Exploring the effects of Bingocize®: an interactive community-based physical activity intervention for older adults in the UK

July 2020

By Geoff Middleton, Hannah Henderson, Georgia Clay, Anna Mongan & Dan Martin (University of Lincoln, UK)

In collaboration with:

K. Jason Crandall & Matthew Shake (Western Kentucky University Center for Applied Science in Health & Aging, USA)

David Broom (Coventry University, UK)

Content

List of tables and figures:

1. Background and aim

The world's population aged 60 years and over is set to increase from 841 million in 2013 to more than 2 billion by 2050 (Chatterji et al., 2015; United Nations, 2015). With advancing age comes the heightened risk of developing chronic, degenerative diseases such as cardiovascular disease, cancer, respiratory diseases, and diabetes (Prasad et al., 2012; WHO, 2015). In a growing elderly population, 'healthy ageing' is becoming a crucial factor to reduce the burden of disease and disability and related healthcare costs (Hamer et al., 2014; WHO, 2015). For older adults, negative health outcomes are associated with the presence of chronic disease, mobility impairment and loss of functional independence/capability (Grimmer et al., 2019, Satariano et al., 2012). Physical activity (PA) in different forms has been shown to improve mobility, balance and reduce risk for falls in later life (Cadore et al., 2013, Thomas et al., 2019). Community-based, group exercise programmes which incorporate motivators such as social support, have been shown to be one means of increasing PA levels and adherence to an active lifestyle for older adults (Hambrook et al., 2020; Hernandes et al., 2013). Regular exercise in the community setting has beneficial effects on older people's physical function; improving mobility, flexibility, and upper and lower limb function (Keogh, et al., 2014).

This project aim was to examine the effects of Bingocize® on older adult health. Bingocize® is an interactive game, played on a tablet (electronic screen device connected to the internet), which uses the traditional game of bingo integrating low-level exercise and health education messages during sessions (Crandall & Shake, 2016). Bingocize® was designed to engage with the older adult population and details of this American-based health promotion programme can be viewed here: https://www.wku.edu/bingocize/. As an intervention, Bingocize® aims to improve functional mobility, independence and cognition of older adults in the community across the spectrum of care including assisted living and long-term care. Bingocize® is approved by the United States (U.S.) National Council on Aging as an evidence-based falls prevention programme. In addition, the programme is approved as an obesity treatment and prevention programme by the United States Department of Agriculture. The programme is currently implemented in 35 U.S. states and three additional countries. The majority of facilities using Bingocize® deploy the non-software application version.

In partnership with Dr. Jason Crandall & Dr. Matthew Shake (at Western Kentucky University, USA; developers of Bingocize®) and Age UK Lincoln, we investigated the effects of the interactive Bingocize® game with older adults from Lincolnshire. We examined the effects on physical and cognitive function of a group of volunteers from Age UK Lincoln, following a 10-week period of playing the interactive game. Our findings from this pragmatic non-randomised trial using convenience sampling will inform our intentions toward a larger trial in the UK, establishing the feasibility and suitability of the current game format for the Lincolnshire population. This project connects to the preventative agenda, where alternative strategies which aid healthy ageing require immediate study attention and evaluation (National Institute of Health Research, 2017). This project was funded by the College of Social Science, University of Lincoln, UK with a grant of £2,700.

2. Study approach

2.1. Design and participant eligibility

A quasi-experimental design was adopted for this study. After receiving ethical clearance, two independent groups of participants were invited to take part in the study. An intervention group (11 participants, average age of 74 years) and a control group (11 participants, average age of 66 years) were observed before (baseline) and after a 10-week period, participating in a number of assessments.

In this study, the control group acted as a counterfactual reference for the comparison of several physical, cognitive and self-reported health assessment outcomes.

To participate in the study (eligibility), both males and females were required to: 1) be 60-90 years old; 2) not participate in regular structured exercise (gym classes, walking groups etc); 3) maintain their normal / habitual physical activity levels for 10-weeks; 4) complete physical screening measures; gauging the risk of exercise to health. The study did not recruit any participants with severe or uncontrollable physical, mental or cognitive impairment. All the participants in this study were given a financial incentive (£40) once they had completed both baseline and 10-week assessments.

2.2. The intervention: Bingocize®

Initially, Age UK Lincoln promoted the study's intervention Bingocize® to members via flyers and word-of-mouth at their premises on Park Street, Lincoln, UK. From the initial interest, appropriate screening procedures and assessment of attendance commitment; the University of Lincoln research team recruited 11 participants (age = 73.5 ± 6.4 years) which formed the intervention group. The intervention group participated in Bingocize® twice a week for 10 weeks of the intervention period in two separate groups (7 and 4 participants in each). Each Bingocize® session was conducted with at least one day's rest between each session. Each session lasted between 45-60 minutes and was delivered inside a suitable teaching space designated to small group education with connection to the internet. Participants were provided with suitable refreshments by Age UK Lincoln. Participants in the intervention group were asked to maintain their normal lifestyle and refrain from any scheduled or planned activity (i.e. fitness/dance classes) for the duration of the study.

During the sessions, each participant was provided with a small electronic tablet to view the Bingocize® game on the screen. Participants were encouraged to operate the tablet and were assisted in the beginning of each session to operate this effectively. A (6 x6) digital bingo game card was issued to each participant on the tablet screen (Figure 1, below). A digital game of bingo with a numbered 'spinning wheel' was illustrated on screen to enact the traditional game in front of the participants (see Figure 2, page 4). Each participant was required to press a number shown on the screen after completing an exercise or answering a health-related question, which could be answered with numerous attempts until the correct option was selected to enhance education (See Figure 3, page 4). Each participant's card had a different arrangement of numbers to determine a winner. When a full row of numbers was complete a 'winner' was declared (See Figure 4, page 5). After group members achieved a 'full row', the session still continued. Group members who attended received small prizes for coming first, second and third (based on £5 expenditure per session).

Figure 1. A participant's digital Bingocize® bingo card with instructions to exercise

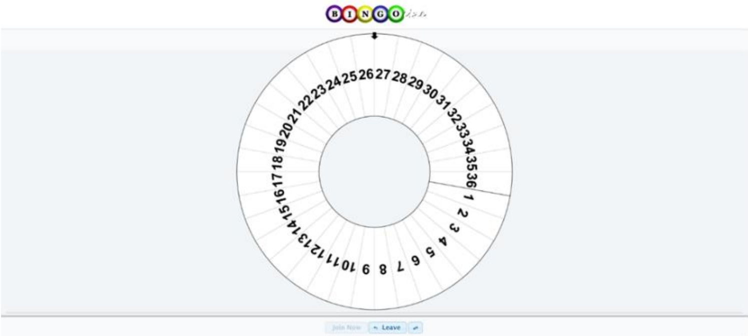

Figure 2. The 'spinning wheel' from the Bingocize® game

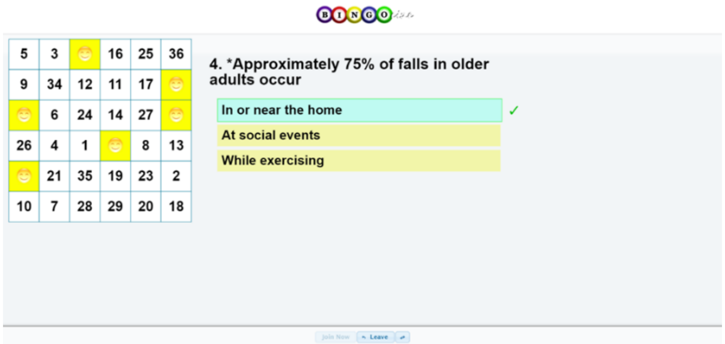

Figure 3. A participant answering a health-related question from the Bingocize® game

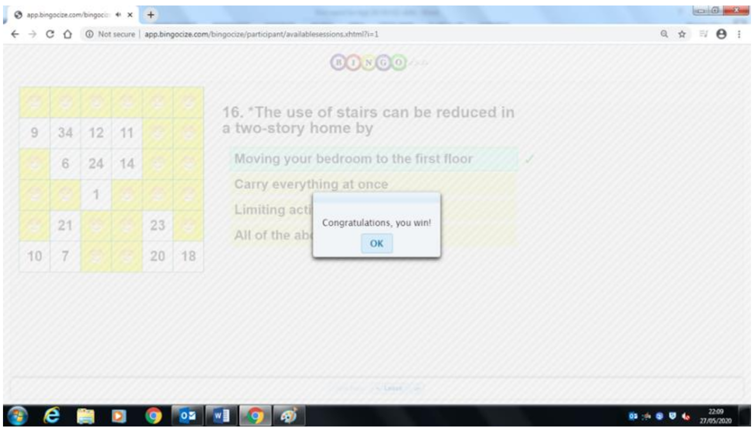

Figure 4. 'Bingo': A winning participant card from Bingocize®

The delivery of Bingocize® was prepared, organised and monitored by two game leaders (GL) who coordinated each session via a main laptop computer. Prior to each session, a GL selected exercises from the Bingocize® software database and typically delivered 16 exercises per session in a random order to prevent repetition and boredom. In-between the main session was a standardised warm up and cool down involving chair-based marching leg movements and stretches. GLs selected typically 12 health-related questions from the software, and these were also issued per session, aimed at educating falls prevention information to the older adults. Initially, participants were encouraged to conduct as many repetitions as they could for between 30-60 seconds per exercise.

After 5 weeks of the intervention, participants were encouraged to perform exercises for up to 60 seconds or perform repeated sets (e.g. 2 x 30 seconds, 2 x 45 seconds). The GLs demonstrated the exercises in front of the participants which were supported by videos shown on the tablet in front of each older adult. GLs assisted and adopted subtle changes and managed any minor translation issues when necessary. The Bingocize® software database consisted of a combination of exercises focused on improving cardiovascular fitness (e.g. marching), muscular strength and endurance (e.g. Bicep curl), flexibility (e.g. Chair sit-and-reach) and balance (e.g. 3 point-balance with reach/cueing drill/leg extension) within the guidelines set for older adults (Chodzko-Zajko et al., 2009). Graded resistance bands (low and medium grades) were provided to aid members with certain exercises requiring strength. The exercises and similar procedures have been used before in published studies (Crandall et al., 2019; Shake et al., 2018).

2.3. The control group: the counterfactual

The non-intervention control group consisted of 11 participants (age = 66.0 ± 4.8 years) and were recruited in a second phase of the study. The control group was recruited via email after advertisement on the University of Lincoln's staff request platform. Control group participants were instructed to refrain from any structured exercise or fitness-based activity and were simply monitored over time to establish a suitable counterfactual reference for comparison in the analysis This part of the project occurred at the University of Lincoln, Human Performance Centre facilities. Participants were able to access parking at the facility without cost for their visit.

2.4. Assessments and outcomes

The following were measures conducted with the intervention and control group, at baseline and at 10-weeks.

Screening measurements:

Body mass (kg), *Height* (m), *Body Mass Index* (kg/m^2), *resting heart rate* (b/min), *systolic* and *diastolic blood pressure* (mmHg).

Functional Fitness assessments:

The Short Physical Performance Battery (SPPB) (Guralnik et al., 1994) was conducted with all participants in the following order: three balance tests (*side-by-side*, *semi-tandem* & *tandem* stands), two 3m *gait speed* tests, one *repeated chair sit-to-stand test.* Protocols for these tests were adhered to, accurately following relevant descriptions and standardised operating procedures for older adults (United States Department of Health and Human Services, n.d.). A *30 second bicep/arm curl* test was also conducted separately to the battery following protocols from the Senior Fitness Test manual (Rikli & Jones, 2013).

Cognition and executive function assessments:

Executive function is regarded as a set of control processes that regulate human thoughts and behaviours (Miyake & Friedman, 2012). Core executive functions are attention, impulsion, working memory, cognitive flexibility (thinking 'outside of the box') and inhibition (Diamond, 2013; Kramer et al., 2014). Executive functioning is regarded as important for the maintenance of physical, emotional and mental health and has an important 'stake' in daily life (Diamond, 2013). The following executive function tests were deployed (in order) via a screen to participants sitting in front of a laptop computer: the *Flanker*; *Set Shifting*; *Dot Counting* (two scoring systems used); *Go-No-Go, 1-Back*, and; *Anti-Saccades* (two trials). The tests were administrated by software and were based on the Executive Function Framework (Kramer et al., 2014). The instructions stated by the University of California San Francisco's Memory and Ageing Centre (2018) were followed for all tests. Instructions to the participants appeared on screen. Before tests commenced, verbalised guidance was provided by one member of the research team to aid understanding while the participant completed the battery of tests one by one.

Self-reported living ability assessments:

An assessment of fear of falling was conducted by participants completing the *Falls Efficacy Scale-International* (Yardley et al., 2005) developed for older adults and included 16 items. Each item was a description of an activity (e.g. changing clothing), and/or a scenario (e.g. "walking in a place with crowds"). Respondents selected a point along a 4-point continuum between two opposite descriptors depending on the level of personal concern they had with the activity or description (e.g. "not at all concerned"/ "somewhat concerned"/ "fairly concerned" and "very concerned").

Secondly, each participant's independent living function was assessed by the Lawton *Instrumental Activities of Daily Living Scale* (Lawton & Brody, 1969). The scale has eight descriptive domains which outline an everyday functional task (e.g. shopping) and participants indicate if they can complete this as described by selecting a relevant response (e.g. "shops independently for small purchases"). Participants scoring '0' suggest they were 'unable' to do the task suggested. Participants score 1 if they were able to execute the task (Lawton & Brody, 1969).

Data analysis of outcomes:

Using a statistical software package (IBM SPSS statistics, V24), a paired t-test was deployed to compare measured outcomes between baseline and 10-weeks for each group. A 2 x 2 mixed analysis of variance (ANOVA) was performed to analyse the data collected after suitable data normality checks. The ANOVA calculates the statistical difference between the two related time measurement outcomes (at baseline and at 10-weeks) and whether there is an interaction between the intervention and the control (group x time).

3. Key findings

Screening measurements:

Participants of the intervention group experienced a significant reduction in *systolic* (**-8.1 mmHg, 5.7%**) and *diastolic blood pressure* (**-3.6 mmHg, 6.5%**) after 10-weeks. At a statistical level, no significant differences were detected despite a larger reduction in the intervention group compared to the control group. *Resting heart rate* was found to increase in this group (**+6.2 bpm, 8.2%**) over time and there was a statistical difference between groups. There was no indication of any improvement with *body mass* and *body mass index* and weight of the participants remained relatively the same. Table 1 highlights the findings (Page 7).

Table 1. Intervention and control group characteristics and screening measurement data (Values presented are mean ± standard deviation).

Characteristic / measures / group	*Baseline*	*After 10-weeks*	*Difference (+/-)*
Gender (female/male):			
Intervention:	11/0		
Control:	5/6		
Age (years):			
Intervention:	73.5 ± 6.4		
Control:	66.0 ± 4.8		
Stature (m):			
Intervention:	1.59 ± 0.1	1.59 ± 0.1	
Control:	172.0 ± 0.1	172.0 ± 0.1	
Body mass (kg):			
Intervention:	62.9 ± 10.8	62.5 ± 9.9	-0.4
Control:	81.3 ± 20.8	81.7 ± 18.7	+0.4
Body Mass Index (kg/m^2):			
Intervention:	24.9 ± 4.2	24.8 ± 4.1	-0.1
Control:	27.2 ± 3.4	27.2 ± 3.7	0
Resting Heart Rate (b/min):			
Intervention:	69.7 ± 13.4	75.9 ± 8.5*	+6.2**
Control:	68.1 ± 8.1	66.3 ± 11.8	-1.8
Systolic blood pressure (mmHg):			
Intervention:	142.1 ± 14.1	134.0 ± 12.6*	-8.1*
Control:	135.5 ± 15.4	134.1 ± 12.4	-1.4
Diastolic blood pressure (mmHg):			
Intervention:	77.9 ± 10.0	73.5 ± 9.5*	-4.4*
Control:	81.9 ± 7.9	79.9 ± 8.5	-2.0

*denotes a statistical significant difference (p<0.05) between baseline and 10-weeks
**denotes interaction between intervention and control group (p<0.05)

Functional fitness assessments:

After 10 weeks, improvements were observed with the following outcomes with the participants from the intervention group: *2nd gait speed walking test* (s), **7.5%** = 2.7 (±0.4) to 2.5s (±0.3), and; the *repeated chair sit-to-stand* time (s), **24.3%** = 14.0 (±3.5) to 10.6 (±2.4); Both the summarised scores for the *repeated chair sit-to-stand test* (0-4) and the *total SPPB Score* (0-12) also illustrated notable increases. A statistical interaction between group x time was shown, illustrating these improvements were greater than the control group in comparison. The control group did not show any significant improvements and outcome variables remained similar over time and no statistical differences were detected for all other comparisons. Table 2 highlights the findings (Page 8).

Table 2. Intervention and control group performance on the functional fitness assessments
(Values presented are mean ± standard deviation).

Characteristic / measures / group	*Baseline*	*After 10-weeks*	*Difference (+/-)*
Side-by-side stand score (0-1):			
Intervention:	1.0 ± 0.0	1.0 ± 0.0	0
Control:	1.0 ± 0.0	1.0 ± 0.0	0
Semi-Tandem stand score (0-1):			
Intervention:	1.0 ± 0.0	1.0 ± 0.0	0
Control:	1.0 ± 0.0	1.0 ± 0.0	0
Tandem test stand score (0-2):			
Intervention:	1.9 ± 0.3	1.9 ± 0.3	0
Control:	1.9 ± 0.3	1.8 ± 0.4	-0.1
Stand test score (0-4):			
Intervention:	3.9 ± 0.3	3.9 ± 0.3	0
Control:	3.9 ± 0.3	3.8 ± 0.4	-0.1
1st gait walking test (s):			
Intervention:	2.8 ± 0.5	2.7 ± 0.4	-0.1
Control:	2.5 ± 0.3	2.6 ± 0.4	+0.1
2nd gait walking test (s):			
Intervention:	2.7 ± 0.4	2.5 ± 0.3*	-0.2**
Control:	2.4 ± 0.3	2.5 ± 0.4	+0.1
Gait walk score (0-4):			
Intervention:	4.0 ± 0.0	4.0 ± 0.0	0
Control:	4.0 ± 0.0	4.0 ± 0.0	0
Repeated chair-sit-stand time (s):			
Intervention:	14.0 ± 3.5	10.6 ± 2.4*	-3.4**
Control:	12.6 ± 3.9	11.9 ± 2.9	-0.7
Repeated chair-sit-stand score (0-4):			
Intervention:	2.5 ± 1.0	3.5 ± 0.8*	+1.0**
Control:	2.8 ± 1.3	3.1 ± 1.0	+0.3
Total Short Physical Performance Battery Score (0-12)			
Intervention:	10.4 ± 1.2	11.5 ± 0.8	+1.1
Control:	10.7 ± 1.3	10.9 ± 1.2	+0.2
30 second Bicep Curl (repetitions completed):			
Intervention:	12.5 ± 3.6	14.5 ± 4.4*	+2.0
Control:	18.0 ± 5.1	17.4 ± 3.6	-0.6

*denotes a statistical significant difference (p<0.05) between baseline and 10-weeks
**denotes interaction between intervention and control group (p<0.05)

Cognition and executive function assessments:

After 10 weeks, improvements were observed with the following assessments for the participants from the intervention group: the *Flanker* (s), **4.8%** = 8.1 (±0.9) to 8.5 (±0.6), and; the *1-Back* (s), **27%** = 1.9 (±0.6) to 2.6 (±0.8); The *Set shifting* and the *Go-No-Go* tests also illustrated notable statistical improvements. A statistical interaction between group x time was not shown on this set of assessments, indicating that the intervention group achieved no better improvements than the control group in comparison. The control group did show an improvement in the *Go-No-Go* (97.8 ±1.8

to 99.1 ±1.8) task but all other executive function assessments remained similar over time. Table 3 highlights the findings (below).

Table 3. Intervention and control group performance on the executive function assessments (Values presented are mean ± standard deviation).

Characteristic / measures / group	*Baseline*	*After 10-weeks*	*Difference (+/-)*
Flanker (0-10):			
Intervention:	8.1 ± 0.9	8.5 ± 0.6*	+0.4
Control:	8.4 ± 0.5	8.5 ± 0.5	+0.1
Set shifting (0-10):			
Intervention:	7.5 ± 1.4	7.7 ± 1.2*	+0.2
Control:	7.6 ± 0.8	7.6 ± 1.0	0
Dot counting score (0-27):			
Intervention:	13.7 ± 3.4	14.3 ± 2.1	+0.6
Control:	15.3 ± 3.5	15.4 ± 2.4	+0.1
Dot counting 'lenient' score (0-27):			
Intervention:	20.0 ± 4.0	21.5 ± 4.0	+1.5
Control:	21.6 ± 4.6	22.0 ± 2.5	+0.4
Go/No-Go (0-100):			
Intervention:	97.9 ± 2.0	99.5 ± 0.8*	+1.6
Control:	97.8 ± 1.8	99.1 ± 1.8*	+1.3
1-Back (0-5):			
Intervention:	1.9 ± 0.6	2.6 ± 0.8*	+0.7
Control:	2.4 ± 0.6	2.5 ± 0.5	+0.1
Anti-Saccades -Trial 1 (/20):			
Intervention:	18.5 ± 3.0	18.8 ± 2.8	+0.3
Control:	18.4 ± 2.8	18.4 ± 2.1	0
Anti-Saccades -Trial 2 (/20):			
Intervention:	19.5 ± 0.9	19.1 ± 1.4	-0.4
Control:	18.3 ± 2.2	17.5 ± 2.8	-0.8

*denotes a statistical significant difference (p<0.05) between baseline and 10-weeks
**denotes interaction between intervention and control group (p<0.05)

Self-reported living ability assessments:

Both the *Falls Efficacy* and *Instrumental Activities of Daily Living* scales showed no change from baseline to 10 weeks in either group. No statistical differences were detected between the intervention and control groups with the data analysed from *sum of* scale responses. Table 4 highlights the findings (Page 10).

Table 4. Intervention and control group performance on the self-reported living ability assessments (Values presented are mean ± standard deviation).

Characteristic / measures / group	*Baseline*	*After 10-weeks*	*Difference (+/-)*
***Falls Efficacy scale* (16-item score):**			
Intervention:	19.5 ± 2.1	20.0 ± 3.5	+0.5
Control:	18.8 ± 4.7	19.5 ± 4.1	+0.7
***Activities of Daily Living scale* (8-item score):**			
Intervention:	8.0 ± 0.0	8.0 ± 0.0	0
Control:	8.0 ± 0.0	8.0 ± 0.0	0

*denotes a statistical significant difference ($p<0.05$) between baseline and 10-weeks
**denotes interaction between intervention and control group ($p<0.05$)

4. Summary and Conclusion

From the data, Bingocize® was able to improve agility, speed, flexibility and strength in the sample of participants in this investigation. Indeed, compared to a recruited control group, the *repeated chair sit-to-stand test time* and *3m walk test* reduced by small, but meaningful margins (in-terms of statistical significance). Furthermore, *blood pressure* was positively influenced by involvement in two sessions of Bingocize® per week for 10 weeks with the intervention group. Importantly, Bingocize® did not illustrate physical on the majority of outcomes and several improvements were noted compared to a counterfactual reference group and there were no reported injuries or adverse events during Bingocize® sessions. The findings regarding *resting heart rate* was contradictory to this but it is established that a reduction in resting heart rate should not be expected by exercise training in older adults (O'Hartaigh et al. 2014). Additionally, the recruited intervention group was older (on average) and differences existed with other characteristics compared to the control group (including prescribed medications) which may have influenced our findings.

Data illustrated participation in Bingocize® led to small but significant cognitive improvement in older adults. Over the same time period, the control group showed less of an improvement but without firm differential improvement compared to a counterfactual reference group, our findings remain inconclusive. Importantly, Bingocize® did not illustrate any cognitive regression or decline on the battery of executive function assessments used in this study, which infers that there was a neutral experience from participation in the intervention and this does appear to be suitable for use with older people in the UK.

Any implications from these results are noted with a degree of caution as this study was limited to a relatively low number of participants in both groups. The statistical power of the tests deployed to analyse the data would be higher if a larger sample was recruited. The recruited control group was younger (on average) and differences existed with other characteristics. A further trial will need to match the intervention group closely for stronger comparisons on effectiveness to be made. Importantly, the research team could not control cofounding variables in this study which may have been influential to the outcomes. For instance, the research team were unable to individually monitor each participant during Bingocize®. The intensity of the session, pacing of exercise movement repetitions and selection of resistance, where appropriate, was determined by self-selection. Additionally, this study did not assess motivation of participants in each class that they attended or over the course of the 10-week period. Measurements of in-session intensity would be a feasible extension of the study along with an assessment of fidelity to the intervention for older adults.

Never-the-less, there are encouraging signs that Bingocize® does contribute to an improvement in functional fitness for the 60 plus age group. Certainly, the participant feedback suggested that involvement in this study's intervention was a positive experience. Other work could explore the experience of Bingocize® using qualitative methods. Furthermore, this small trial of Bingocize® has been useful for the research team as the learning from the experience of study has been invaluable. Whilst the research team is confident that Bingocize® is efficacious and should be scaled up nationally, we are now in a position to assume the preparation, time and staffing commitments associated with delivery of a larger scale trial to test this with precision. We would welcome an opportunity to apply for further grants at a time when addressing physical inactivity, increased sedentary behaviour and associated weight gain during the current COVID-19 pandemic is high on the government's agenda.

Acknowledgements

We wish to thank Age UK Lincoln for their support in the recruitment stage and the use of their facilities throughout. We would also like to thank the participants who took part in the project for their time and commitment, otherwise this study would not have been possible.

Conflict of interest

Dr Jason Crandall and Dr Matt Shake designed and developed Bingocize®. The risk of any bias has been mitigated by the inclusion of Professor David Broom as an independent reviewer of the report and associated findings.

5. References

Cadore, E.L., Rodríguez-Mañas, L., Sinclair, A., & Izquierdo, M. (2013). Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. *Rejuvenation Research, 16*(2), 105-114.

Chatterji, S., Byles, J., Cutler, D., Seeman, T., & Verdes, E. (2014). Health, functioning, and disability in older adults-present status and future implications. *Lancet*, *385*(9967), 563-575.

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone, Singh, M. A., Minson, C. T., Nigg C. R., Salem, G. J., & Skinner, J.S. (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Medicine & Science in Sports & Exercise*, *41*(7), 1510-1530.

Crandall, K., & Shake, M. (2016). A mobile application for improving functional performance and health education in older adults: A pilot study. *Aging Science*, *4*(2), 2-6.

Crandall, K. J., Shake, M., & Ziegler, U. (2019). Assessing the impact of a game-centered mobile app on community-dwelling older adults' health activation. *OBM Integrative and Complementary Medicine*, *4*(3), 12.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135-168.

Guralnik, J. M., Simonsick, E. M., Ferrucci, L., Glynn, R. J., Berkman, L. F., Blazer, D. G., Scherr, P. A. & Wallace, R. B. (1994). A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology*, *49*(2), 85-94.

Grimmer, M., Riener, R., Walsh, C. J., & Seyfarth, A. (2019). Mobility related physical and functional losses due to aging and disease - a motivation for lower limb exoskeletons. *Journal of NeuroEngineering and Rehabilitation, 16*(2), 1-21.

Hambrook, R., Middleton, G., Bishop, D. C., Lee, C., Broom, D. R. (2020). Time to speed up, not slow down: A narrative review on the importance of community-based physical activity among older people. *Journal of Health and Social Science*, *5*(1), 73-90.

Hernandes, N. A., Probst, V. S., da Silva, R. A., Januário, R. S. B., Pitta, F., & Teixeira, D. C. (2013). Physical activity in daily life in physically independent elderly participating in community-based exercise program. *Brazilian Journal of Physical Therapy*, *17*(1), 57–63.

Keogh, J., Rice J., Taylor, D., & Kilding, A. (2014). Objective benefits, participant perceptions and retention rates of a New Zealand community-based, older-adult exercise programme. *Journal of Primary Health Care, 6*(2), 114-122.

Kramer, J. H., Mungas, D., Possin, K. L., Rankin, K. P., Boxer, A. L., Rosen, H. J., Bostrom, A., Sinha, Berhel, L. & Widmeyer, M. (2014). NIH EXAMINER: Conceptualization and development of an executive function battery. *Journal of the International Neuropsychological Society*, *20*(1), 11–19.

Lawton, M. P., & Brody, E. M. (1969). Assessment of older people: self-maintaining and instrumental activities of daily living. *The Gerontologist, 9*(3), 179-186.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: four general conclusions. *Current Directions in Psychological Science, 21*(1), 8-14.

O'Hartaigh, B., Pahor, M., Buford, T. W., Dodson, J. A., Forman, D. E., Gill, T. M., & LIFE Study Group. (2014). Physical activity and resting pulse rate in older adults: Findings from a randomized controlled trial. *American Heart Journal*, *168*(4), 597-604.

Prasad, S., Sung, B., & Aggarwal, B. B. (2012). Age-associated chronic diseases require age-old medicine: role of chronic inflammation. *Preventive Medicine*, *54*, 29-37.

Rikli, R. E., & Jones, C. J. (2013). *Senior fitness test manual* (2nd ed.). Champaign, USA: Human Kinetics.

Satariano, W. A., Guralnik, J. M., Jackson, R. J., Marottoli, R. A., Phelan, E. A., & Prohaska, T. R. (2012). Mobility and aging: new directions for public health action. *American Journal of Public Health*, *102*(8), 1508–1515.

Shake, M. C., Crandall, K. J., Mathews, R. P., Falls, D. G., & Dispennette, A. K. (2018). Efficacy of Bingocize®: a game-centered mobile application to improve physical and cognitive performance in older adults. *Games for Health Journal*, *7*(4), 253-261.

Thomas, E., Battaglia, G., Patti, A., Brusa, J., Leonardi, V., Palma, A., & Bellafiore, M. (2019). Physical activity programs for balance and fall prevention in elderly: a systematic review. *Medicine*, *98*(27), 1-9.

United Nations. (2015). *World Population Ageing 2015.* Department of Economic and Social Affairs Population Division. https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf

United States Department of Health and Human Services. (n.d.). *Short Physical Performance Battery (SPPB): Assessing Physical Performance in the Older Patient*. National Institute on Aging. https://www.nia.nih.gov/research/labs/leps/short-physical-performance-battery-sppb.

University of California San Francisco. (2018). *Measures and Instruments for Neurobehavioral Evaluation and Research (EXAMINER).* Weill Institute for Neurosciences, Memory and Ageing Centre. https://memory.ucsf.edu/sites/memory.ucsf.edu/files/wysiwyg/ExaminerBatteryFormC-Adult.pdf

Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and Ageing*, *34*(6), 614-619.