Novel Television-Based Cognitive Training Improves Working Memory and Executive Function

Evelyn Shatil1,2,3, Jaroslava Mikulecká3, Francesco Bellotti4, Vladimír Buresˇ3

1 CogniFit Inc., New York, New York, United States of America, 2 Department of Psychology and the Center for Psychobiological Research, Max Stern Academic College of Emek Yezeel, Yezeel Valley, Israel, 3 Faculty of Informatics and Management, University of Hradec Králové, Hradec Králové, Czech Republic, 4 Department of Electrical, Electronic, Telecommunications Engineering and Naval Architecture, University of Genoa, Genoa, Italy

Abstract

The main study objective was to investigate the effect of interactive television-based cognitive training on cognitive performance of 119 healthy older adults, aged 60–87 years. Participants were randomly allocated to a cognitive training group or to an active control group in a single-blind controlled two-group design. Before and after training interactive television cognitive performance was assessed on well validated tests of fluid, higher-order ability, and system usability was evaluated. The participants in the cognitive training group completed a television-based cognitive training programme, while the participants in the active control group completed a TV-based programme of personally benefiting activities. Significant improvements were observed in well validated working memory and executive function tasks in the cognitive training but not in the control group. None of the groups showed statistically significant improvement in life satisfaction score. Participants’ reports of “adequate” to “high” system usability testify to the successful development and implementation of the interactive television-based system and compliant cognitive training contents. The study demonstrates that cognitive training delivered by means of an interactive television system can generate genuine cognitive benefits in users and these are measurable using well-validated cognitive tests. Thus, older adults who cannot use or afford a computer can easily use digital interactive television to benefit from advanced software applications designed to train cognition.

Citation: Shatil E, Mikulecká J, Bellotti F, Buresˇ V (2014) Novel Television-Based Cognitive Training Improves Working Memory and Executive Function. PLoS ONE 9(7): e101472. doi:10.1371/journal.pone.0101472

Editor: Kevin Paterson, University of Leicester, United Kingdom

Received April 14, 2014; Accepted June 6, 2014; Published July 3, 2014

Copyright: © 2014 Shatil et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data Availability: Authors confirm that all data underlying the findings described in their manuscript are fully available without restriction. Data can be found in Supporting Information files. Study participants were assured that gathered data would be used merely for the study purposes. Appropriate formulation was a part of the written informed consent signed by each participant. In case of interest to verify or replicate the study, anonymized data can be used. Two files are submitted as Supplementary Files. Whereas VitalMind_Data.sav comprises raw data, the file titled VitalMind_PLUGGED_DATA.sav contains data modified according to the procedure stated in the manuscript and used for further analyses. The first column containing IDs had to be removed due to the aforementioned reason.

Funding: This study was created with the support of the Vital Mind project - 7th EU Framework Programme project num. 215387. This manuscript creation has been partially supported by the internal Excellence Project ‘Agent-based models and Social Simulation’ funded by the University of Hradec Králové. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: Vladimir Bureš, Jaroslava Mikulecká and Francesco Bellotti have no competing financial interests. Evelyn Shatil is employed at CogniFit. She holds no stocks or shares, owns no patents or patent applications. This does not alter the authors’ adherence to PLOS ONE policies on sharing data and materials.

* Email: vladimir.bures@uhk.cz

Introduction

With increasing age crystallised intelligence (the ability to acquire and store general and cultural knowledge) is believed to rise while fluid intelligence (the ability to observe complex relationships and to infer or predict subsequent relationships or actions on the basis of those observations) is known to decline, starting already in the middle of the fourth decade of life [1], [2]. Computerised cognitive training is widely available for the preservation of cognitive function in older adults [3], [4], [5] but computer and internet use decrease sharply with age, even in affluent countries [6], [7], [8]. Social, financial, cognitive, or psychological barriers [6], [9] impede seniors’ use of computer-based information technology, and increased stress and decreased self-efficacy loom large in their interactions with computers [10]. Television (TV) via a TV set, however, remains by far the most popular medium viewed by Europeans [11] and the elderly report being most comfortable with it [12]. Interactive TV (iTV) provides users with new TV viewing experiences. Interactivity in iTV can be defined as simply being anything that takes the user beyond passive watching and lets the user make choices and take action [13]. Thus iTV can be considered as an alternative to computer for cognitive training delivery representing cheap alternative based on technology already available in households and most elderly citizens are familiar with it. Moreover, it does not usually engender fear and awe as computers might [14].

Therefore, using the iTV cognitive training, we attempted to enhance fluid cognitive abilities such as working memory (the ability to hold and manipulate novel, transient information), executive control (the ability to regulate and monitor thought and action) and analogical reasoning (the ability to identify analogical relationships and to draw inferences on the basis of that comprehension). In the two years that preceded the study reported here an iTV system, equipped with TV-compatible cognitive training content was designed, tested and operated that enabled...
older adults, who cannot use or afford a computer, to engage in
cognitive training activities. To design the iTV system and
compliant applications and to run the experiment reported here,
eight academic and commercial institutions collaborated within
the FP7 framework of the European Union (see Table 1). The iTV
system design fulfilled requirements of open development
supporting testing in lab and home settings; prompt system-
effectiveness feedback; application use independently of underlying
TV stream and seamless transportation of users’ data on different
TV sets. The system consisted of an iTV Philips simulator, a flash
disk containing applications and data, a digital TV set, and two
cursor-moving devices: a novel pointer and a remote control. The
simulator replicated a TV set-top box (STB) in terms of memory,
computation power and graphics and enabled efficient designing,
running and verifying the iTV applications in a single platform.
The cognitive training programme was developed by CogniFit,
Israel, and included twenty one cognitive tasks, including divided
attention, focus, planning, updating, monitoring, inhibition,
memory, perception, and naming. The TV compatible software
for this programme was developed by the University of Genoa,
Italy. This software managed, stored, and visually displayed user
interaction data in real time, the Individualised Training System,
was responsible for scheduling the tasks according to the actual
user profile and allowed the user to interact with the tasks.

### Research Objective

Unlike computerised cognitive training, which is widely used
and researched, iTV cognitive training is a brand new concept. To
our knowledge, the only such existing system in the world is the
system we developed in this project and used for this study. The
goal of this study was, therefore to verify whether iTV-delivered
cognitive training would engender genuine and measurable
benefits in cognitive function, specifically in fluid cognition. To
answer this question we trained and subsequently measured
higher-order processing general abilities such as working memory,
executive control and analogical reasoning.

### Methods

The study was undertaken with the understanding and written
informed consent of each participant and according to the World
Medical Association Declaration of Helsinki principles. Since the
research was conducted in the FP7 Framework, the Ethical
Roadmap Report was created and followed.

### Participants and design

The efficacy of iTV-delivered cognitive training was tested in a
controlled experiment with 140 participants randomly assigned to
an equal sized cognitive training or a control group. The study
participants were recruited through advertising and by invitation
to presentations. All were told that they would engage in cognitive

---

### Table 1. Members of the Vital Mind consortium.

| Name of Institution or Business | Responsibility |
|---------------------------------|----------------|
| Cognifit Ltd., Yokneam Illit, Israel | Coordination of the project, design and testing of cognitive content. |
| Goldsmiths’ College, London, United Kingdom | Dissemination, exploitation, standards and ethics. |
| Philips Consumer Lifestyle B.V., Eindhoven, Netherlands | Design, development and testing of user interface. |
| Czech Technical University in Prague, Prague, Czech Republic | Design, implementation and testing of content (applications Family Tree, Physical Exercises and Training and User Error Rate Evaluation). |
| Universita degli Studi di Genova, Genoa, Italy | VM technology design and cognitive content implementation. Design and implementation of the Family Screen Composer application. |
| The University of Dundee, Dundee, United Kingdom | Experimental evaluation of user interface technology, design of cognitive content verification. |
| University of Hradec Kralove, Hradec Kralove, Czech Republic | Cognitive content and technology verification. |
| Czech Television, Prague, Czech Republic | iTV system verification. |

---

### Table 2. Cognitive training and control groups’ attributes at the onset of the study.

| Attributes | Cognitive Training Group | Control Group |
|------------|--------------------------|--------------|
|            | (N = 60) | SD | (N = 59) | SD | t statistics** |
| Age (in years) | 67.7 [60–87] | 5.8 | 68.3 [61–85] | 5.8 | 0.55 |
| Cognitive Reserve (Formal and informal education in years) | 19.6 [11–43] | 7.1 | 17.9 [11–46] | 7.7 | −1.25 |
| MMSE* | 28.4 [17–30] | 2.1 | 28.9 [23–30] | 1.4 | 1.24 |
| SEIQoL* | 73.2 [21 – 100] | 17.1 | 77.2 [47– 100] | 11.4 | −1.47 |
| Gender (N female;% female) | 38; 63.3% | | 37; 62.7% | Chi-Square 0.55 |

*MMSE = Mini-Mental State Examination, SEIQOL = Schedule for the Evaluation of Individual Quality of Life.

** None of the t or Chi-Square values reached statistical significance.

doi:10.1371/journal.pone.0101472.t001
doi:10.1371/journal.pone.0101472.t002
enhancement activities and provided informed consent. Individuals who scored <27 on MMSE or had corrected vision below 20/40 were excluded. Researchers were aware of group assignment. Except for 5 couples in the cognitive training group who trained at home, all study participants trained at the university laboratories. Cognitive group participants who trained at home were similar to those who trained in the lab on age, education and sex distribution ($t = -1.23$, $p = .22$, $t = -0.36$, $p = .97$ and Chi-Square = 2.83, $p = .09$, respectively). These subjects were included in the main analysis, but their cognitive outcome data was also used to verify the feasibility of home-based TV-delivered cognitive training. Both interventions were designed to be iTV compliant, lasted eight weeks and were delivered weekly in three 20 minute sessions, each containing 3 different activities. Demographic, cognitive and life satisfaction information was collected at the onset of the study for screening and group-equating purposes, and paper and pencil standardised cognitive tests were administered at the university laboratories before and after the intervention. Baseline and post-training scores were compared between and within the groups. System usability was evaluated at the end of the intervention period Cognitive Training Group Control Group

| Cognitive Training Group | Control Group |
|--------------------------|---------------|
| (N = 60)                 | (N = 59)      |
| Mean [Range]             | Mean [Range]  |
| SD                       | SD            |
| Total challenging mental activities in hours | 42.1 [0 – 263] | 47.2 [0 – 240] |
| Total physical activities in hours | 165.9 [14 – 486] | 150.5 [13 – 388] |

Table 3. Challenging mental and physical activities.

Table 4. Means, SDs, mean differences and Fs for the two groups at baseline.

| Cognitive Training Group N = 60 | Active Control Group N = 59 |
|----------------------------------|------------------------------|
| Mean SD                          | Mean SD                      |
| Mean Difference                  | F (df = 1.119)               |
| DSF 5.69 1.35                   | 5.92 1.21                    | –0.23 0.85                  |
| DSR 4.90 1.18                   | 4.93 1.34                    | –0.03 0.99                  |
| DST 10.62 2.18                  | 10.85 2.16                   | –0.23 0.28                  |
| TMT-A 48.42 19.37              | 46.35 13.40                  | 2.07 0.51                   |
| TMT-B 100.23 54.78             | 92.76 31.21                  | 7.47 1.03                   |
| TMT-T 148.65 69.15             | 139.10 41.14                 | 9.55 0.99                   |
| TONI-3 107.05 14.75            | 107.80 16.83                 | –0.75 0.08                  |
| WHO-5 64.53 20.27             | 67.36 16.56                  | –2.83 0.71                  |

doi:10.1371/journal.pone.0101472.t003
doi:10.1371/journal.pone.0101472.t004
validated Test of Nonverbal Intelligence [29]. TONI-3 also has the further benefit of being available in parallel forms, which means there are two versions of the test which are directly comparable with each other but which are distinct enough in their content to remove the possibility of learning or interference effects between baseline and post-training administrations.

Trail Making Test (TMT), parts A (TMT-A) and B (TMT-B) [30], measures executive functions, such as complex visual-motor conceptual screening, planning, organisation, abstract thinking and response inhibition [31]. Both the TMT-A and TMT-B versions were administered.

Digit span (DS) is a test of working memory [32]. The forward version (DSF) of this test is based on the presentation of a sequence of individual digits starting with 2 digits. On completion of presentation, participants repeat the digit sequence. The sequence length then increases following a correct response. The test continues until the longest sequence is failed twice. The reverse version (DSR) of the test has the same procedure as the forward one, except that participants respond with the sequence of digits in reverse order. Both the forward and backward versions were administered.

The well-being index (WHO-5) is a short screening instrument, compiled by the World Health Organisation, for the detection of depression in the general population and provides subjective ratings of current mental & physical wellbeing [33]. It was used to measure possible indirect effects of training. Each of the five items is rated on a 6-point Likert scale from 0 (= not present) to 5 (= constantly present). The theoretical raw score ranges from 0 to 25, higher scores mean better wellbeing.

iTv system usability was examined using the statement “Overall, I would rate the user-friendliness of this product as: Worst Imaginable/Awful/Poor/OK/Good/Excellent/Best Imaginable”.

Data processing

i. Statistical analyses. SPSS 17 [34] software package was used for statistical analyses. T-tests for independent samples and Chi-Square tests were used to determine differences in personal and demographic attributes between the two groups at baseline (Tables 2 and 3). Mixed effects models for repeated measures were used to evaluate differences within and between groups in the cognitive outcomes (DSF, DSR, Digit Span Total - DST, TMT-A, TMT-B, TMT Total – TMT-T, TONI-Test of non-verbal intelligence, 3rd ed., and WHO-5 Well-Being Index). A separate model was established for each variable. The models allowed us to assess differences in baseline scores between the two groups (Table 4), differences between baseline and post-training scores within each group (Tables 5 and 6), and whether any of the differences varied between the groups (Table 7). The independent variables included group (cognitive training or active control), time (baseline or post-training), and group by time interaction; the dependent variable was the cognitive outcome variable.

### Table 5. Baseline and post-training Means and SDs; mean differences and Fs for the cognitive training group.

| Cognitive Training Group | Baseline Mean N = 60 | SD | Post-training Mean N = 60 | SD | Mean Difference | F (df = 1.119) |
|--------------------------|----------------------|----|--------------------------|----|-----------------|---------------|
| DSF                      | 5.69                 | 1.35 | 6.87                     | 1.48 | 1.18             | 34.07***      |
| DSR                      | 4.90                 | 1.18 | 6.02                     | 1.33 | 1.12             | 35.11***      |
| DST                      | 10.62                | 2.18 | 12.89                    | 2.57 | 2.27             | 50.40***      |
| TMT-A                    | 48.42                | 19.37 | 39.85                    | 16.35 | −8.57           | 20.23***      |
| TMT-B                    | 100.23               | 54.78 | 81.90                    | 41.63 | −18.33          | 26.15***      |
| TMT-T                    | 148.65               | 69.15 | 121.75                   | 55.86 | −26.90          | 34.19***      |
| TONI-3                   | 107.05               | 14.75 | 111.77                   | 14.16 | 4.72             | 6.58*         |
| WHO-5                    | 64.53                | 20.27 | 65.80                     | 20.43 | 1.27             | 0.26          |

### Table 6. Baseline and post-training Means and SDs; mean differences and Fs for the active control group.

| Active Control Group | Baseline Mean N = 59 | SD | Post-training Mean N = 59 | SD | Mean Difference | F (df = 1.119) |
|----------------------|----------------------|----|--------------------------|----|-----------------|---------------|
| DSF                  | 5.92                 | 1.21 | 6.12                     | 1.35 | 0.27            | 1.73          |
| DSR                  | 4.93                 | 1.34 | 5.19                     | 1.24 | 0.27            | 1.86          |
| DST                  | 10.85                | 2.16 | 11.36                    | 2.35 | 0.52            | 0.10          |
| TMT-A                | 46.35                | 13.40 | 41.62                    | 14.07 | −4.73           | 6.05*         |
| TMT-B                | 92.76                | 31.21 | 85.26                    | 29.23 | −7.50           | 4.30*         |
| TMT-T                | 139.10               | 41.14 | 126.87                   | 39.14 | −12.23          | 6.94*         |
| TONI-3               | 107.80               | 16.83 | 108.88                   | 12.60 | 1.08            | 0.34          |
| WHO-5                | 67.36                | 16.56 | 71.53                     | 16.24 | 4.17             | 2.74          |

doi:10.1371/journal.pone.0101472.t005
doi:10.1371/journal.pone.0101472.t006
and time were categorical fixed factors, with the participant being the random factor.

ii. Missing values. We processed and analysed 1904 cognitive data points [119 participants × 8 total scores variables (obtained by summing up correct responses on individual items) per administration × 2 administrations]. Among the 1904 data points, 51 (2.6 per cent) had missing data. To prevent substantial loss of data from the data analysis owing to these missing data, and to be able to conduct a more stringent per-protocol analysis, using Cohen & Cohen procedure [35], the scores for the missing variables were plugged by deriving an individual predicted score based on an individual’s actual scores on the non-missing cognitive measures. The following steps were followed to predict missing scores. All the non-missing measures were entered as independent variables in a multiple regression analysis with the dependent variable being the missing variable. Predicted scores were then computed by multiplying each variable by its Beta weight and then adding up the products plus the constant. The 51 missing values were then replaced by their corresponding predicted scores. Pre-test scores were predicted based on pre-test measures for all participants. Post-test scores were predicted separately for each group, based on the group’s pre-test or post-test measurements.

Table 7. F statistics for the between group comparisons in the mixed models for repeated measures analysis.

|        | Mean Difference* | F (df = 1.119) | Cohen's d |
|--------|------------------|----------------|-----------|
| DSF    | 0.91             | 10.09**        | 0.58^    |
| DSR    | 0.85             | 10.26**        | 0.58^    |
| DST    | 1.75             | 14.83***       | 0.70^    |
| TMT-A  | −3.84            | 2.02           |          |
| TMT-B  | −10.83           | 4.53*          | −0.40^   |
| TMT-T  | −14.67           | 5.05*          | −0.40^   |
| TONI-3 | 3.64             | 1.94           |          |
| WHO-5  | −2.90            | 0.67           |          |

Comment to tables 4, 5, 6, and 7: DSF = Digit Span Forward, DSR = Digit Span Reverse, DST = Digit Span Total, TMT-A = Trail Making Test Part A, TMT-B = Trail Making Test Part B, TMT-T = Trail Making Test Total, TONI-3 = Test of non-verbal intelligence, 3rd ed., WHO-5 = WHO Well-Being Index.
1. Significance levels. * = significant at the level of 0.05. ** = significant at the level of 0.01. *** = significant at the level of 0.001.
2. Cohen’s d effect sizes. ^ = small-sized effect. ∩ = medium-sized effect.
3. TMT test. Lower scores indicate better performance.
doi:10.1371/journal.pone.0101472.t007

Figure 1. Baseline and post-training mean differences on the Digit Span.
doi:10.1371/journal.pone.0101472.g001
Results

Participants

Before controlled testing began, 12 participants withdrew due to time and health constraints; within the first week, at the beginning of baseline testing, another 9 withdrew due to disinterest or health problems. Thus 119 (85%) of enrolled participants completed the study (60 in the cognitive training group and 59 in the active comparator control group). Tables 2 and 3 show that both groups were comparable on the personal and demographic attributes measured at baseline, on cognitive reserve and on engagement in challenging mental and physical activities during the length of the intervention.

Baseline, Between-Group and Within-Group Differences

Tables 4, 5, 6 and 7 present mixed models statistics for working memory task (DSF, DSR and DST), executive control (TMT-A, TMT-B and TMT-T), non-verbal analogical reasoning (TONI 3) and life satisfaction (WHO-5) for the 119 participants (60 participants in the cognitive training group and 59 in the control group).

i. Groups performance at baseline. Table 4 shows that, at the onset of the study, the groups were equally competent on the selected outcomes.

ii. Within-group comparisons. Tables 5 and 6 and Figures 1, 2 and 3 present intervention gains for each group separately. A significant effect of cognitive training was observed within the cognitive training group (Table 5) for the working memory and executive control tasks at the alpha level of 0.00625, corrected for multiple comparisons. Within the active control group (Table 6) there was no significant effect, at the corrected alpha level of 0.00625. The corrected alpha level (0.00625) was obtained by dividing the traditionally accepted alpha level (0.05) by the number of comparisons (8 comparisons).

iii. Between-groups comparisons. Table 7 presents the main results of the experiment: the between-groups comparisons. The table shows that, when compared to the active control group, on pre to post intervention gain, the cognitive training group showed significant improvements on DSF, DSR, DST, and on TMT-B as well as TMT-T. Using the Mean Differences and their Standard Deviations, Cohen’s $d$ calculated for those cognitive abilities, fell in the small to medium range (Table 7).
System Usability

After eight weeks of cognitive training 68% of users rated the iTV system usability as “good” or “excellent”. All home users rated the iTV system as “good” or “excellent”, compared to 62% of lab users.

No significant 3-way (OUTCOME by GROUP [cognitive training vs. control group] by DEVICE [pointer vs. remote control]) interactions were observed when data were analysed to examine the contribution of pointer and remote control to DSF, DSR, DST, TMT-A, TMT-B, TMT-T or TONI-3 scores (df = 4,12) and F = 1.95, p = .22; F = 1.06, p = .39; F = 1.59, p = .18; F = 1.13, p = .32; F = 1.71, p = .15; F = 1.36, p = .10; F = 1.07, p = .38 respectively), suggesting that pointer and remote control were equally effective devices.

Personal diaries were collected from 104 [87.4%] participants, of which 36 (22 [44%] in the cognitive training group and 14 [26%] in the control group) indicated that using a computer represented a main challenge in their independent cognitive activities.

Discussion

This study aimed to design, implement and test iTV-delivered, user-friendly cognitive training that might improve fluid, higher-order cognitive function in persons aged 60 years or older. We found that, when compared to an active control group, the cognitive training group improved more than the control group on well validated tests of working memory and executive control and that 67% of lab participants and 100% of home users rated the iTV system user-friendliness as “good” or “excellent”. Also, it is of special interest that none of the participants left the study after the first week of baseline testing, indicating widespread acceptance of the iTV system and activities. To our knowledge, this is the first time that an engineered iTV system has enabled older people to engage autonomously in cognitive training in laboratory and home settings and has yielded improvements on well-known and well-validated untrained cognitive measures for the cognitive training group only. The findings provide evidence for the viability and usability of TV-based cognitive training, and add to the evidence base for computer-based cognitive training induced plasticity in healthy [13], [16] and frail [18], [22] older adults, and for the significant plasticity of their prefrontal control system [4]. Older people who could benefit from cognitive enrichment but cannot use or afford a computer can easily learn how to use their television set and a pointer or remote control to engage in cognitive training, a conclusion strengthened by other published data [36] and by informal observation. Our records show that, after installation of the iTV, home users required only one brief tutorial to use the iTV cognitive training autonomously for the length of the study. Support from a partner or relative could be an important motivating factor in this context [16]. The active control group showed improvement in life satisfaction at control were equally effective devices.

These results may have broad societal implications. A cognitively healthy population fuels economic growth and prosperity because people remain active in society longer and put less strain on health and social care systems [37], [38]. With rising life expectancy and age as the leading risk factor for cognitive decline and dementia and in view of the computer-literacy hurdles faced by older adults, TV-based cognitive training might help to prolong personal autonomy in people who do not use computers but own or have access to TV. Unlike computer literacy, which is strongly associated with age, income and education [7], the omnipresence of the TV set means that, regardless of socio-economic status, cognitive training may eventually reach the homes of older persons to enable maintenance and growth of cognitive function.

Acknowledgments

We thank David Cohen, Professor and Marjorie Crump Chair in Social Welfare, UCLA Luskin School of Public Affairs for his critical discussion and reading of the manuscript. Authors would like to thank all Vital Mind project members from the Philips Consumer Products Innovative Lab, Czech Technical University in Prague, University of Genoa, Czech TV, University of Dundee, University of Hradec Králové, Goldsmith College in London, and CogniFit, the coordinator, for their valuable contribution to the project.

Supporting Information

Data S1 VitalMind_DATA_S1.sav comprises anonymised data gathered during the experiment.

Plugged Data S1 S_VitalMind_PLUGGED_DATA_S1.sav contains adjusted data used for analyses (as described in the section Missing values).

Cognitive Training Programme S1 Cognitive training programme_S1.docx lists names and descriptions of tasks in the cognitive training programme.

Author Contributions

Conceived and designed the experiments: ES JM VB. Performed the experiments: JM VB. Analyzed the data: ES JM. Contributed reagents/materials/analysis tools: FB. Wrote the paper: ES JM VB FB.

References

1. Craik FIM, Bialystok E (2006) Cognition through the lifespan: mechanisms of change. Trends Cogn Sci 10: 131–138.
2. Jones HE, Conrad HS (1933) The growth and decline of intelligence: a study of a homogeneous group between the ages of ten and sixty. Genet Psychol Monogr 15: 223–298.
3. Papp KV, Walsh SJ, Snyder PJ (2009) Immediate and delayed effects of cognitive interventions in healthy elderly: a review of current literature and future directions. Alzheimers Dement 5: 50–60.
4. Anguera JA, Boccanfuso J, Rintoul JL, Al-Hashimi O, Faraji F, et al. (2013) Video game training enhances cognitive control in older adults. Nature 501: 97–101.
5. Buiza C, Gonzalez MF, Facal D, Martinez V, Diaz U, et al. (2009) Efficacy of cognitive training experiences in the elderly: Can technology help?. Lect Notes Comput Sci 5614: 324–333.
6. Charness N, Boot WR (2009) Aging and Information technology use: Potential and barriers. Curr Dir Psychol Sci 18: 253–258.
7. Neves BB, Amaro F, Fonseca JRS (2013) Coming of (Old) Age in the Digital Age: ICT Usage and Non-Usage Among Older Adults. Sociol Res Online 18(2):6.

8. Seybert H (2011) Internet use in households and by individuals in 2011: Industry, trade and service. Eurostat statistics in focus 66/2011. Available: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-11-066/EN/KS-SF-11-066-EN.PDF. Accessed 9 April 2014.

9. McMurtry ME, McGaughey RE, Downey JP, Zeltmann SM (2011) Seniors and information technology: results from a field study. J Comput Inform Syst 51: 22–30.

10. Nap HH, De Greef HP, Bouwhuis DG (2012) Self-efficacy support in senior computer interaction. Int J Cogn Perform Support 1: 27–39.

11. Eurostat (2012) Media Use in the European Union. Standard Eurobarometer 78. Available: http://ec.europa.eu/public_opinion/archives/eh/eb78/eb78_media_en.pdf. Accessed 9 April 2014.

12. Valezuela MJ, Sachdev P, Randek T, Bennett DA (2006) Cognitive leisure activities, but not watching TV, for future brain benefits. Neurology 67: 729–735.

13. Gawlinski M (2003) Interactive Television Production. Oxford: Focal Press. 288 p.

14. Lee B, Chen Y, Hewitt L (2011) Age differences in constraints encountered by seniors in their use of computers and the internet. Comput Hum Behav 27: 1231–1237.

15. Petret C, Korczyn AD, Shatil E, Aharonson V, Birmboim S, et al. (2011) Computer-Based, Personalized Cognitive Training versus Classical Computer Games: A Randomized Double-Blind Prospective Trial of Cognitive Stimulation. Neuropsychirolgy 36: 91–99.

16. Shatil E (2013) Does combined cognitive training and physical activity training enhance cognitive abilities more than either alone? A four-condition randomized controlled trial among healthy older adults. Front Aging Neurosci 5: 8.

17. Gigler KL, Blomeke K, Shatil E, Weintraub S, Reber PJ (2013) Preliminary evidence for the feasibility of at-home online cognitive training with older adults. Gerontechnology 12(1): 26–35.

18. Haimov I, Shatil E (2013) Cognitive Training Improves Sleep Quality and Cognitive Functioning among Older Adults with Insomnia. PLoS One 8: e61390.

19. Preiss M, Shatil E, Cermakovska R, Cimermannova D, Flesher I (2013) Personalized cognitive training in unipolar and bipolar disorder: a study of cognitive functioning. Front Hum Neurosci 7: 108.

20. Horowitz-Kraus T, Breznitz Z (2009) Can the error detection mechanism enhance cognitive abilities more than either alone? A four-condition randomized controlled trial among healthy older adults. Front Aging Neurosci 5: 8.

21. Shatil E, Metzer A, Horvitz O, Miller A (2010) Home-based personalized cognitive training in MS patients: A study of adherence and cognitive performance. NeuRehabilitation 26: 143–153.

22. Verghese J, Mahoney J, Ambrose AF, Wang C, Holtzer R (2010) Effect of Cognitive Remediation on Gait in Sedentary Seniors. J Gerontol A Biol Sci Med Sci 65: 1338–1343.

23. Haimov I, Hanuka E, Horowitz Y (2008) Chronic insomnia and cognitive functioning among older adults. Behav Sleep Med 6: 32–54.

24. Thompson HJ, Demiris G, Rue T, Shatil E, Wilamowska K, et al. (2011) A Holistic approach to assess older adults’ wellness using e-health technologies. Telemed J E Health 17: 794–800.

25. Klepeva V (2007) How to Form and Strengthen Your Body on a Chair (with Brain Jogging Included). Brno: Computer Press. 152 p.

26. O’Boyle CA, McGee H, Hickey A, Joyce CEB, Browne J (1993) The Schedule for the Evaluation of Individual Quality of Life (SEIQoL): Administration Manual. Dublin: Royal College of Surgeons in Ireland.

27. Krivolavá J (2009) Psychology of Health. Published in Czech. Prague: Portál. 280 p.

28. Folstein MF, Folstein SE, McHugh PR (1975) “Mini-mental state”: A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 123(3): 189–198.

29. Brown L, Sheberon RJ, Johnson SK (1997) Test of Nonverbal Intelligence (3rd ed.). Austin, TX: PRO-ED. 142 p.

30. Reitan RM (1986) Trail Making Test: Manual for Administration and Scoring. Tucson: Reitan Neuropsychological Laboratory. 10 p.

31. Cangoz B, Karakoc E, Selekler K (2009) Trail Making Test: Normative data for Turkish elderly population by age, sex and education. J Neurol Sci 283(1–2): 73–78.

32. Strauss E, Sherman EMS, Spreen O (2006) A compendium of neuropsychological tests: Administration, norms, and commentary (3rd ed.). Oxford: Oxford University Press. 1240 p.

33. Strauss E, Spreen O (2006) A compendium of neuropsychological tests: Administration, norms, and commentary (3rd ed.). Oxford: Oxford University Press. 1240 p.

34. Bonsignore M, Barkow K, Janssen F, Heun R (2001) Validity of the five-item WHO Well-Being Index (WHO-5) in an elderly population. Eur Arch Psychiatry Clin Neurosci 251: 27–31.

35. Tabachnick BG, Fidell LS (2013) Using multivariate statistics. 6th ed. Boston: Pearson. 1024 p.

36. Cohen J, West SG, Aiken LS (2002) Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences (3rd ed.). Mahwah, NJ: Lawrence Erlbaum. 736 p.

37. Buret V (2012) Interactive digital television and voice interaction: experimental evaluation and subjective perception by elderly. Electron Elektrotech 6: 87–90.

38. Mikulecky P (2012) User adaptivity in smart workplaces. Letz Notes Comput Sci 7197: 401–410.

39. Krejcar O, Jancilek D, Motolova L (2009) Complex Biomedical System with Mobile Clients. IFMBE Proc 25: 141–144.