min session of practice but do not significantly improve performance thereafter. One limitation of our study was the relatively short length of training in our older participants. It is possible that significant improvements in performance may be observed with long-term (over weeks, months) practice. Issues surrounding the effect of DDR practice on stepping performance over both the short and long term are currently under investigation in our laboratory.

While all participants were able to successfully complete trials at a step rate of 1 step every 2 s, only two-thirds of them could complete the task when the step rate was increased to 1.25 steps/s. Fewer than 10% of participants were then able to successfully complete the 1.5 steps/s condition, suggesting a dramatic change in the nature of the task when moving to the higher step rate. It is possible that, as step rate was accompanied by a concomitant increase in the number of drifting arrows on screen (upwards of four at step rates of 1.25°/s), these results may reflect an increase in the cognitive challenge posed by the system. We have previously shown[18] that, relative to younger adults, older adults, particularly those who are at high risk for falling, have an impaired ability to initiate and execute quick, accurate steps, particularly when a cognitive load is present. The DDR system therefore provides a number of parameters by which the effect of cognitive load on stepping performance could be measured and tracked over time.

SUMMARY AND CONCLUSION

We have developed a novel system for training stepping responses in older adults that is based on a popular video game that links stepping movements to visual cues. Performance parameters related to coordinated stepping and errors in decision are systematically related to characteristics of game play. The system provides a low-cost technique by which older adults can be engaged in the kind of balance challenging exercises reported to reduce the risk of falls. In addition, the

What is already known on this topic?

- We know that older adults are at increased risk of falling and that exercise can reduce that risk. We also know that a number of factors influence the compliance with exercise and that home-based exercise interventions are associated with greater compliance rates than interventions undertaken outside of the home.

What does this study add?

- This study demonstrates that older adults can engage with a novel, video game-based system for exercise and step training. Furthermore, we have developed a series of parameters that can be used to quantify stepping performance in older adults.

system also enables performance to be monitored on a daily basis such that home-based estimation of stepping ability is possible. As such, this is one of the first demonstrations of an exergame system that can be used as a telehealth device.

Acknowledgements This research was supported by a National Health and Medical Research Council (NHMRC) Project grant awarded to SRL, STS, SS and CS. STS is also supported by an NHMRC Career Development Award. The authors would like to thank Ms Mon-Shuan Wu who helped with data collection and Mr Jamie Lennox for programming.

Funding National Health and Medical Research Council.

Competing interests None.

Ethics approval This study was conducted with the approval of the University of New South Wales Human Research Ethics Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

Patient consent Obtained.

Contributors We would like to thank Ms Mon-Shuan Wu who assisted in data collection and Mr Jamie Lennox for programming.

REFERENCES

1. **Shumway-Cook A**, Woollacott, MH. *Motor control: theory and practical applications.* Baltimore, Maryland, USA: Williams & Wilkins, 1995.
2. **Rogers MW**, Johnson ME, Martinez KM, *et al.* Step training improves the speed of voluntary step initiation in aging. *J Gerontol A Biol Sci Med Sci* 2003;**58**:46–51.
3. **Jöbges M**, Heuschkel G, Pretzel C, *et al.* Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. *J Neurol Neurosurg Psychiatr* 2004;**75**:1682–7.
4. **Pai YC**, Bhatt TS. Repeated-slip training: an emerging paradigm for prevention of slip-related falls among older adults. *Phys Ther* 2007;**87**:1478–91.
5. **Sherrington C**, Whitney JC, Lord SR, *et al.* Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008;**56**:2234–43.
6. **Oman RF**, King AC. The effect of life events and exercise program format on the adoption and maintenance of exercise behavior. *Health Psychol* 2000;**19**:605–12.
7. **King AC**, Haskell WL, Young DR, *et al.* Long-term effects of varying intensities and formats of physical activity on participation rates, fitness, and lipoproteins in men and women aged 50 to 65 years. *Circulation* 1995;**91**:2596–604.
8. **Maddison R**, Mhurchu CN, Jull A, *et al.* Energy expended playing video console games: an opportunity to increase children's physical activity? *Pediatr Exerc Sci* 2007;**19**:334–43.
9. **Graves L**, Stratton G, Ridgers ND, *et al.* Energy expenditure in adolescents playing new generation computer games. *Br J Sports Med* 2008;**42**:592–4.
10. **Warburton DE**, Bredin SS, Horita LT, *et al.* The health benefits of interactive video game exercise. *Appl Physiol Nutr Metab* 2007;**32**:655–63.
11. **Epstein LH**, Beecher MD, Graf JL, *et al.* Choice of interactive dance and bicycle games in overweight and nonoverweight youth. *Ann Behav Med* 2007;**33**:124–31.
12. **Baranowski T**, Buday R, Thompson DI, *et al.* Playing for real: video games and stories for health-related behavior change. *Am J Prev Med* 2008;**34**:74–82.
13. **Tamura T**, Sekine M, Shinchi T, *et al.* PC-based rehabilitation tool for the elderly. *Conf Proc IEEE Eng Med Biol Soc* 2007;**2007**:1808–9.
14. **Brainard DH**. The Psychophysics Toolbox. *Spat Vis* 1997;**10**:433–6.
15. **Pelli DG**. The VideoToolbox software for visual psychophysics: transforming numbers into movies. *Spat Vis* 1997;**10**:437–42.
16. **Jacobs JV**, Horak FB. External postural perturbations induce multiple anticipatory postural adjustments when subjects cannot pre-select their stepping foot. *Exp Brain Res* 2007;**179**:29–42.
17. **Hatzitaki V**, Voudouris D, Nikodelis T, *et al.* Visual feedback training improves postural adjustments associated with moving obstacle avoidance in elderly women. *Gait Posture* 2009;**29**:296–9.
18. **St George RJ**, Fitzpatrick RC, Rogers MW, *et al.* Choice stepping response and transfer times: effects of age, fall risk, and secondary tasks. *J Gerontol A Biol Sci Med Sci* 2007;**62**:537–42.

A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults

S T Smith, C Sherrington, S Studenski, et al.

Br J Sports Med 2011 45: 441-445 originally published online November 29, 2009
doi: 10.1136/bjsm.2009.066845