Playful Cognitive Training with Physical Interactive Tiles for Elderly

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***Abstract*—We propose novel cognitive training which focuses on certain specific cognitive abilities. The training is formed by playing games with physical interactive tiles (the MOTO tiles). A randomized controlled trial was conducted so as to examine the effect of the designed cognitive training program. 19 older adults (some with mild dementia) completed full trial and were analyzed. The results show that our short training (10 sessions of 30 minutes) improved reaction time of Visual Search task, which indicates beneficial effects on attention, scanning and visualization abilities**

Keywords—playware, cognition, exergaming, cognitive training

I. INTRODUCTION

Aging is a pervasive issue in modern society. One serious consequence of aging process is the decline of cognitive functioning. In order to prevent or reduce the decline of cognition, there were myriad attempts to discover training paradigms that are beneficial to human cognition. Most of the effective trainings were specific cognitive trainings [1], namely trainings that focus on a particular cognitive ability. Such trainings often results in improvement of cognitive tasks that are very similar to the training, but rarely show benefit to other cognitive tasks.

Apart from specific trainings, there were also researches showed that some training paradigms, such as video game training, musical training, and physical training can produce positive effect on general cognitive functioning [1]. However such evidence is much less than specific trainings. In the physical domain, Groot et al. [2] conducted a meta-analysis and concluded that physical activities could positively influence cognitive abilities of dementia patients.

Based on the evidence that specific trainings and physical activities are able to produce beneficial effects on cognitive function. We propose a novel physical cognitive training which perform specific training by a playful physical interactive manner. The training was implemented by the MOTO tiles, a typical modular playware. The MOTO tiles is a distributed system consisting of 10 slave tiles and a master tablet. Users use the tablet to control and check results of games. Each tile has a pressure sensor and 8 LEDs which can be lighted up in rainbow colors. The tiles communicate with the tablet via ANT protocol. Fig. 1 shows a number of MOTO tiles combined together. However, since the tiles are controlled by the tablet wirelessly, the tiles can also be setup separately and thus there are infinite possibilities of the setup of the MOTO tiles.

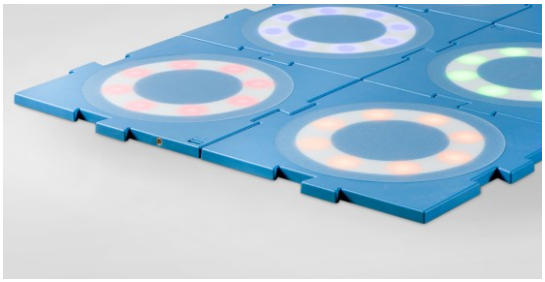

Fig. 1. The MOTO tiles.

Based on the theories of cognitive learning and transfer, we develop a MOTO tile training program which focuses on attention, reaction, and memory abilities. The training consists of 5 games specifically for different cognitive abilities. The games are played by stepping on the tiles and therefore the training is also a physical exercise. A randomized controlled trial was conducted in Shanghai in collaboration with an elderly care company i-Zhaohu for the evaluation of the effect of the designed training program for seniors (avg. 81 years old, including a few with mild dementia).

II. MOTO TILE GAMES

Most contemporary researches of cognitive training showed that training of a cognitive task can only improve the performance of cognitive tasks very similar to the training task [3]. One widely accepted method to judge whether two cognitive tasks are similar is to apply taxonomy [4]. Carroll's three-stratum model [5] is one of the most famous model for this purpose. A schematic diagram of the model is shown in Fig. 2. The model divides human cognition into three levels: one general intelligence (stratum III), nine broad abilities (stratum II), and 63 narrow abilities (stratum I). If two cognitive tasks involve the similar abilities, they can be regarded as similar task and therefore training of one task can potentially improve the performance of the other task.

Based on the theories described above, we develop five MOTO tile games prepared for different cognitive abilities. The descriptions of the games are listed below:

Special One: One tile lights up in a special color (another color than the rest of the tiles). Player will step on this special tile. Then all colors will change and next round will begin.

Special Pattern: One tile lights up in a special pattern (four LEDs lighted up, while the rest of the tiles have eight LEDs lighted up). Player will step on this special tile. Then the special tile will change and next round will begin.

Final Countdown: All tiles light up in red. The tiles will count down by turning off one LED in sequence. Player will keep light in all tiles by pressing on them before any tile count down to zero.

Simon Says: The tiles light up in a specific sequence, starting with one tile. Player will press on the tiles in the same sequence as they were shown, in order to reach next round. A new tile will be added to the sequence for each round.

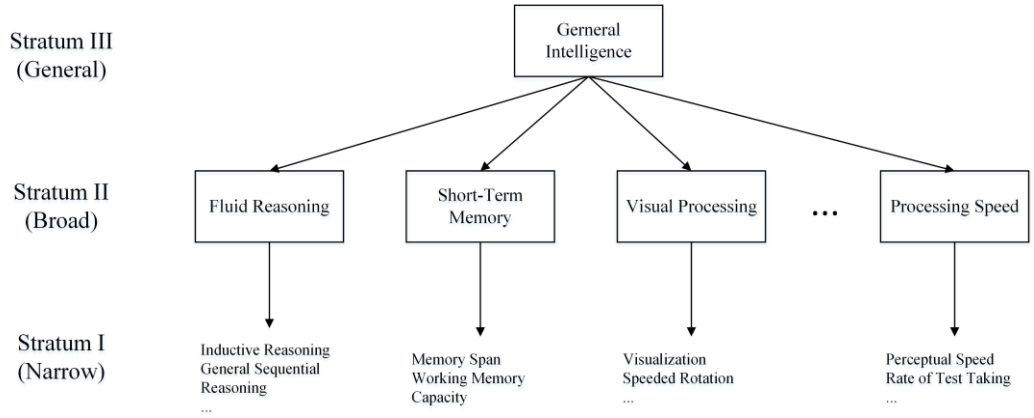

Fig. 2. The three-stratum mode.

Pattern Memory: A certain number of tiles will light up for one second. Player has to remember the lighted tiles, and then presses these tiles. For each iteration, correct presses of all lighted tile will gain one point; wrong press will gain no point.

The game Special One and Special Pattern entail similar cognitive abilities. In the visual processing category, the two games utilize the following narrow abilities: visualization, flexibility of closure and spatial scanning. In the processing speed category, the two games utilize the following narrow abilities: perceptual speed and rate-of-test-taking.

The cognitive abilities involved by the game Final Countdown are similar to Special One and Special Pattern, since all the three games are essentially searching for particular tile (i.e., a special tile or tiles whose LEDs are almost counted down). However, note that players may be able to find a walking pattern which can be used repeatedly so that the tiles can be kept light. Therefore, Final Countdown can also involve a narrow ability inductive reasoning, which is the core of the broad ability fluid reasoning.

Both Simon Says and Pattern Memory are memory games that aim to enhance short-term memory ability. There are two narrow abilities that belong to short-term memory: memory span and working memory capacity. Both are involved in the two games.

III. Outcome Measures

In the last section, it has been mentioned that the chosen MOTO tile games will entail three broad abilities: visual processing, processing speed, and short-term memory. Three games are chosen for training visual processing and processing speed, and two games are chosen for short-term memory. Since the abilities visual processing and processing speed are trained together, they are regarded as a combined outcome construct. Hence we need to measure two outcome constructs: one for visual processing and processing speed, and the other for short-term memory. Clearly, more measures of a construct will result in more accurate results. However, due to the fact that the subjects of this trial are elderly people, and it is not feasible to ask them perform too many tests in a short time, we selected only two cognitive tests for each outcome construct. For visual processing and processing speed, Choice Reaction Time (CRT) and Visual Search (VS) will be used to evaluate the outcome. For short-term memory, n-back test and Match to Sample (MTS) will be applied. These tests will be introduced in the following subsections.

A. Choice Reaction Time

In the CRT task, subjects are required to determine which of two possible stimuli is presented. There are many variations of the choices in CRT task, such as four-choice [6] and three-dimensional objects [7]. However, previous research showed that those variations will not affect the RT, provided that subjects have sufficient practice [8]. Thus, the basic color discrimination CRT (blue/red) was used in the trial.

In 1960, Bertelson and Boons [9] found that the RT can be influenced by the uncertainty of the time intervals between stimuli. Apparently, when the interval is a constant, it is possible to anticipate the timing of the coming stimulus, and thus get better preparation to the stimulus. Therefore, in this study, the time interval was a random number varying between one to two seconds.

Compared with simple reaction time test where subjects simply need to react to a repeated stimuli, CRT also requires the decision making and processing abilities [9]. In the case of color discrimination, it indicates the utilization of Visualization, Perceptual Speed, and Rate-of-Test-Taking, which is well matched to the MOTO tile games for visual processing and processing speed.

B. Visual Search

In a VS task, typically a number of items are displayed to subjects. Then subjects determine if a specific target is presented or not among irrelevant non-targets. The VS task has been a critical tasks in visual attention study for over 40 years [10]. There are two common types of VS task: feature search where the target is defined by a particular feature, such as a specific letter or color, and conjunction search where the target is defined by conjunctions of two different features, such as a particular letter with a particular color.

In this trial, we conducted both the feature search and conjunction search tasks. Each task consists of 18 stimuli. For the feature search, targets were a cross "×", and non-targets were circle "O" and plus sign "+". For the conjunction search, targets were red "+" or blue "O", and non-targets were blue "+" and red "O".

C. N-back Test

In n-back tests, subjects are required to respond to a series of stimuli, and judge if the current stimuli is the same as the one presented n steps before. In most studies of n-back tests, n varied from 0 to 3. When n equals to 0, the task is actually to respond if a predefined target is presented.

In our trial, in order to match the abilities of the elderly, the test was designed on the basis of a previous n-back test for mild cognitive impairment and elderly depression [11]. We applied a 1-back test. The possible stimuli were numbers 1, 2, 3, and 4. Each stimuli lasted for 1.8 s. Totally 20 stimuli were displayed and subjects had to react to the last 19 stimuli.

D. Match to Sample

In the MTS tests, a stimulus is presented to subjects. After a delay, two or more options are presented. Typically, the stimuli are matrix filled by different colors. Subjects have to determine which of them matches the original stimuli.

The MTS test of this trial was designed according to previous research [12], which analyzed how the matrix size and delay time affected the performance on MTS. We selected parameters so that subjects can get moderate score and have some room to improve. The MTS test was 4×4 matrix filled by blue and red, 1 s stimuli, 3 s delay, and two options for choice. Totally 15 stimuli were presented to each subject.

IV. Design of the Trial

The trial was conducted in cooperation with an elderly care company i-Zhaohu from 14. May 2018 to 16. June 2018. Participants took the cognitive tests described in the last section before and after the training program as pre- and post-tests. In addition, we conducted a measure of expectation after the pre-test in order to eliminate the placebo effect caused by different expectation [13]. In the measure of expectation, subjects answered their expectation of the overall performance of the cognitive tests by 3-item Likert-type scale. The three items were "no effect", "may produce effect", and "must produce effect".

The intervention included 10 sessions of the MOTO tile training. In each session, subjects played the games in the following sequence:

- Special One, 1 minute
- Special Pattern, 1 minute
- Final Countdown, slow, 1 minute
- Pattern Memory, 20 iterations
- Special One, 1 minute
- Special Pattern, 1 minute
- Final Countdown, slow, 1 minute
- Simon Says, 5 minutes

The session was designed such that reaction/attention games and memory games were played alternately. The game Special One can be replaced by one more Special Pattern for subjects who have difficulty in distinguish colors. There were one-minute breaks between each games. The breaks can be extended depending on subjects' physical state.

The control condition of this trial was a routine table games program provided by i-Zhaohu. The number of sessions and duration of each session were the same as the MOTO tile intervention.

V. Results

Totally 37 older residents of i-Zhaohu were recruited. Three of them refused to participate, and 15 were excluded because of meeting exclusion criteria. The rest were randomly assigned to the intervention group (n = 10) and the control group (n = 9).

Before comparing the performance of the intervention and the control group, the baselines of the two groups were compared by the Mann–Whitney U test. The ages and all performance of the cognitive tests were comparable except the accuracy of n-back. The control group performed better than the intervention group in terms of the accuracy of n-back test. In addition, the measure of expectation showed that the expectation of the intervention and control condition were also comparable, which meant the outcome measures had little chance to be influenced by placebo effects.

The changes of the performance from the pre-test to the post-test with related statistical analyses are shown in Table I. Again the Mann–Whitney U test was applied for the comparison. For a regular significance level $\alpha = 0.05$, significant difference can be observed in the RT of VS feature, the RT of VS conjunction, and the accuracy of n-back. However, since the baselines of the accuracy of n-back of the intervention group and the control group did not match each other, it is not credible to conclude that the intervention outperformed the control condition in terms of the n-back test.

In order to eliminate the bias due to the mismatch of the baselines, ANCOVA was applied to reanalyze the n-back test. The results showed that the difference between the intervention group and the control group was not significant after controlling for the pre-test performance ($\alpha = 0.05,\ p = 0.63$).

VI. Discussion & Conclusion

In this paper, we proposed a physical cognitive training program implemented by the MOTO tiles. The training was designed based on theories of cognitive transfer. The training could be beneficial to cognitive abilities from both the aspects

TABLE I. OUTCOME MEASURES AND RESULTS OF STATISTICAL TESTS.

Test	**Measure**	**Intervention group**		**Control group**		***p*-value**
		Change (Mean (±) SD)	***Percentage change (%)***	***Change (Mean (±) SD)***	***Percentage change (%)***	
CRT	RT (ms)	-109.519 (±) 774.038	-6.45	204.735 (±) 829.118	13.26	0.274
	Accuracy	0.040 (±) 0.140	4.58	0.022 (±) 0.054	2.33	0.516
n-back	RT (ms)	230.028 (±) 605.540	20.47	-31.464 (±) 438.160	-2.79	0.121
	Accuracy	0.168 (±) 0.250	24.62	-0.041 (±) 0.146	-4.70	0.027
VS feature	RT (ms)	-2422.611 (±) 1785.250	-39.30	402.809 (±) 1903.867	7.94	0.003
	Accuracy	0.150 (±) 0.151	20.30	0.093 (±) 0.134	11.45	0.330
VS conjunction	RT (ms)	-1970.661 (±) 2438.944	-31.31	829.432 (±) 1135.218	14.31	0.005
	Accuracy	0.039 (±) 0.183	5.07	-0.068 (±) 0.157	-8.03	0.139
MTS	RT (ms)	390.240 (±) 1006.003	10.58	-420.963 (±) 2596.823	-7.89	0.200
	Accuracy	0.053 (±) 0.171	7.92	0.000 (±) 0.204	0.00	0.139

of specific training and physical training. Moreover, the essence of game can also motivate participants to train themselves.

During the trial, we noticed some issues that might bring negative results. A common issue was that the elderly sometimes had difficulty to switch between different games. For example, after playing the Special Pattern game, when switching to the Final Countdown, some of them might still look for a tile with four LEDs on, even though they were told that this was a new game and the rule of the game was clearly illustrated. Besides, some participants could hardly understand the memory games Simon Says and Pattern Memory, which would made the training frustrating for both the elderly and caregivers. The reason for the above issues could be attributed to the decline of the abilities of the participants. Three of the analyzed subjects had mild dementia. For the remaining participants, even though qualitative diagnoses did not show that they had dementia, considering the average age of the population (81.7 years old), many of them could also have small extent of cognitive impairment but just under the criteria of mild dementia. Therefore, future training program could be designed based on the cognitive ability of target users. For those who have relatively good cognitive ability, multiple games including memory games can be assigned. For those whose cognitive ability has declined, they could simply play some intuitive games such as Color Race and Special One. The games could also be repeated for a number of times rather than switching between different games.

The statistical analyses of the cognitive tests revealed that the intervention group outperformed the control group in the RTs of VS feature and VS conjunction. Indeed, the intervention group increased RT by average 39% and 31% (and accuracy by average 20% and 5%) respectively in the two VS tests. Due to mismatched baseline in the pre-test of the accuracy of the n-back test, it was reanalyzed by ANCOVA which took the pre-test performance into account. The result of ANCOVA indicated that there was no significant difference though direct comparison showed significant difference. ANCOVA used linear regression to eliminate the effect of covariates, but how pre-test correlated to the changes of performance was not clear, so there still can be small possibility that there was significant difference in the accuracy of the n-back test (where the intervention group increased accuracy by average 25% compared to the control groups decrease of 5%). However, since the analysis should be rigorous, we must regard it insignificant based on current evidence.

The results of the trial somewhat matched the transfer theories described in Section II. Since many subjects did not understand the memory games very well, we could estimate that their improvement in the memory games was little, and consequently there should be even less transfer effects on the memory tests. By contrast, most subjects enjoyed the attention games (e.g., special one), which resulted in significant transfer to the VS task whose objective is similar to the attention games (i.e., searching for a special target).

Previous studies proved that aerobic exercises could produce positive effects on cognitive abilities as described in Section I, which leads to a question: was the improvement resulted from the games themselves, or the fact that the play of MOTO tiles is a kind of aerobic exercise? In some recent reviews [2, 14] , aerobic exercise could be beneficial to the overall cognitive abilities, including memory, processing speed, etc. Thus, we could infer that the effect of aerobic exercise was insignificant as the improvement in memory tasks was not observed. The inconsistency to the previous theories might be due to the short time frame of the training. Among those studies where aerobic exercises were effective, the minimal training duration was 9 weeks [15], whereas in this study the duration was only about 2 weeks. Further research may conduct a longer trial in order to obtain the effects of aerobic exercise.

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REFERENCES

[1] C. S. Green and D. Bavelier, "Exercising your brain: a review of human brain plasticity and training-induced learning," *Psychology and aging,* vol. 23, p. 692, 2008.

[2] C. Groot, A. Hooghiemstra, P. Raijmakers, B. Van Berckel, P. Scheltens, E. Scherder*, et al.*, "The effect of physical activity on cognitive function in patients with dementia: a meta-analysis of randomized control trials," *Ageing research reviews,* vol. 25, pp. 13-23, 2016.

[3] D. J. Simons, W. R. Boot, N. Charness, S. E. Gathercole, C. F. Chabris, D. Z. Hambrick*, et al.*, "Do "brain-training" programs work?," *Psychological Science in the Public Interest,* vol. 17, pp. 103-186, 2016.

[4] S. M. Barnett and S. J. Ceci, "When and where do we apply what we learn?: A taxonomy for far transfer," *Psychological bulletin,* vol. 128, p. 612, 2002.

[5] J. B. Carroll, *Human cognitive abilities: A survey of factor-analytic studies*: Cambridge University Press, 1993.

[6] W. Scott, J. Whitwam, and R. Wilkinson, "Choice reaction time: A method of measuring postoperative psychomotor performance decrements," *Anaesthesia,* vol. 38, pp. 1162-1168, 1983.

[7] R. N. Shepard and J. Metzler, "Mental rotation of three-dimensional objects," *Science,* vol. 171, pp. 701-703, 1971.

[8] G. Mowbray and M. Rhoades, "On the reduction of choice reaction times with practice," *Quarterly Journal of Experimental Psychology,* vol. 11, pp. 16-23, 1959.

[9] P. Bertelson and J.-P. Boons, "Time uncertainty and choice reaction time," *Nature,* vol. 187, p. 531, 1960.

[10] J. M. Wolfe, "What can 1 million trials tell us about visual search?," *Psychological Science,* vol. 9, pp. 33-39, 1998.

[11] A. Borkowska, W. Drożdż, P. Jurkowski, and J. K. Rybakowski, "The Wisconsin Card Sorting Test and the N-back test in mild cognitive impairment and elderly depression," *The World Journal of Biological Psychiatry,* vol. 10, pp. 870-876, 2009.

[12] W. Phillips, "On the distinction between sensory storage and short-term visual memory," *Perception & Psychophysics,* vol. 16, pp. 283-290, 1974.

[13] W. R. Boot, D. J. Simons, C. Stothart, and C. Stutts, "The pervasive problem with placebos in psychology: Why active control groups are not sufficient to rule out placebo effects," *Perspectives on Psychological Science,* vol. 8, pp. 445-454, 2013.

[14] J. M. Northey, N. Cherbuin, K. L. Pumpa, D. J. Smee, and B. Rattray, "Exercise interventions for cognitive function in adults older than 50: a systematic review with meta-analysis," *Br J Sports Med,* pp. bjsports-2016-096587, 2017.

[15] W. J. Bossers, L. H. van der Woude, F. Boersma, T. Hortobágyi, E. J. Scherder, and M. J. van Heuvelen, "A 9-week aerobic and strength training program improves cognitive and motor function in patients with dementia: a randomized, controlled trial," *The American Journal of Geriatric Psychiatry,* vol. 23, pp. 1106-1116, 2015.