AUTODIDACTIC COGNITIVE TRAINING DEVICE AND METHOD THEREOF

FIELD OF INVENTION

[1] The invention relates generally to an autodidactic cognitive training device and method thereof.

BACKGROUND

[2] Memory loss is a common neurodegenerative condition that comes with aging. It is especially so for patients diagnosed with dementia, which is a set of signs and symptoms affecting the cognitive functions of memory. One such example of dementia is Alzheimer's diseases. Approved drugs are used on patients with Alzheimer's diseases but they do not cure or prevent the symptoms. Therefore, alternative interventions are called for to treat the memory loss of the patients.

[3] Trans-cranial direct current stimulation (tDCS) is one such alternative intervention. It is a neuromodulatory method that delivers low-intensity, direct current to cortical areas facilitating or inhibiting spontaneous neuronal activity. However, since tDCS elicits after-effects lasting for up to an hour, it may in some instances cause unnecessary side-effects to the cognitive functions of the subject.

[4] With the existing techniques and tools, it is difficult to provide a personalized memory training system that meets the needs of the subject. Each subject has a different degree of affected memory functions, i.e., a patient of dementia may exhibit two or more dementing processes at the same time.

[5] It is also possible for a subject to advance in the dementing processes at a different rate, making it difficult to provide an objective assessment of the cognitive functions of memory. An objective cognitive assessment will be helpful to provide a personalized training program to aid in the training of the cognitive functions of a subject.

[6] A need therefore exists to provide an objective cognitive assessment which can be used to provide a personalized memory training program.

SUMMARY

[7] According to a first aspect, there is provided a method for cognitive training, the method comprising obtaining sensor data of a subject during a memory exercise; determining whether the sensor data includes predetermined information indicative of cognitive functions used for remembering; advancing the memory exercise when it is determined that the sensor data includes predetermined information indicative of cognitive functions used for remembering; and calculating an objective cognitive assessment of the subject in response to completion of the memory exercise, wherein cognitive training is measured at least partially in response to the advancing the memory exercise.

[8] According to a second aspect, there is provided an autodidactic cognitive training device comprising an input device for receiving the sensor data of a subject during a memory exercise; a cognitive function evaluator adapted to receive the sensor data from the input device and determine whether the sensor data includes predetermined information indicative of cognitive functions used for remembering; an exercise device adapted to advance the memory exercise when it is determined that the sensor data includes the predetermined information indicative of cognitive functions used for remembering, the exercise device comprising a calculating device adapted to calculate an objective cognitive assessment of the subject in response to completion of the memory exercise.

[9] According to a third aspect, there is provided a system comprising two or more devices according to the second aspect as described above wherein the receiver is further operable to receive the objective cognitive assessment of two or more subjects corresponding to the two or more devices and the server operable to correlate the two or more subjects with their respective objective cognitive assessments.

BRIEF DESCRIPTION OF THE DRAWINGS

[10] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[11] Figure 1 shows a flowchart that illustrates a method for cognitive training according to a first embodiment;

[12] Figure 2 shows an autodidactic cognitive training device, according to a second embodiment;

[13] Figure 3 shows a picture of a setup for brain computer interface training;

[14] Figure 4 shows a plan view of a memory exercise;

[15] Figure 5 shows a graphical representation of the change in difficulty level and the time taken;

[16] Figure 6 shows a graphical representation of the change in number of cards and the difficulty level;

[17] Figure 7 shows a block diagram of autodidactic cognitive training devices in a system.

DETAILED DESCRIPTION

[18] Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

[19] Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as "scanning", "calculating", "determining", "replacing", "generating", "initializing", "outputting", or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the

computer system into other data similarly represented as physical quantities within the computer system or other information storage, transmission or display devices.

[20] The present specification also discloses apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes, or may comprise a general purpose computer or other device selectively activated or reconfigured by a computer program stored in the computer. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate. The structure of a conventional general purpose computer will appear from the description below.

[21] In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that the individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the disclosure contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer program, which can use different control flows without departing from the spirit or scope of the invention.

[22] Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a computer program may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with a general purpose computer. The computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or wireless medium such as exemplified in the GSM mobile telephone system. The computer program when loaded and executed on such a general-purpose computer effectively results in an apparatus that implements the steps of the preferred method.

[23] The invention may also be implemented as hardware modules. More particular, in the hardware sense, a module is a functional hardware unit designed for use with other components or modules. For example, a module may be implemented using discrete

electronic components, or it can form a portion of an entire electronic circuit such as an Application Specific Integrated Circuit (ASIC). Numerous other possibilities exist. Those skilled in the art will appreciate that the system can also be implemented as a combination of hardware and software modules.

[24] Figure 1 shows a flowchart 100 that illustrates a method for cognitive training according to a first embodiment. This methodology provides cognitive training for a subject in a personalized manner.

[25] In step 102, sensor data relating to a subject is obtained. In step 104, it will be determined whether or not the sensor data includes predetermined information indicative of cognitive functions used for remembering. In an embodiment, the sensor data could come from physiological and / or behavioral sensor. In another embodiment, the sensor data could come from video camera and / or electroencephalography (EEG) electrode. In step 106, the memory exercise is advanced. In step 108, it will be determined whether or not the memory exercise is completed. In step 110, an objective cognitive assessment is calculated.

[26] In step 104, the obtained sensor data from step 102 will be compared with predetermined information indicative of cognitive functions used for remembering to determine whether or not the sensor data includes the predetermined information. The presence of the predetermined information indicates that the subject is using cognitive functions for remembering.

[27] When it is determined that the sensor data includes predetermined information indicative of cognitive functions used for remembering, the memory exercise will advance in step 106. In the event that it is determined that the sensor data does not include predetermined information indicative of cognitive functions used for remembering, step 104 will be repeated until it is determined that the sensor data includes the predetermined information indicative of cognitive functions for remembering.

[28] The determining step includes determining when a predetermined portion of the memory exercise is completed in predetermined time duration. In one instance, an indicator is provided to illustrate to the subject the progress of completing the portion of the memory exercise within the predetermined time duration. The indicator may be a visual signal, light signal or an audio signal. In the event that the portion of the memory exercise

is not completed within the predetermined time duration, step 104 will be repeated and the indicator will indicate the same to the subject.

[29] The determining step includes whether a score is achieved for a current level of the memory exercise in step 104 before the memory exercise will advance in step 106. The score is taken based on several parameters, i.e., time taken to complete the memory exercise, the complexity and difficulty of the exercise, accuracy of the subject, profile and condition of the subject. The score can be adjusted according to the requirements of the subject. The score indicates a measure of the cognitive function used for remembering when at least a portion of the memory exercise is completed.

[30] In step 108, it is determined whether the memory exercise is completed. When it is determined that the memory exercise is completed, step 110 is invoked. The results from step 110 provide for a value that is an objective assessment of the cognitive ability for remembering of the subject, based on documented parameters suitable for the subject and the performance of the subject during the exercise, i.e., time taken to complete the exercise and the accuracy. The objective cognitive assessment obtained in step 108 can be used to adjust the predetermined information that is used in the determining step 104.

[31] The performance of the subject for the completed memory exercise will be assessed in response of the calculated objective cognitive assessment. The subject profile will be updated accordingly in response to the objective cognitive assessment. This allows the clinical professionals to keep track of the progress of the training.

[32] The memory exercise is then configured in response to the objective cognitive assessment of the subject and the subject profile. This provides a personalized cognitive training method for the subject in accordance to the condition and needs of the subject. The predetermined information that is used in the determining step will also be adjusted accordingly. If the subject has completed the memory exercise before the expected time duration, the predetermined duration that is used in determining whether the sensor data includes the predetermined information will be shortened and the reverse applies. If the subject were to take a longer time to complete the memory exercise than expected, the predetermined information that is used in analyzing the sensor data will be adjusted accordingly. In this manner, a personalized memory exercise will be provided.

[33] Figure 2 shows an apparatus 200, according to a second embodiment for cognitive training. Sensor data is acquired via an input device 203. An example of the input device 203 is an electrode that is attached to the forehead of the subject, as illustrated in Figure 3. In one embodiment, the input device 203 could be physiological and / or behavioral sensor. In another embodiment, the input device 203 could be a video camera and / or electroencephalography (EEG) electrode.

[34] The input device 203 is arranged to be coupled to the cognitive function evaluator 206. The cognitive function evaluator 206 is adapted to determine whether the sensor data includes predetermined information indicative for remembering.

[35] The cognitive function evaluator 206 is further adapted to determine when a predetermined portion of the memory exercise is completed in predetermined time duration. In one instance, an indicator is provided to illustrate to the subject the progress of completing the portion of the memory exercise within the predetermined time duration. The indicator may be a visual signal, light signal or an audio signal. In the event that the portion of the memory exercise is not completed within the predetermined time duration, the cognitive function evaluator will repeat the determining step and the indicator will indicate the same to the subject.

[36] In an embodiment, there is a sensor signal translator 204 that is adapted to translate the acquired sensor data via input device 203 for use in the cognitive function evaluator 206 to determine whether the translated sensor data includes the predetermined information indicative of cognitive functions for remembering. In another embodiment, the sensor signal translator 204 could be an EEG translator and could be adapted to translate the acquired EEG data for use in the cognitive function evaluation 206 to determine whether the translated sensor data includes the predetermined information indicative of cognitive functions for remembering.

[37] In an embodiment, the cognitive function evaluator 206 comprises a filter 205. The sensor data received from the input device 203 or sensor signal translator 204 will be passed through the filter 205 before the cognitive function evaluator 206 determines whether the sensor data includes the predetermined information.

[38] The cognitive function evaluator 206 is coupled to an exercise device 208. The exercise device 208 is adapted to advance the memory exercise when it is determined

that the sensor data includes the predetermined information indicative of cognitive functions used for remembering. The exercise device 208 is adapted not to advance when it is determined that the sensor data does not include the predetermined information indicative of cognitive functions used for remembering. The exercise device 208 is adapted to determine whether or not a score is achieved for a current level of the memory device and advance the memory exercise accordance with machine learning techniques when it is determined that the score is achieved for the current level of the memory exercise. The score indicates a measure of the cognitive function used for remembering when at least a portion of the memory exercise is completed.

[39] The exercise device 208 includes a calculating device 209 that is adapted to calculate an objective cognitive assessment of the subject in accordance with probabilistic modeling when it is determined by the exercise device that the memory device is completed. In an embodiment, the calculating device 209 calculates the objective cognitive assessment of the subject in response to the performance and/or score of the subject, i.e., time taken to complete the memory exercise, accuracy of the performance.

[40] The exercise device 208 is coupled to a cognitive assessor 210 that is adapted to receive the calculated objective cognitive assessment of the subject. The cognitive assessor 210 assesses the performance of the subject for the memory device in response to the calculated objective cognitive assessment.

[41] The cognitive assessor 210 is coupled to an optimizer 212 which is adapted to store information including the sensor data from input device 203, the sensor signal translator 204, parameter pertaining to the memory exercise, and a subject profile corresponding to the subject. The subject profile includes the condition and historic objective cognitive assessment from completing the memory exercises. The optimizer 212 is adapted to receive the assessed objective cognitive assessment and update the subject profile accordingly in response to the objective cognitive assessment. This allows the clinical professionals to keep track of the progress of the training.

[42] The optimizer 212 is coupled to a configurator 214 which is adapted to configure the memory exercise in response to the assessed objective cognitive assessment of the subject and the subject profile. This provides a personalized cognitive training method for the subject in accordance to the condition and needs of the subject. In one embodiment, the configurator 214 adjusts the predetermined information that is used in the determining

step by the cognitive function evaluator 206 in response to the assessed objective cognitive assessment. If the subject has completed the memory exercise before the expected time duration, the predetermined duration that is used in determining whether the sensor data includes the predetermined information will be shortened and the reverse applies. If the subject were to take a longer time to complete the memory exercise than expected, the predetermined information that is used in analyzing the sensor data will be adjusted accordingly.

[43] In one embodiment, the configurator 214 will configure the predetermined duration that is used in determining whether the sensor data includes the predetermined duration in response to the assessed objective assessment. If the subject has completed the memory exercise before the expected time duration, the predetermined duration that is used in determining whether the sensor data includes the predetermined information will be shortened and the reverse applies.

[44] In one embodiment, the configurator 214 configures the complexity and /or difficulty of the memory exercise in response of the assessed objective cognitive assessment. If the subject has completed the memory exercise before the expected time duration, the complexity and /or difficulty of the memory exercise will be increased and the reverse applies.

[45] In one embodiment, the optimizer 212 is coupled to the cognitive function evaluator 206. The cognitive function evaluator 206 will configure the predetermined information indicative of cognitive functions for remembering in response to the assessed objective assessment. If the subject has completed the memory exercise before the expected time duration, the predetermined information that is used in determining step will be increased and the reverse applies.

[46] In one embodiment, the cognitive function evaluator 206 will configure the predetermined duration that is used in determining whether the sensor data includes the predetermined duration in response to the assessed objective assessment. If the subject has completed the memory exercise before the expected time duration, the predetermined duration that is used in determining whether the sensor data includes the predetermined information will be shortened and the reverse applies.

[47] In an embodiment, there is a second input 207 from the user via the selection made during the memory exercise. This can be in the form of keyboard, joss stick or computer mouse control.

[48] Figure 4 shows that in accordance with the present embodiment, the memory exercise includes flipping and matching cards illustrating pictures and/or words in different languages. Memory of a subject includes immediate memory, visuospatial /constructional memory, attention memory and delayed memory. The actual performance of the memory of the subject is determined by the subject's speed and the difficulty of the memory exercise. One example is the time duration needed for a subject to flip and match the cards which utilizes the subject's cognitive function. Through this memory exercise, the objective cognitive assessment measures the performance of cognitive function for remembering, i.e., memory of the subject.

[49] However, those skilled in the art will realize that many other exercises could be used so long as they measure the performance of the memory by addressing two or more of the four components in memory including immediate memory, visuospatial /constructional memory, attention memory and delayed memory.

[50] The memory exercise requires the sensor data acquired from the subject to meet predetermined information before the exercise will advance, hence, the subject is required to use the cognitive function for remembering so as to complete the exercise. In the event that the subject is not using the cognitive function for remembering in a manner that is suitable for him/her, the subject will be informed by the indicator.

[51] Existing techniques may assume cognitive function and simple indicator of the difficulty like the number of cards in the memory exercise. However, varying cognitive efforts in the same subject and different level of difficulty associated with even the same number of cards will easily render such techniques inaccurate and their results inconsistent from time to time. Therefore, embodiments of the invention seek to solve the problem in the following way.

[52] First, it incorporates image processing techniques to automatically analyse the similarity matrix between cards. It then computes a mathematical model of difficulty that combines the similarity measure and the size of the card tiles. Second, the subject's actual cognitive function for remembering is measured and used to normalize the cognitive

workload using an appropriate mathematical model. A robust mathematical model is applied that combines results from multiple test sessions into an objective measurement of memory capacity, which minimizes the effects of irrelevant conditions.

[53] Embodiments use the information from the objective cognitive assessment to probabilistically maximize the effect of training. The configurator 214 configures the difficulty measure. In an embodiment where the memory exercise involves matching of pairs of cards having the same pictures, this will be done by optimizing the number of cards and the selection of cards so as to best match the difficulty measure to the subject's cognitive capacity.

[54] For example, the difficulty measure can be controlled such that the subject will be expected to complete it within a given time. The embodiment also adjusts the predetermined information for generating the indicator, such that the subject is able to complete tasks efficiently.

[55] The performance index is calculated computationally. Two variables are considered, namely, the difficulty level λ of a computer-based training game (or a computer- based memory exercise, without loss of generality, we use the term training game that also covers the memory exercise), and the minimum of the expectation of time cost τ for completing the game by the subject.

[56] Time is also affected by the workload or the cognitive function of the subject during the memory exercise. Therefore, in one embodiment, τ is considered as the theoretical time in which the subject is fully utilizing the cognitive function for remembering.

[57] Figure 5 shows a graphical representation of the change in difficulty level and the time taken. Consider the time τ as a function of the difficulty level λ. Both variables are non- negative. To factor in various difficulty levels, the area under the function curve from 0 is used up to a specified difficulty level, λ_0

$$P = \int_0^{\lambda_0} \tau(\lambda) d\lambda \qquad (1)$$

[58] The time τ is a monotonic function over λ, since a more difficult game requires a longer time to finish. Mathematically, it says

$$\frac{d\tau}{d\lambda} \geq 0, \lambda \geq 0 \qquad (2)$$

[59] λ that objectively quantifies the difficulty of a game is measured in the following way. Without loss of generality, the game of remembering is used as an example. Given a layout of a game, there are a few factors that determine the difficulty.

- Number of cards, which can be described by an even number n
- Distance between each pair of cards, which can be described by a matrix K ;
- Similarity between each pair of cards, which can be described by a matrix S;

[60] The difficulty is determined by the three variables.

$$\lambda = f(K, S, n) \qquad (3)$$

[61] It should be noted that the three variables are dependent. For example, the size of K and S are essentially determined by $n \, x \, n$ The following model describes the function by ignoring K and reducing the information in the matrix S to the mean similarity s between pairs.

$$\lambda = \exp\left(\alpha \bar{s}\left(\frac{n}{2} - 1\right)\right) - 1 \quad (4)$$

[62] Figure 6 shows a graphical representation of the change in number of cards and the difficulty level.

[63] In the event that a subject plays and finishes memories exercise in time τ_0, this time is determined by both the subject's cognitive function ability, as well as the difficulty of the game. With the information about cognitive function for remembering from algorithm, the variable of cognitive function is reduced by introducing a normalized time duration in which the subject can finish the session if fully utilizing his/her cognitive function for remembering.

$$\tau = \tau_0 \left[\int_0^{\tau} \left(\frac{1}{1+e^{a(t)}}\right) dt\right]^{-1} \qquad (5)$$

[64] The overall memory capacity shall take into account all the possible difficulty level. However, given a number of samples of difficulty-time pairs, it is not straightforward to estimate the area under the function curves till a given upper bound of difficulty level.

[65] Therefore, for computing the performance index as in Eq. 1, samples of time and difficulty level are computed above, except the coefficient α in Eq. 4 which requires determination. Estimating the function in Eq. 1 becomes a curve-fitting problem.

[66] Since the difficulty level above already account for high orders that the relationship between it and the time is expected to of a low order. Particularly, consider an M-th order polynomial estimation:

$$y = \sum_{j=1}^{M} b_j x^j \qquad (6)$$

[67] The zero-order is dropped since $y = 0$ for $x = 0$.

[68] For this estimate to be monotonic in the range of [0, ∞], a strong, sufficient condition is

$$b_j \geq 0 \quad \forall j \qquad (7)$$

[69] Therefore, both the coefficients b's and α need to be determined. In the event that there is a data set of N samples of training game data in terms of triples: $\bar{s}_i$ (reminder: the mean similarity measure of images in the training game), n_i the number of image tiles, and the normalized time duration τ_i for completing the game, it is possible to summarize the above description to formulate the function of τ with respect to the variables

$$\tau_{\alpha,b}(\bar{s}, n) = \sum_{j=1}^{M} b_j \left[\exp(\alpha \bar{s}(\tfrac{n}{2} - 1)) - 1\right]^j \qquad (8)$$

[70] Then the optimization problem is formulated as

$$\max_{a,b\geq 0} \sum_{i=0}^{N} \left(\tau_{a,b}(\bar{s}_i, n_i) - \tau_i\right)^2 \qquad (9)$$

[71] Optimization toolboxes are then utilized to solve the problem. Since the function is highly nonlinear, a globally optimum solution may not be guaranteed.

[72] With the estimated coefficients, the performance index defined by the area under the curve is then given by

$$P = \int_0^{x_0} \sum_{j=1}^{M} b_j x^j dx = \sum_{j=1}^{M} \frac{b_j}{j+1} x_0^{j+1} \qquad (10)$$

[73] Use of the area under the curve rather than use of the time at a particular difficulty level can provide a more robust estimation of performance, since the latter is more susceptible to noise and also does not account for varying difficulty levels. Besides, this allows prediction of a subject's overall performance up to an arbitrary difficulty level.

[74] In the scenario that the subject undergoing the exercise shall complete a round of memory exercise within a given time at a maximum possible difficulty level, this can be casted as a statistical problem:

$$P(\tau \leq t_0 | \lambda_{pl}) \leq \zeta_c \qquad (11)$$

where t_0 is the given time for the subject to complete the game, ζ_C is a confidence level, e.g., 0.95.

[75] For each difficulty level, the time τ can be viewed as a non-negative random variable with a mean value, e.g., $\bar{\tau}$ is determined by Eq. 6.

[76] Using maximum entropy principle, the variable τ shall be Gamma distributed where the distribution function is determined by two parameters: the scale parameter θ (or its inverse, the rate parameter $\lambda = \frac{1}{\Theta}$ and the shape parameter *k*. That is,

$$p(\tau; k, \theta) = \frac{1}{\theta^k} \frac{1}{\Gamma(k)} \tau^{k-1} e^{-\frac{\tau}{\theta}};\ \tau \geq 0 \text{ and } k, \theta > 0 \qquad (12)$$

where Γ() is a gamma function given by

$$\Gamma(k) = \int_0^\infty t^{k-1} e^{-t} dt \qquad (13)$$

[77] Since each difficulty level is associated with a particular random variable for the time τ, the two parameters k and θ are essentially functions of the difficulty level. Practically, we may choose an appropriate k to match the shape of the empirical distribution and then θ is easily determined by both mean and k since $\overline{\tau} = k\theta$.

[78] The cumulative distribution function (CDF) of the gamma function is then

$$F(\tau ; k, \theta) = \frac{1}{\Gamma(k)} \gamma \frac{\tau}{\theta} \qquad (14)$$

where γ() is the incomplete gamma function.

[79] Then the selection of difficulty level is by solving the following problem

$$\max \lambda(n, \overline{s}) \text{ subject to } F(t_0 ; k(\lambda), \theta(\lambda)) \leq \zeta_C \qquad (15)$$

[80] In a practical system with a finite number of image subsets, every subset and the difficulty level using n and $\overline{s}$ are computed. Then CDFs and the largest one with CDF no larger than ζ_C are calculated.

[81] The device and method employ a personalized approach that aims to maximize the training efficiency for each subject. Particularly, this is obtained by using an automated mechanism, called personalized training configuration optimization (PTCO). This mechanism determines the layout of the training program and sets the parameters that best fit to the subject's conditions in terms of behavioral condition and cognitive condition. The two conditions will be evaluated using the other two unique components: the sensor signal translator using the brain-computer interface technology, and the cognitive assessment engine.

[82] The basic scientific principle is that interactions between attention and working memory have been established in neuroscience and psychology. Yet, combining the two through active neuro- physiological computing for more effective cognitive training is a new area, and the feasibility and effects needs to be validated both technically and

clinically.

[83] The core technology comprises the following.

- A computer-based system for simultaneous training of memory and attention that uses advanced neurocomputing and machine learning techniques;
- An objective cognitive (memory) assessment tool that provides information for optimizing training program as well as for cognitive evaluation in clinical use;
- An automatic, personalized setting optimization method with probabilistic modelling of difficulty level;
- Incorporation of advanced attention detection method that uses physiologic data to evaluate the attention condition in real-time;
- New system comprising server-based training system supporting multiple clients

[84] Figure 7 shows a block diagram of the devices 702 (a) – (e) in a system 700. In accordance with the present embodiment, the system 700 has at least one of the devices 702(a) – (e) and a receiver 706. The receiver is operable to receive the objective cognitive assessment of the subject from the at least one of the devices 702(a) – (e). The system 700 also includes a data storage 708 for receiving and storing the subject profile from the at least one of the devices. The system 700 is also operable to correlate two or more subjects with their respective objective cognitive assessment when it is coupled to two or more of the devices 702 (a) – (e).

[85] A fifth embodiment provided a computer readable medium for cognitive training. The computer readable medium has stored thereon computer program code which when executed by a computer causes the computer to perform at least the following: obtaining sensor data of a subject during a memory exercise; determining whether the sensor data includes predetermined information indicative of cognitive functions used for remembering; advancing the memory exercise when it is determined that the sensor data includes predetermined information indicative of cognitive functions used for remembering ; and calculating an objective cognitive assessment of the subject in response to completion of the memory exercise, wherein cognitive training is measured at least partially in response to the advancing the memory exercise.

Experiments and Discussion

Participants

[86] A total of 38 subjects were assessed for eligibility, among which 3 were excluded for not meeting the criteria. A total of 35 participants were randomized (17 in BCI intervention and 18 in waitlist control). Two participants were found to be ineligible and had been incorrectly randomized; neither received any of the intervention. This left a total of 33 patients in the intention-to-treat (ITT) population, 15 in BCI intervention and 18 in waitlist control. One participant was lost to follow-up after randomization and one other withdrew after completing the week one assessment (both from the waitlist control arm). Neither received any intervention. Therefore, of these 33 in the ITT population, 31 (15 in BCI intervention and 16 in waitlist control) contributed information to the primary efficacy and acceptability analysis. All 31 participants completed all 24 sessions (adherence rate: 100%).

Procedure

[87] The BCI system used in the present study has been elaborated upon in a previous publication. Before training, all participants underwent a calibration Stroop task. This Stroop task allowed the BCI system to develop an individualized EEG profile representing each participant's attentive state.

[88] Participants in both the intervention and the wait-list group underwent the BCI intervention for 24 sessions over the span of 8 weeks. Each session was planned to take 30-minutes to complete. During each session, participants played a card-pairing memory game, in which they had to focus their attention in order to open or close the cards on screen (see Figure 2). After each training session, participants were queried as to whether they experienced any adverse events. The intervention group underwent the BCI treatment in their first 8 weeks of being in the trial. The waitlist control arm did not undergo the intervention until after 8 weeks. From Week 9 to 16 the waitlist control arm underwent the same BCI training intervention procedure as the Intervention Arm. All study procedures from the first recruitment to the last follow up was completed between April 2012 and January 2013.

Outcome Measures

[89] A usability and acceptability questionnaire (adapted from (26)) was administered at each participant's final BCI training session (week 8 for intervention arm and week 16 for the waitlist control). Participants rated how strongly they agreed with each item on a scale of 1(Strongly Disagree) to 7 (Strongly Agree).

Questionnaire item	Mean	SD	Median	Range
Overall I am satisfied with how easy it is to use this device.	6.4	0.8	7	4 to 7
I feel comfortable using this device.	6.4	0.7	6	5 to 7
I enjoyed playing the game.	6.8	0.5	7	5 to 7
I think the device is useful in training my memory and attention.	6.6	0.8	7	4 to 7
I will recommend this device to my friends and family.	6.5	0.8	7	4 to 7
Overall I am satisfied with the interface of the game.	6.5	0.6	7	5 to 7
Overall I am satisfied with the whole system.	6.5	0.7	7	1 to 7

Table 1. Descriptive summary of responses to all items in the usability and acceptability questionnaire

[90] The efficacy outcome measure was the total score of Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), which was conducted for the intervention arm at Weeks 1, 8 and 16; and the waitlist control arm at Weeks 1, 9 and 16. Adverse or serious adverse events were assessed by querying participants after each session of BCI training if they have experienced any discomfort during the session. A summary of these events, if any, were then collated for each participant at the end of the study.

[91] The primary endpoints were: acceptability rate of the BCI device based on participants overall rating scores on a usability questionnaire; and change in total score of

the RBANS at week 8 from week 1. Acceptability rate was defined as proportion of participants whose rating score to the whole system was greater than 4 (scale range 1-7).

[92] Secondary endpoints included: adherence rate which was defined as the proportion of participants who finished no fewer than 19 BCI sessions (out of 24 offered); changes in the five domain scores of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) at week 8 from week 1, and the change between pre and post BCI sessions for the five domain scores of the RBANS and the total scale index score pooled across groups.

Changes in RBANS scores

[93] The median scores of the two arms in the two periods are shown in Table 3. The median difference in the RBANS total scale index score between week 8 and week 1 in the intervention arm pre and post training was 3.0 (range -6 to 28), as shown in Table 2. In the waitlist control arm, the corresponding median of the difference was 2.0 (-18 to 19) during the waitlist period. The waitlist control arm received the BCI intervention between week 9 and 16. The median of the difference in the RBANS total scale index score was 4.5 (-9 to 22) during the intervention period. The corresponding median of the difference between week 8 and week 16 in intervention arm who did not receive treatment during this period was 1.0 (-20 to 29).

[94] The Hodges-Lehmann estimate of the median difference in the change scores (from week 1 to week 8) of the total RBANS score between arms was 7.0 (95% CI: -4.0 to 15.0; p=0.332) which was not statistically significant. The point estimate (7.0) reflects an effect size of approximately 0.6 SD. The Hodges-Lehmann estimate of the median differences between arms in the change scores (from week 1 to week 8) of the 5 RBANS domains ranged from 0.5 to 9.5, suggesting an improvement in each of the domains for those participants in the intervention arm. However, none of the differences in change scores across the domain scores were statistically significantly different (Table 2).

[95] Pooling the pre and post BCI data from both arms, the median of the changes in total score of the RBANS pre and post BCI was 4.0 (95% CI: -9.0 to 28.0; $p < 0.001$) (Table 3).The median of the changes in immediate memory, visuospatial/constructional, attention and delayed memory domain scores pre and post BCI, both arms pooled, were all statistically significant, except the language domain score.

Change in RBANS Scores between Week 1 and 8	Intervention	Wait-list	P-value[1]	Median diff. (95% CI)[2]
Immediate Memory				
Mean (SD)	8.3 (18.4)	-1.8 (17.2)		
Median (range)	6.0 (-17 to 44)	-3.0 (-33 to 40)	0.160	9.5 (-3.0, 25.0)
Visuospatial/Constructional				
Mean (SD)	4.1 (12.3)	3.5 (15.4)		
Median (range)	4.0 (-13 to 32)	1.5 (-21 to 37)	0.782	2 (-10.0, 12.0)
Language				
Mean (SD)	0.1 (21.6)	-1.4 (20.7)		
Median (range)	-4.0 (-30 to 42)	0.0 (-36 to 38)	0.937	0.5 (-15.0, 17.0)
Attention				
Mean (SD)	4.1 (12.2)	3.0 (13.5)		
Median (range)	6.0 (-27 to 25)	1.5 (-29 to 31)	0.677	1 (-6.0, 10.0)
Delayed Memory				
Mean (SD)	6.5 (11.2)	2.1 (11.3)		
Median (range)	4.0 (-7 to 37)	0.0 (-24 to 22)	0.362	2.5 (-4.0, 11.0)
RBANS Total Scale Index Score				
Mean (SD)	7.6 (11.4)	1.2 (11.3)		
Median (range)	3.00 (-6 to 28)	2.0 (-18 to 19)	0.332	7 (-4.0, 15.0)

Table 2. A comparison of change in RBANS Domain Index Scores between Week 1 and Week 8 for Intervention and Waitlist control arms

[1] P-value from the Mann-Whitney U test

[2]Hodges-Lehmann estimation and its associated 95% confidence interval

Change in RBANS scores pre and post-treatment	Summary statistics	P-value[1]
RBANS Domain Index Scores		
Immediate Memory		
Mean (SD)	6.9 (17.6)	
Median (range)	6.0 (-28 to 44)	0.038
Visuospatial/Constructional		
Mean (SD)	5.2 (11.2)	
Median (range)	4.0 (-13 to 32)	0.014
Language		
Mean (SD)	2.4 (16.8)	
Median (range)	0.0 (-30 to 42)	0.547
Attention		
Mean (SD)	3.4 (11.0)	
Median (range)	6.0 (-27 to 25)	0.039
Delayed Memory		
Mean (SD)	6.1 (10.0)	
Median (range)	6.0 (-12 to 37)	<0.001

Table 3. Changes of RBANS individual index sub-scores and total scale index score pre and post intervention, pooling data from both Intervention and Waitlist control arms.

[1]P-value from the Wilcoxon signed rank test

Safety

[96] There were no adverse or serious adverse events reported during the study period by any of the participants.

Discussion

[97] As seen from the responses for the usability and acceptability questionnaire, feedback from participants was positive. The very high adherence rate also suggested a high level of motivation among the participants. These factors indicated that elderly users may be sufficiently motivated to adhere to the training program even in their own homes.

[98] RBANS total scores improved by a similar magnitude pre and post training, and this occurred for both intervention and waitlist control arms (between Week 1 and 8 for intervention, and Week 9 and 16 for waitlist control). The RBANS total scores did not change in the waitlist control arm before the intervention. In addition, between Weeks 9

and 16 when the intervention arm ceased treatment, their mean RBANS total score neither decreased to baseline level nor improved at an equally large magnitude as between weeks 1 and 8. The time sequence of the changes can be taken as support that improvements in mean RBANS total scores between weeks 1 and 8 for the intervention arm were due to the BCI treatment effect.

[99] While the data indicated that the intervention arm showed a larger improvement in RBANS total scores between Weeks 1 and 8 as compared to the waitlist control arm, this difference did not reach statistical significance. Thus, the study does not provide conclusive evidence for a difference in attention and memory in the normal elderly as assessed by the total score on the RBANS between intervention arm and waitlist control. Nevertheless, an effect size of 0.6 SD was obtained. This decision is also supported by the highly significant result obtained when data from both arms were pooled, showing a positive shift in RBANS total scores pre and post-BCI training.

[100] It is notable that, pooling both arms, the scores for all five RBANS domains showed statistically significant positive changes pre and post BCI, except for language. This differentiated improvement suggests that gains in RBANS scores are valid indications of the efficacy of the training program, which targets attention and memory but not language. The significantly positive change in Visuospatial/Constructional could be attributed to the visual and pictorial nature of the memory task. This may have honed the participants' attentiveness to pictorial stimuli, which are used to assess the Visuospatial/Constructional domain in RBANS. In addition, while the nature and modality of tasks used in training and assessment were very different (e.g. visual memory of pictures vs auditory memory of word lists), putative improvements in memory and attention during training were translated to score increases in both the relevant domain and global scores for RBANS. This could be taken as further evidence that the training results in global rather than task-specific improvements in cognitive functioning.

[101] While several exemplary embodiments have been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist, including variations as to the information that is used as input and how the memory exercise is carried out.

[102] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments

without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

What is claimed is :

1. An autodidactic method for personalized memory training comprising :

obtaining real-time neural sensor data of a subject during a memory exercise comprising electroencephalography (EEG) signals obtained from the subject by one or more EEG electrodes attached to the subject during the memory exercise;

obtaining real-time physiological and behavioural sensor data of a subject during a memory exercise comprising real-time visual information of the subject during the memory exercise obtained from at least one visual recording device, the real-time neural sensor data and the real-time physiological sensor data comprising real-time neuro-physiological data;

determining throughout the memory exercise whether the real-time neuro-physiological sensor data includes predetermined information indicative of cognitive functions used for remembering, wherein a subject's cognitive functions used for remembering comprise immediate memory, visuospatial memory, attention memory and delayed memory, and wherein the memory exercise is configured to assess in real-time at least two of the subject's cognitive functions used for remembering as the subject performs the memory exercise;

advancing the memory exercise when it is determined that the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering;

calculating an objective cognitive assessment of the subject in response to completion of the memory exercise, the objective cognitive assessment of the subject assessing the subject's performance of the cognitive functions used for remembering as such performance varies throughout the memory exercise and calculated at least partially in response to the advancing the memory exercise; and

revising the memory exercise to test for an adjusted set of the subject's cognitive functions used for remembering in response to the calculated objective cognitive assessment of the subject.

2. The method according to claim 1, wherein the memory exercise will not advance when it is determined that the real-time neuro-physiological sensor data does not include the predetermined information indicative of the cognitive functions used for remembering.

3. The method according to any one of the preceding claims, wherein determining whether the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering comprises determining the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering in response to one or more of a predetermined portion of the memory exercise is completed in a predetermined time duration, complexity of the memory exercise, difficulty of the memory exercise, accuracy of the subject and condition of the subject.

4. The method according to any one of the preceding claims, further comprising determining whether a score is achieved for a current level of the memory exercise before the advancing step, the score being indicative of a time taken to complete the memory exercise.

5. The method according to any one of the preceding claims, wherein the memory exercise comprises matching of pictures and/or words and determining the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering comprises determining the real-time neuro-physiological sensor data obtained during the memory exercise includes predetermined information indicative of at least visuospatial memory and immediate memory.

6. The method according to any one of the preceding claims, wherein the step of determining whether the sensor data includes the predetermined information indicative of the cognitive functions used for remembering comprises passing the real-time neuro-physiological sensor data through a filter to determine whether the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering.

7. The method according to any one of the preceding claims, wherein the visual information of the subject during the memory exercise obtained from at least one visual recording device comprises visual information obtained from a video camera during the memory exercise.

8. An autodidactic personalized memory training device comprising:

at least a first input device and a second input device for receiving real-time neuro-physiological sensor data of a subject during a memory exercise, wherein the first input device comprises one or more electroencephalography (EEG) electrodes attached to the subject during

the memory exercise for obtaining real-time EEG signals comprising real-time neural sensor data, and wherein the second input device comprises at least one visual recording device for obtaining real-time visual information of the subject during the memory exercise comprising real-time physiological sensor data, and wherein the real-time neuro-physiological sensor data comprises the real-time neural sensor data and the real-time physiological sensor data;

a cognitive function evaluator adapted to receive the real-time neuro-physiological sensor data from the at least one input device and determine whether the real-time neuro-physiological sensor data includes predetermined information indicative of cognitive functions used for remembering, wherein a subject's cognitive functions used for remembering comprise immediate memory, visuospatial memory, attention memory and delayed memory, and wherein the memory exercise is configured to assess in real-time at least two of the subject's cognitive functions used for remembering as the subject performs the memory exercise; ~~and~~

an exercise device adapted to advance the memory exercise when it is determined that the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering, the exercise device comprising a calculating device adapted to calculate an objective cognitive assessment of the subject in response to completion of the memory exercise, the objective cognitive assessment of the subject assessing the subject's performance of the cognitive functions used for remembering as such performance varies throughout the memory exercise, wherein the calculating device is further adapted to calculate the objective cognitive assessment of the subject at least partially in response to the advancing of the memory exercise;

a cognitive assessor coupled to the exercise device and operable to receive and assess the calculated objective cognitive assessment of the subject;

an optimizer coupled to the cognitive assessor and adapted to store information, the information comprising the real-time neuro-physiological sensor data and the memory exercise; and

a configurator coupled to the optimizer, the configurator adapted to configure the memory exercise in response to the received assessed objective cognitive assessment of the subject, the configurator revising the memory exercise to test for an adjusted set of the subject's cognitive functions used for remembering in response to the calculated objective cognitive assessment of the subject,

wherein the cognitive assessor is adapted to transmit the assessed objective cognitive assessment of the subject to the optimizer.

9. The autodidactic personalized memory training device according to claim 8, wherein the exercise device is adapted not to advance the memory exercise when it is determined that the real-time neuro-physiological sensor data does not include the predetermined information indicative of the cognitive functions used for remembering.

10. The autodidactic personalized memory training device according to either of claims 8 or 9, wherein the cognitive function evaluator is further adapted to determine the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering in response to one or more of a predetermined portion of the memory exercise is completed in a predetermined time duration, complexity of the memory exercise, difficulty of the memory exercise, accuracy of the subject and condition of the subject.

11. The autodidactic personalized memory training device according to any of claims 8 to 10, wherein the exercise device is further adapted to determine whether a score is achieved for a current level of the memory exercise and advance the memory exercise when it is determined the score is achieved for the current level of the memory exercise.

12. The autodidactic personalized memory training device according to any of claims 8 to 11, wherein the at least one visual recording device comprises a video camera.

13. The autodidactic personalized memory training device according to any of claims 8 to 12, wherein the at least one input device is coupled to a sensor signal translator, the sensor signal translator operable to translate the real-time neuro-physiological sensor data received from the at least one input device, and wherein the cognitive function evaluator is coupled to the sensor signal translator and operable to receive the translated real-time neuro-physiological sensor data and determine whether the translated real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering.

14. The autodidactic personalized memory training device according to any of claims 8 to 13 wherein the optimizer is further adapted to store information comprising a subject profile corresponding to the subject and update the subject profile of the subject in response to each of the received objective cognitive assessment of the subject received from the cognitive assessor.

15. The autodidactic personalized memory training device according to claim 14, wherein the configurator is adapted to configure the memory exercise in response to both the received assessed objective cognitive assessment of the subject and the subject profile.

16. The autodidactic personalized memory training device according to claim 15, wherein the configurator is further adapted to adjust the predetermined information indicative of cognitive functions used for remembering corresponding to the subject in response to the updated subject profile.

17. The autodidactic personalized memory training device according any of claims 8 to 16, wherein the memory exercise comprises matching of pictures and/or words, and wherein the exercise device is further adapted to determine whether the real-time neuro-physiological sensor data received during the memory exercise includes predetermined information indicative of at least visuospatial memory and immediate memory.

18. The autodidactic personalized memory training device according to any of claims 8 to 17, wherein the cognitive function evaluator comprises a filter, and wherein the cognitive function evaluator is further adapted to pass the real-time neuro-physiological sensor data through the filter so as to determine whether the real-time neuro-physiological sensor data includes the predetermined information indicative of the cognitive functions used for remembering.

19. The autodidactic personalized memory training device according to any of claims 8 to 18, wherein the exercise device is further adapted to advance the memory exercise in accordance with machine learning techniques.

20. The autodidactic personalized memory training device according to any of claims 8 to 19, wherein the calculating device is further adapted to calculate the objective cognitive assessment of the subject in accordance with probabilistic modeling.

21. The autodidactic personalized memory training device according to any of claims 8 to 20, wherein the calculating device is further adapted to calculate the objective cognitive assessment of the subject in response to time taken to complete the memory exercise.

22. A system comprising :

an autodidactic personalized memory training device as claimed in any of claims 14 to 21; and

a server coupled to the autodidactic personalized memory training device and comprising a receiver operable to receive the objective cognitive assessment of the subject from the autodidactic personalized memory training device.

23. The system according to claim 22, wherein the server is operable to receive and store the subject profile.

24. The system according to either claim 22 or claim 23 comprising two or more autodidactic personalized memory training devices as claimed in any of claims 14 to 21, wherein the receiver is further operable to receive the objective cognitive assessment of two or more subjects corresponding to the two or more autodidactic personalized memory training devices, and wherein the server is further operable to correlate the two or more subjects with their respective objective cognitive assessments.

25. A computer readable medium for autodidactic personalized memory training, the computer readable medium having stored thereon computer program code which when executed by a computer causes the computer to perform at least the following:

determining whether real-time neuro-physiological sensor data obtained from a subject throughout a memory exercise includes predetermined information indicative of cognitive functions used for remembering, wherein a subject's cognitive functions used for remembering comprises immediate memory, visuospatial memory, attention memory and delayed memory, and wherein the memory exercise is configured to assess in real-time at least two of the subject's cognitive functions used for remembering as the subject performs the memory exercise, the real-time neurophysiological sensor data including at least real-time neural sensor data obtained from the subject during the memory exercise by one or more

electroencephalography (EEG) electrodes attached to the subject during the memory exercise and real-time physiological sensor data including at least real-time visual information of the subject during the memory exercise obtained from at least one visual recording device;

advancing the memory exercise when it is determined that the real-time neuro-physiological sensor data includes predetermined information indicative of the cognitive functions used for remembering;

calculating an objective cognitive assessment of the subject in response to completion of the memory exercise; and

revising the memory exercise to test for an adjusted set of the subject's cognitive functions used for remembering in response to the calculated objective cognitive assessment of the subject,

wherein the objective cognitive assessment of the subject assesses the subject's performance of the cognitive functions used for remembering as such performance varies throughout the memory exercise, and

wherein the objective cognitive assessment of the subject is also calculated at least partially in response to the advancing the memory exercise.