Lumosity

What claims does the company make / what does the programme target?

Lumosity's website is at the time of writing (early 2015) relatively vague as to who the programme targets and what benefits users should expect to see. What is promised is simply an enjoyable, game-based brain-training programme that mimics exercises created by neuroscientists, and is likely to be of interest the general public.

This is in contrast to previous iterations of Lumosity documentation. These (Lumosity, 2009) describe, in addition to use by the general public, specific training courses designed to improve students' performance in school, and others to remediate neurological disorders like ADHD and traumatic brain injury.

Evidence for efficacy:

Lumosity's website provides "13 summaries of peer-reviewed papers and conference presentations on the efficacy of Lumosity training". Some studies have indeed been independently published in peer-reviewed scientific journals. They include:

Kesler et al. (2013):

This pilot study, published in *Clinical Breast Cancer*, used a waitlist control design to test whether Lumosity training could feasibly remediate some of the long-term cognitive deficits that accrue in breast cancer survivors. 41 survivors (on average 6 years post-therapy) participated in the study. 21 were assigned to the active condition, and 20 to the waitlist condition. Each completed 48 sessions (of 20–30 minutes) of adaptive training using 13 different Lumosity exercises. The authors do not list exactly which Lumosity exercises were used, although say:

> *In summary, the training tasks were composed of switching games (eg, based on the spatial location of the stimulus, participants responded to either a specific number or a specific letter of the stimulus), mental rotation games (eg, navigate a rotating maze), n-back memory games (eg, determine if the current picture or symbol matched the one shown 1 or 2 screens back), spatial sequencing memory games (eg, recall the location of coins and then find them in the order of their value), word stem completion games (eg, use various word stems such as "cog" to produce as many different words as possible), route planning (eg, navigate a maze by using the fewest number of moves possible), and rule-based puzzle solving (eg, determine if groups of figures follow an implicit rule).*

The researchers used a number of tests to assess the effect of training, including the Wisconsin Card Sorting Test (WCST), the letter fluency test from the Delis-Kaplan Executive Function System (assesses executive function and language), the Hopkins Verbal Learning Test Revised (HVLT-R) (assesses verbal memory), the digit span and symbol search subtests of the WAIS-IV. A self-report measure of executive function, the Global Executive Composite score of the Behavioural Rating Inventory of Executive Function (BRIEF), was also used. Baseline tests were performed no more than 3 days before beginning the training program, or after completing their baseline cognitive testing

Analysis revealed that those in the active condition demonstrated significant improvement in their WCST scores compared with the waitlist control group. They also improved significantly their scores on the letter fluency and symbol search tests, and improvement on the HVLT-R approached significance. There was, however, no significant difference in digit span scores, nor on global BRIEF scores (although the authors did conduct exploratory analysis on BRIEF subscales which suggested significant improvements on the planning and organization subscales).

Limitations: passive control only, so does not control for motivational/Hawthorne effects; waitlist control, so difficult to assess follow-up; small sample size, so hard to statistically address effect of disease and treatment history; does not provide evidence of transfer to real- world tasks.

Kesler, Lacayo, and Jo (2011):

This pilot study, published in *Brain Injury*, sought to investigate whether training with Lumosity exercises could feasibly remediate impaired executive function in children who survived leukaemia or brain tumours. 23 paediatric cancer survivors (aged 7–19) participated in the study. The participants had to be at least 7 years old, have completed their cancer treatment at least six months prior to the study, and show impaired executive function (defined as at least 1 SD below the test normative mean or their own Full Scale IQ scores on two or more executive function tests). The 19 participants who completed the intervention each underwent 40 sessions (of 20 minutes) of training. This was supposed to be across an 8- week period although most in fact required longer.

The researchers used a range of tests to assess the effect of training. The tests administered differed for those aged between 7-16 and those aged between 17-19. Those aged 7-16 underwent screening using the WISC-IV, the List Memory and Picture Memory components of the Wide Range Assessment of Learning and Memory 2nd Edition (WRAML2), the NEPSY II Animal Sort (to assess cognitive flexibility), the Woodcock-Johnson 3rd Edition (WJ-III) Cancellation Test (to assess attention and processing speed), and the Motor Free Test of Visual Perception 3rd Edition (MVPT-3) (to assess spatial relationships, visual discrimination, and visual memory). Those aged 17–19 undertook the WAIS-III instead of the WISC-IV and the Delis Kaplin Executive System (DKEFS) Sorting Test instead of the NEPSY II Animal Sort, but otherwise underwent the same testing.

Participants demonstrated (statistically) significant improvement between pre- and post-intervention testing in the Processing Speed Index of the WISC/ WAIS, the sort tests, and the List Memory and Picture Memory components of the WRAML2. Once the data were subjected to a Jacobson-Truax RCI analysis to account for practice effects, only changes in processing speed index and sort test scores were classed as clinically significant. Encouragingly, however, many participants' scores on these tests not only improved, but also fell post-intervention within the normative distribution, allowing a classification of 'recovered'.

The researchers also used fMRI to investigate the neural correlates of training. They observed significant increases in dorsolateral prefrontal cortex activation.

Tasks used: 6 — Spatial Speed Match, Monster Garden, Lost in Migration, Birdwatching, By the Rules, Colour Match.

Limitations: lack of a control group — improvement could be due to practice effects (although the RCI analysis was conducted); could not control for differential demographic and medical effects due to lack of statistical power; somewhat surprising that working memory and visual attention were not improved by the training program.

Kesler, Sheau, Koovakkattu, & Reiss (2011):

This pilot study, published in *Neuropsychological Rehabilitation*, sought to investigate whether the teaching of a mathematics strategy known as 'decomposition' coupled with practice of this strategy using Lumosity exercises could feasibly remediate deficits in mathematics skills in girls with Turner syndrome (TS). 16 girls with TS (7–14 years) participated in the study. They had to have been exposed to single digit addition to be eligible to participate.

Training consisted of:

(1) Instruction regarding the use of the 'decomposition' strategy for mathematics — this involves "decomposing math problems into smaller problems that are easier and/or already memorised. For example, 39 + 12 = 39 + 10 + 2."

(2) Lumosity games — namely, Chalkboard Challenge, Raindrops and By the Rules. Participants were required to train for 20 minutes per day, five days per week for six weeks.

The researchers looked at a number of outcome measures to determine the interventions' efficacy. These included:

- maths skills as assessed by the KeyMath Diagnostic Assessment (3rd Edition) — contains Basic Concepts, Operations and Applications subscales;
- "math-related" cognitive skills including:
  - the WISC-IV Working Memory (WMI) and Processing Speed (PSI)) indices;
  - the sky search subtest of the Test of Everyday Attention for Children — to assess attention;
  - the animal sorting subtest of the NEPSY-II — to assess cognitive flexibility; and
  - the Motor-free Visual Perception Test (3rd Edition, MVPT) to assess visual-spatial processing.

These tests were administered twice — first within 1 week prior to beginning training to establish a baseline, and then within 1 week after completing training. The researchers also collected fMRI data to assess the neural correlates of any improvements seen.

Linear mixed modelling (using age and PRI as covariates) revealed significant increases in participants' KeyMath Total, Basic Concepts and Operations post-intervention scores, although no significant changes were seen in KeyMath Applications score. Further significant increases could be seen in participants' processing speed index, Animal Sort and MVPT scores. An RCI analysis was also conducted, the researchers concluding that the increases in KeyMath Total and Basic Concepts scores, PSI, Animal Sort and MVPT test scores were also clinically significant and could be classified as 'recovered'.

fMRI data showed a decrease in frontal-striatal and mesial-temporal activation but an increase in parietal lobe activation after participants completed the training programme. The authors (p. 447), citing Rivera et al. (2005) concluded this "may imply that less proficient math performers rely on attention, memory and/or verbal-based strategies as these are typically subserved by frontal-striatal and temporal regions, while more proficient performers utilise more spatial/retrieval-based strategies that are associated with parietal regions."

Limitations: multiple treatments, so unknown how important the decomposition training was; no control group — so practice effects and regression to the mean are not controlled for; small sample size.

Finn and McDonald (2011):

This pilot study, published in *Brain Impairment*, used a waitlist control design to investigate whether Lumosity training could improve cognitive functioning (related to attention, processing speed, visual memory and cognitive control) in older adults with mild cognitive impairment (MCI). 25 participants diagnosed with MCI (amnestic and/or multiple domain) according to standardised criteria were randomly allocated to the treatment (n = 12) and waitlist (n = 13) groups. Participants completed 30 training sessions of training, completing four or five cognitive exercises per session.

The researchers used a range of measures to assess the effect of training. Their primary outcome measures came from the Cambridge Automated Neuropsychological Test Battery (CANTAB) and included:

- paired-associates learning and pattern recognition memory tasks to assess visual memory;
- total errors on intra-dimensional and extra-dimensional set shifting tasks to assess rule acquisition and attentional set shifting;
- a test of spatial working memory to assess working memory and executive function; and
- a test of rapid visual information processing ("in this case a measure of how quickly and accurately targets (three separate triple-digit sequences; e.g., 2– 4–8) are detected from among distractors") to assess visual sustained attention.

The researchers also administered the Memory Functioning Questionnaire (MFQ), Memory Controllability Inventory (MCI) and 21-item Depression Anxiety and Stress Scale (DASS21) as secondary outcome measures.

Only 16 participants (8 treatment, 8 waitlist) completed the study. In terms of the CANTAB measures, the only significant difference between the trained and waitlist groups after the former's training was their score on the rapid visual information processing test which was due not only to an improvement in the scores of the treatment group following training, but unfortunately also to a decline in the waitlist group's scores on this task. There was no significant difference in scores on the MFQ, MCI or DASS21.

Limitations: all but one improvement insignificant and so does not provide strong support for Lumosity's efficacy at all; passive control only, so does not control for motivational/Hawthorne effects and not blinded; small sample sizes (although was only a pilot study).

Kpolovie (2012): [NB: Lumosity's website does not refer to this study.]

The author of this study, published in *Educational Research*, sought to compare the effectiveness of Lumosity training, 'brain-boosting food' and 'brain-boosting food supplements' on learning.

The participants were 72 boarding students from Nigeria. The author used a "randomized six- group experimental design" (p. 224) which is described as an expanded version of a Solomon four-group design to take into account two independent variables.

Their learning was assessed using an 'Experimental Learning Test' which tested content related to statistical inference, phonetics and community health. After baseline assessment (for relevant groups), all participants were provided with learning material related to the test content. Those not assigned to a Lumosity training group were instructed to study this material for 2 hours per working day for six weeks. Those assigned to undertake Lumosity cognitive training took either 30 or 60 minutes (depending on group allocation) out of the 2 hours worth of study time to do so.

The author found that students who undertook 60 minutes of daily Lumosity training showed significantly greater improvements on their Experimental Learning Test scores than those who undertook 30 minutes of daily Lumosity training, who in turn showed showed significantly greater improvements compared with the untreated control groups. (Brain-boosting food and brain-boosting food supplements also brought about significantly greater improvements on the Experimental Learning Test compared with the untreated control groups)

Limitations: only passive control groups. A number of conclusions do not seem adequately

supported. For example the author claims "[r]esults of this experiment have shown overwhelmingly that the benefits of Lumosity training transfer to core cognitive abilities such as processing speed, problem solving, and task switching; and these doubtlessly make a person to learn better and forget less." This is odd, as the experiment does not appear to have involved any assessment of processing speed, problem solving or task switching.

Further studies are reported in article format, but are authored by Lumosity's creators:

Hardy, Drescher, Sarkar, Kellett, and Scanlon (2011):

This study, published in the *Mensa Research Journal*, sought to investigate the efficacy of Lumosity in healthy adults. 23 volunteers (with a mean age of 54 years) participated in the study. 14 were assigned to the training group, and 9 to the control group. The participants underwent 5 weeks of training, training daily for 20 minutes per day.

The researchers used a range of tests to assess the effect of training. These included:

- a divided visual attention test where the participant had to fixate on and identify a letter presented in the centre of the screen, and at the same time click on stimuli flashed outside the centre — the outcome being the average distance between the location of the stimuli outside the centre and the participant's mouse clicks.
- a forward visual memory span test;
- a reverse visual memory span test; and
- a letter memory test where the participant was briefly shown a string of letters of a certain length and then required to type out the string, with the length of the string increasing by one character for each correct answer.

The results indicated that, compared to the control group, the trained participants showed significant increases in the divided visual attention and forward visual memory span tests. The trained participants also showed significantly increased reverse visual memory span test results, but there was no significant group-by-time interaction for this test. No significant differences were seen for the letter memory test in either group.

Tasks used: 4 — Birdwatching, Speed Match, Memory Match, Monster Garden.

Limitations: financial interests — Hardy, Drescher, Sarkar and Scanlon all have financial interests in Lumosity; waitlist passive control only, so does not control for motivational/Hawthorne effects; the Mensa Research Journal is not itself peer-reviewed, although according to its website only accepts papers "first published in or accepted by (not just submitted to) a peer-reviewed journal, or presented at a peer-reviewed professional conference".

Some of these studies are *about* Lumosity, but do not directly support its efficacy:

Sternberg, Ballard, Katz, Doraiswamy, and Scanlon (2013):

The authors first investigated whether Lumosity users' self-reported sleep and alcohol consumption correlated with their initial performance. They found that users who reported getting larger amounts of sleep — up to 7 h per night — performed better After 7 h, however, performance began to decrease. In terms of alcohol consumption, those who reported having 1 or 2 drinks per day performed the best, with performance decreasing as intake increased from there.

Second, the authors investigated age influences improvement over the first 25 training sessions of particular cognitive tasks. They found that for all exercises, older users performed worse, but that

this effect was greater for exercises involving fluid intelligence rather than any crystallised knowledge.

Finally, some studies do not appear to be reported in article format at all, and instead take the form of conference posters. These are — summarised very briefly — as follows:

Ballard, Sternberg, Hardy, and Scanlon (2012) "Training-related improvements in cognitive performance persist over time but depend on age; an online study including > 140,000 participants."

Researchers found:

(1) Long gaps in training (> 1 week) can limit performance improvements.

(2) Given the same quantity of training, young users showed greater improvement compared with older users.

(3) Gaps are more detrimental to older users' performance.

Sternberg, Hardy, and Scanlon (2013) "Cognitive performance peaks at different times of day depending on the task."

Researchers found:

(1) Baseline performance on — as well as training improvements in — working memory and attention tasks generally peaks in the morning and then declines thereafter.

(2) More elaborative/creative tasks are different. Their baseline performance is higher later in the day (i.e., afternoon and evening), and they tend to remain responsive to training throughout the day.

(3) The effect of the time of day is less noticeable in older users.

Gyurak, Ayduk & Gross (2010) "Training executive functions: emotion regulatory and affective consequences."

Researchers found:

(1) Lumosity training may improve emotional regulation as measured by eye-gaze fixations on negative regions in a picture from the International Affective Picture System.

(2) Lumosity training led to lower depressive ruminative thinking and higher self- esteem scores compared to a control group as measured 3-months post-training.

Katz, Hardy & Scanlon (2011) "Dramatic improvements in arithmetic abilities between the ages of 13 and 17 in a worldwide sample of over 440,000 adolescents and young adults playing an online game."

Researchers looked at baseline performance in the Raindrops exercise by age. They found large improvements in baseline performance levels between children aged 13 to 17, with the biggest increase between 14 and 15.

Further, the researchers' investigation into learning rates revealed that the younger children (below 15) appeared to benefit less from training on the Raindrops exercise than the older children.

Ng, Sternberg, Katz, Hardy, and Scanlon (2013) "Improving Cognitive Capacities in School-aged Children: A large scale, multi-site implementation of a web-based cognitive training program

in academic settings."

Of 1204 students across 40 schools in 6 different countries, 816 (mean age 11.25) received Lumosity cognitive training, while the remaining 388 students (mean age 11.20) were placed in the no-treatment control condition. The amount of cognitive training administered to the training group varied depending on teacher needs and preference. Students in the training group could also use the software at home if they had a computer and internet access. Based on data from Lumosity's BPT taken pre- and post-intervention, researchers found:

(1) The training group's Brain Performance Test (BPT) scores improved significantly more than the control group's did.

(2) There is a positive correlation between hours spent training and improvement on the BPT.

Sternberg, Hardy, Katz, Ballard, and Scanlon (2012) "Preliminary findings of transfer from cognitive training to a repeatable, dynamically generated assessment."

This poster details preliminary findings into the reliability of the Lumosity Brain Performance Test (BPT). The researchers claimed:

(1) Test-retest reliability is "comparable to validated brief intelligence tests, such as the Wechsler Abbreviated Scale of Intelligence (FSIQ-2, 15 minute version, r = 0.88)."

(2) BPT scores change with age — in a similar way to what one would expect of scores on a test of fluid intelligence.

(3) Correlations between the different subtests range from 0.28 to 0.72. They argue this means the subtests reflect distinct cognitive abilities.

(4) There is a positive correlation between hours spent training and improvement on the BPT.

Evidence against efficacy:

Shute, Ventura, and Ke (2015):

This study, published in *Computers & Education*, sought to compare the effect on problem solving skills, spatial skills, and persistence of playing eight hours of the videogame *Portal 2* with completing 8 hours of Lumosity cognitive training.

77 undergraduates (aged 18–22) participated in the study. 42 were randomly allocated to play *Portal 2*, and 35 to train using Lumosity. Gameplay/training was split across three sessions. Each lasted three hours, with participants undertaking eight hours worth of play or training (time was taken from the first session for baseline assessment). Participants also had to attend one further one-hour session for post-intervention reassessment.

The researchers used a battery of online tests for baseline and post-intervention cognitive assessment. This included:

- problem solving measures — Raven's progressive matrices (RPM), a verbal insight test and the remote-association test (RAT);
- spatial cognition measures — mental rotation test (MRT), spatial orientation test (SOT), virtual spatial navigation assessment (VSNA); and
- persistence measures — these differed at baseline and post-intervention testing. At baseline testing, a persistence self-report survey was administered. At post-intervention testing, a picture comparison task was administered. This involved the user identifying four differences in two pictures in up to 180s, or skipping that set of pictures

if they could not do so, the key measurement being the time spent on impossible sets of pictures. The self-report survey was used as a covariate for the picture comparison task.

When comparing post-intervention scores between groups, the researchers found significantly different results in favour of *Portal 2* in performance on the insight test as well as the MRT and VSNA, even controlling for player enjoyment. When comparing within-condition baseline—post-intervention performance, there were no significant gains either for the Lumosity or *Portal 2* group across any of the problem solving measures. There were further no significant gains on any of the spatial cognition measures for the Lumosity group. *Portal 2* players did, however, show significant improvements on the MRT and VSNA tests.

Limitations: small sample size and so may lack power; low reliability of tests used; use of one- tailed statistical tests.

Note the general limitations of studies supporting Lumosity's effectiveness as discussed above — particularly the lack of an active control group. Further note that the studies do not relate to developmental learning disabilities, and that not all Lumosity exercises may be as effective as others — the literature seems to use only a few games of those available.

Price:

Individual, Monthly: USD 11.95 /month.

Individual, Yearly: USD 5.00 /month.

Individual, Two Year: USD 3.75 /month.

Individual, Lifetime: USD 299.95.

Group package (up to 5 members), Yearly: USD 8.33 /month.

What it involves:

Lumosity markets an online brain training programme to the general public (aged between 18-89) involving (at the time of writing) 56 discrete adaptive games, broadly grouped into five categories, being memory, attention, speed, flexibility and problem solving. The programme can be accessed via a web browser, and also via apps on smartphones and tablets.

When users first create an account, they must select which aspects of cognition they would like to improve using Lumosity. The aspects users can select from are:

Memory • remembering patterns and locations • associating names with faces • keeping track of multiple pieces of information in your head • recalling sequences of objects and movements	*Attention* • dividing your attention between multiple tasks and demands • attending to key information within a large area • ignoring distractions • quickly pointing out patterns

Speed • decision-making in time-sensitive situations • quickly recalling recent information • reorienting yourself as perspectives change • reacting quickly	*Flexibility* • rapidly selecting words from your mental vocabulary • quickly adjusting to shifting rules • inhibiting initial responses • switching between tasks efficiently
Problem Solving • using logical reasoning • making quick and accurate estimations • calculating figures in your head • planning efficient routes	

They are then required to complete a 'Fit Test' to establish a baseline for training. This involves assessment using three games — when we tried the software, these were 'Train of Thought', 'Memory Matrix' and 'Speed Match' (see below).

Once users have completed this process, they are given the option to pay to access their personalised training program. This involves playing adaptive games selected from the following series:

Memory:

- *Face Memory Workout*: an *n*-back task where n can vary (up to at least 3). Users have to indicate whether the currently presented face is the same as one presented *n* faces previously. Assessment is based on speed and accuracy.
- *Familiar Faces*: the user takes the place of a cashier at a restaurant. The user's first job is to greet customers, at which point s/he must either ask or type their names. Each customer has a unique name, which never changes. Asking customers what their name is incurs a points penalty. Further, once customers have been greeted, they place an order. The user must remember a number of these orders at a time and — when the food has been prepared — match the orders with the correct person.
- *Follow That Frog*: a spatial span task where the user must remember and recreate the path of a frog on a number of lily pads. The number of jumps the user must remember increases with the number of correct answers.
- *Memory Lane*: a dual *n*-back task where n can vary. A figure appears in a particular window of a house, and a letter is spoken at the same time. The user must press the left arrow key if the currently presented figure's location is the same as one presented *n* times previously, and press the right arrow key if the letter spoken is the same as that spoken *n* times previously.
- *Memory Match*: a timed *n*-back task with *n* of 2. Users have to indicate whether a visual stimulus is the same as one presented two previously.
- *Memory Match Overload/Overdrive*: a timed *n*-back task with *n* of 3. Users have to indicate whether a visual stimulus is the same as one presented two previously.

- *Memory Matrix*: a pattern of lit tiles is briefly shown on a grid (which expands or contracts depending on the appropriate difficulty level). The user must exactly reproduce the pattern shown.
- *Moneycomb*: the user is shown a number of tiles, some of which contain bronze, silver or gold coins. The user must click on the tiles that contain the coins in ascending order of value (i.e., bronze coins first, gold coins last).
- *Monster Garden*: users are shown a grid representing a garden. They are briefly shown which squares in the grid contain monsters and which contain beets. They must then guide a farmer to a flower in the garden by clicking a path of squares which does not contain any monsters.
- *Pinball Recall*: users are shown a grid with bumpers representing the inside a pinball machine. The grid fades from view, and then a light is shown which indicates to the user from where the ball will be fired. The user must predict where the ball will finish, taking into account how it will bounce against the bumpers.
- *Rhyme Workout*: a timed *n*-back task with *n* of 1 or 2. Users have to indicate whether a rhyming word (presented visually) matches that presented *n* times previously. Similar to Memory Match, but uses rhyming words instead of symbols.
- *Rotation Matrix*: the same as Memory Matrix, except that the grid rotates 90 degrees after the pattern is shown but before the user reproduces it.
- *Tidal Treasures*: a number of different objects are shown washed up on a beach. The user must click on each object only once (i.e., must click on a different object each time). More objects wash up throughout the game.

Attention:

- *Train of Thought*: in this game the user must manage a series of switches to ensure a series of coloured trains reach their correspondingly coloured stations. More difficult levels require you to manage a greater number of trains, which appear on the grid at a faster pace.
- *Trouble Brewing*: in this game users take the place of a barista. They must prepare the correct coffees (in terms of ingredients and size) as shown on another screen, and not let the cups overflow. Points are awarded for coffees made correctly, and lost for wasted (i.e. incorrectly prepared) coffees.
- *Star Search*: different kinds of objects (which may be, for example, different shapes, colours and textures) are shown. Users must click on the 'odd object out'. For example, there might be multiple red flat triangles, blue hatched semicircles and green dotted hexagons, but a blue flat semicircle. The user would be required to click the flat blue semicircle.
- *Eagle Eye*: an arrangement of shapes, comprised of one eagle hidden amongst other non-bird distractors, is very briefly flashed on the screen. At the same time a digit is flashed in a square in the centre of the screen. The user must notice, remember and then click on on the location of the bird. They must then indicate the digit shown.
- *Lost in Migration*: based on the flanker paradigm (Kesler, Lacayo, & Jo, 2011). Users are shown birds in various formations, and required to press the arrow key corresponding to the direction the bird in the middle is facing.

- *Rhythm Revolution*: users are required to tap a rhythm with the space bar on their keyboards. At first the task is aided by visual cues (on a spinning record) but these disappear as the user gets better. The rhythm also gets faster and more complex.
- *Birdwatching*: a bird and a letter flash up simultaneously on the screen. Users must click where the bird appeared, at which point they are shown how accurate their click was. They must then type in the letter that is shown. As the user becomes more proficient the space between the bird and letter increases, and the length of time for which the bird and letter are shown decreases.
- *Observation Tower*: a number of bubbles are presented on the screen. Numbers are briefly flashed inside the bubbles. The user must click on the bubbles in order, based on the value of the numbers they contained. Clicking on the correct sequence gets the user points to build a taller tower.
- *Space Junk*: a number of space-related objects are simultaneously and very briefly flashed on the screen. The user must indicate how many objects he or she could count.
- *Playing Koi*: users must feed all the koi in a pond only once. As the koi look identical this requires users to keep track of them as they move. As users progress, there are more koi in the pond, distractor fish (which should not be fed) start to appear, the fish swim in different patterns, and the time between feedings becomes longer.
- *Top Chimp*: similar to *Observation Tower* although somewhat more complex interface where poker chips replace bubbles, and where the user has control over how many chips they want to 'bet on' (on which will briefly flash a number, the user's task being to click the chips in order of the numbers flashed) to win against a chimp opponent.

<u>Speed:</u>

- *Penguin Pursuit*: the user takes the place of a penguin, which must race (using the arrow keys) through a maze against a rival penguin to be the first to get the fish. At higher levels, the maze rotates, but the arrow key controls do not (i.e. the user might need to press the left arrow key to go up).
- *River Ranger*: animals (some of which look remarkably similar) are shown in a river. The user must click on an animal s/he has not clicked before. Increasing numbers of animals appear at a time as the user goes through the levels, and the length of time for which they are shown decreases.
- *Spatial Speed Match*: a simple *n*-back task with *n* of 1; users are shown an arrangement of three circles, one of which is blue. They are required to press the right arrow key if the location of the blue circle matches the previously shown arrangement, and the left arrow key if it does not. Users are scored based on speed and accuracy.
- *Speed Match*: a simple *n*-back task with *n* of 1; users are shown various symbols and asked to press the right arrow key if the symbol presented matches the one immediately before it, and to press the left arrow key if it does not. Users are scored based on speed and accuracy.
- *Speed Match Overdrive*: the same as Speed Match except that users must also indicate whether the second stimulus is a 'partial' match — i.e., same colour or shape (but not both).

- *Speed Pack*: based on Thurstone's Punched Holes task. Users are shown an open suitcase. This contains a grid in each compartment. The user's job is to place an item (as fast as possible) onto an empty space in the grids such that when the suitcase is folded, no two items will be on top of each other.
- *Splitting Seeds*: an even number of seeds are arranged on the screen. The user's job is to rotate a twig as fast as possible so that it splits the seeds exactly in half.

Flexibility:

- *Brain Shift*: two cards (one above the other) are shown to the user. A letter together with a number may appear in either. If they appear in the top card, the user must indicate whether the number is even (left arrow key press for no, right arrow key press for yes). If they appear in the bottom card, however, the user must indicate whether the letter is a vowel.
- *Brain Shift Overdrive*: the same as Brain Shift except that there are four cards. The questions are:
    - top left – is the number even?
    - bottom left – is the number odd?
    - top right – is the letter a vowel?
    - bottom right – is the letter a consonant?
- *Color Match*: based on the Stroop task (Kesler, Lacayo, & Jo, 2011). Users are shown two words — the left labelled 'meaning' and the right labelled 'color'. They have to indicate if the colour of the word on the right matches the meaning of the word on the left.
- *Disconnection*: a number of puzzle pieces with cartoon faces are shown. Users must match these as quickly as possible by moving them next to one another.
- *Disillusion*: a number of puzzle pieces with coloured shapes are shown. Puzzle pieces can be classed as either vertical (notches at top and bottom) or horizontal (notches at left and right). Users must match vertical puzzle pieces as quickly as possible by moving those with symbols of the same colour next to each other. They must match horizontal puzzle pieces as quickly as possible by moving those with symbols of the same shape next to each other.
- *Ebb and Flow*: leaves are presented on a screen and change colour between green and brown. When they are green, the user must press the arrow key corresponding to which way they are pointing. When they are brown, the user must press the arrow key corresponding to which way they are moving.
- *Robot Factory*: based on the go/no-go task, this is a game designed to train response inhibition. Users are presented with outlines of robots they are required to build. Parts for these robots are presented on three pedestals. Users must press the arrow key corresponding to the pedestal (left, right, down) if the part is needed but inhibit their response if it is not (as indicated by a cross that appears under the part).
- *Word Bubbles/Word Bubbles Rising*: a verbal fluency task. Users must type as many words they can think of beginning with a particular set of letters in three minutes. These must be of varying lengths to achieve a high score.

Problem Solving:

- *Addition Storm*: a number of animals rain from the sky. Each animal contains a simple addition question. Animals disappear once the correct answer to the question they contain has been provided. The game is over once three animals reach the ground.
- *By the Rules*: somewhat similar to the Wisconsin Card Sorting Test. Users are shown a single card (on which is printed one or more shapes) and required to indicate whether the card follows the rule or not. The particular rule in play has to be ascertained via trial and error.
- *Chalkboard Challenge*: users are presented with a blackboard divided in two. Single numbers and/or equations are presented on each side. Users must indicate which side is larger (e.g., 18 vs. 12 + 9).
- *Division Storm*: a number of balls rain from the sky. Each ball contains a simple division question. Balls disappear once the correct answer to the question they contain has been provided. The game is over once three balls reach the ground.
- *Multiplication Storm*: a number of fruits rain from the sky. Each fruit contains a simple multiplication question. Fruits disappear once the correct answer to the question they contain has been provided. The game is over once three fruits reach the ground.
- *Pet Detective*: a game designed to train route planning. A grid of roads is presented on which appears lost pets and corresponding houses to which pets need to be returned. Users must plan a route to return the lost pets to their owners using the shortest path possible.
- *Raindrops*: simple maths equations (addition, subtraction, multiplication and division) appear inside rain droplets which fall from the top of the screen. Users must enter the correct answer to the equation shown before the droplet reaches the puddle at the bottom of the screen.
- *Route to Sprout*: users are presented with grids of various shapes which contain a seed, a hole in which the seed should be planted, and a number of ladybugs. Users must plan and execute the most efficient (i.e., requiring the least clicks) route to get the seed to its hole.
- *Subtraction Storm*: a number of cupcakes rain from the sky. Each cupcake contains a simple subtraction question. Cupcakes disappear once the correct answer to the question they contain has been provided. The game is over once three cupcakes reach the ground.
- *Word Sort*: similar to By the Rules but the cards shown contain words instead of shapes. Users are shown a single card (on which is printed a word) and required to indicate whether the card follows the rule or not. The particular rule in play has to be ascertained via trial and error.

Courses

Lumosity's subscribers have access to all of the above games whenever they want. However, the website prescribes an individualised training regime and sends periodic training reminders based on the user's goals and performance.

Assessment

Users are continually provided with feedback about how their performance is improving with training. This feedback takes the form of:

- Scores and high scores from individual games.
- The *Brain Performance Index* (BPI): this indexes a user's cognitive performance across time and games. It can be further broken down into a number of subscores, namely memory, attention, speed, flexibility and problem solving. Users are told (via percentiles) how they compare to other users on their BPI and subscales.
- *Lumosity Points*: these are effort based, accruing to the user simply by completing more games.

Lumosity also offers standalone assessment tools to clinicians and researchers. Sternberg, Hardy, Katz, Ballard, and Scanlon (2012) describe the Brain Performance Test (BPT) which comprises six assessments as follows:

Assessment	**Task Description**	**Measure**
Go/No-Go	Users must click as fast as possible when one kind of fruit appears, but must not respond if any other kind of fruit appears.	Response time.
Trail-making A	Users must connect a series of dots containing numbers going from smallest to largest.	Completion time.
Trail-making B	Users must connect a series of dots containing numbers and letters like so: 1 to A to 2 to B to 3 to C...	Completion time.
Arithmetic Reasoning	Users must answer as many basic arithmetic problems (which are written in words) as they can in 90 seconds.	Correct – incorrect.
Reverse Memory Span	Users are shown a series of tiles. They must repeat the pattern flashed in reverse order.	Maximum span achieved.
Grammatical Reasoning	Users must respond to as many true/false logic questions as they can in 90 seconds.	Correct – incorrect.

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Website / for more information see:

http://www.lumosity.com
http://www.lumosity.com/hcp/research/completed.