Intelligence Amplification Map

Research Report — Intelligence Amplification Research, Part 1 of 3

General Facts

Research area:	Intelligence Amplification
Research topic:	Intelligence amplification map
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Summary

In May through August 2011, we did a literature review on the topic of intelligence amplification, i.e., on approaches to increasing or augmenting a person's intelligence. This served as the basis for later investigation.

Investigation

Background

Intelligence is broadly considered to be a powerful tool with widespread applications. One of these applications is research, and one potential topic of research is effective methods for enhancing intelligence. As such, it stands to reason that it might be positive to spark a positive feedback loop of intelligence amplification (IA), with intelligence amplification researchers making themselves smarter and smarter.

The theoretical possibility of a positive intelligence amplification feedback loop raises a number of important concerns, such as how effective such a process would be, how difficult to spark, and whether the resulting researchers would act in ways that benefited humanity.

In our investigation, our goal was to get a lay of the land, so that we might be better positioned to judge whether any IA interventions were sufficiently promising to investigate further.

Approach

In this case, the lead researcher performed a literature review and made a shallow assessment of different potential research paths in terms of impact (i.e., magnitude of effect), import (i.e., importance of type of effect), p(x) (i.e., probability of working), and cost.

In some cases, we were unable to make a shallow assessment of a given intervention.

Afterwards, the lead researcher wrote a paper describing the results (Appendix I), and an assistant compiled a table (see below).

What We Found

The lead researcher made a shallow assessment of 46 different potential means to amplify intelligence. The results are displayed here:

3	**Intervention**	**Impact**	**Import**	**p(x)**	**Cost**	**Ability/Abilities**
4	**I. Cognitive Training**					
5						
6	Dual N-Back	↘	↑	→	↘	Working spatial memory and working memory for digits.
7						
8	Representative Lumosity Games:					
9						
10	Penguin Pursuit	↓	↓	?	↘	Spatial Orientation
11	Speed Match	↘	↘	?	↘	Visual Information Processing
12	Birdwatching	↘	↘	→	↘	Visual Information Processing
13	Monster Garden	↓	→	↓	↘	Spatial Working Memory
14	Memory Match Overload	↓	→	↘	↘	Visual Working Memory
15	Memory Matrix	↘	→	?	↘	Spatial Working Memory
16	Name Tag	↘	↗	?	↘	Visual Memory (working and long-term)
17	Brain Shift	↘	?	?	↘	Task Switching
18	Playing Koi	?	→	?	↘	Visual Attention
19	Color Match	?	?	?	↘	Response Inhibition
20	Word Bubbles	↘	↑	↘	↘	Verbal Fluency
21	Raindrops	↗	→	↘	↘	Arithmetic Speed and Accuracy
22	Chalkboard Challenge	→	→	↘	↘	Quantitative Reasoning
23	By the Rules	↓	↑	↓	↘	Logical Reasoning (especially hypothesis testing)
24	Action Video Games	→	↗	→	↘	Visual Information Processing, Visual Working Memory
25	Children's Game "Memory"	?	→	?	↘	Visual Memory (working and long-term)
26	Crossword Puzzles	?	↗	?	↘	Verbal Fluency
27	Sudoku	?	↗	?	↘	Logical Reasoning

Intelligence amplification avenues, shallow assessment (screenshot 1 of 3)

3	Intervention	Impact	Import	p(x)	Cost	Ability/Abilities
28						
29	**II. Cognitive Heuristics**					
30						
31	Loci Method	↑	Varies	↑	↘	Long-term memory for information
32	Peg Method	→	Varies	↑	↘	Long-term memory for information
33	Chaining Method	↑	Varies	↑	↘	Long-term memory for information
34	Information Chunking	↗	Varies	↑	↘	Long-term memory for information
35						
36	**III. Meditation**					
37						
38	Short-term Mindfulness Meditation	↘	↑	?	→	Attention, Working Memory, Long-term memory, others
39	Long-term Mindfulness Meditation	→	↑	?	↗	Attention, Working Memory, Long-term memory, others
40						
41	**IV. Biofeedback**					
42						
43	General Neurofeedback Training	↘	↑	?	↗	Many
44						
45	**V. Nootropics**					
46						
47	Caffeine	↘	↗	↑	↗	Attention, some recall of memories
48	Methylphenidate (Ritalin)	↘	↗	↑	↑	Attention, some recall of memories
49	Adderall	↘	↗	↑	↑	Attention, some recall of memories
50	Modafinil	?	↗	?	↑	Attention, working memory, some recall of long-term memories
51	Ampakines	?	→	?	↑	Attention, general clarity of mind
52	Piracetam	→	↗	?	↑	Attention, general clarity of mind, working memory
53	Donepezil	?	→	?	↑	Long-term memory, others

Intelligence amplification avenues, shallow assessment (screenshot 2 of 3)

3	Intervention	Impact	Import	p(x)	Cost	Ability/Abilities
54						
55	**VI. Nutrition**					
56						
57	Blueberries (and other foods with flavanols	↓	↑	↑	↗	Attention, working memory, general memory
58	Creatine	↓	↗	→	↗	Working memory, others
59	Magnesium	↓	↗	?	↗	Working memory, others
60	Omega-3s	↓	↑	?	↗	Many
61	Turmeric	↓	→	?	↗	General memory (especially memory funcs. assoc. with hippocampus)
62	B Vitamins	?	?	?	?	Unknown
63	Trehalose	?	?	?	?	Unknown
64						
65	**VII. Exercise**					
66						
67	Aerobic Exercise	↘	↑	↗	↗	Many
68	Strength Training	?	?	?	?	Many
69						
70	**VIII. Physical Brain Stimulation**					
71						
72	TDCS	?	?	?	↑	Unknown
73	TMS	?	?	?	↑	Unknown
74	Ultrasound	?	?	?	↑	Unknown
75						

Intelligence amplification avenues, shallow assessment (screenshot 3 of 3)

The above table assesses impact, import, p(x), and cost on a 1-5 scale, with the orientation of the arrows visually indicating the numerical rating (red down arrow = 1; yellow down right arrow = 2, etc.). Where we were unable to make an assessment, we put a question mark (“?”).

Conclusions

Main Conclusion

Of the different avenues examined, some seemed likely to yield notable effects in some important circumstances. These were the mnemonic methods:

- Loci Method
- Peg Method
- Chaining Method
- Chunking

The other avenues, where we could make an assessment, either seemed unlikely to yield a large effect if they worked or unlikely to work.

Limitations

As this was a preliminary investigation, and at most a shallow examination of the relevant methods (in most cases without actual testing), we did not place an overly high probability on the accuracy of the results. Nevertheless, this research would contribute to our picture of intelligence, and the prospects for augmenting it, that would develop over time.

Next Steps

With our initial intelligence amplification map having served its purpose, our next step was to do a deeper dive into one of the potential intelligence enhancement modalities: cognitive training.

- Research Report on Cognitive Training of Intelligence *[forthcoming]*

Appendix

Initial Intelligence Amplification Map

INTELLIGENCE AMPLIFICATION MAP 2.0 (8/11/11)

Introduction

The purpose of this document is to lay out, in basic detail, the space of currently known methods of human cognitive enhancement and intelligence amplification (IA) that are at least minimally promising. It will focus on those methods that are truly intended to enhance intelligence, though a bit of time will be spent at the end of the document on techniques that aim to improve human performance in cognitive tasks without really improving any underlying abilities.[1]

One can classify IA methods in any number of ways. One could focus, for instance, on whether the intended gains are temporary or permanent, or on whether the method involved ingesting some type of substance or not. The classification scheme here will be based on the nature of the methods themselves. This scheme has several advantages over what we see as another *prima facie* promising approach—classifying methods in terms of the fundamental abilities or types of performance they aim to improve. First, the issue of what fundamental cognitive abilities there are is notoriously muddled and contentious, and hence it makes a good deal of sense to avoid a categorization scheme that threatens to commit us to a specific theory of cognitive abilities that many individuals will not share.[2] Second, since it is generally easier to describe (what we can roughly call) fundamental cognitive abilities and cognitive performance types than it is to describe many of the training methods discussed, it is correspondingly easier to organize the presentation around the training methods, so that they can each be introduced and discussed in full on one occasion each. This avoids cumbersome repetition of IA method descriptions each time the same method is brought up in connection with a new ability it is thought to improve.

The following are the broad categories that will be discussed in more detail below (note that some composite methods may cross categories):

- Direct Cognitive Training
- Cognitive Heuristics
- Creativity Training
- Meditation
- Biofeedback
- Nootropics
- Nutrition
- Exercise
- Physical Brain Stimulation

I. Direct Cognitive Training

Direct cognitive training methods are methods that aim to improve intelligence by training the specific component abilities (and perhaps meta-level analytical or processing abilities) that are believed to be part of overall intelligence.[3] Currently, there are numerous forms of direct cognitive training available commercially and many new ones on the way. In addition, there are many others available for free from internet sources. It would be virtually impossible to survey the entire range of direct cognitive training methods available, so we will instead focus primarily on popular and representative ones offered from internet sources, both commercial and non-commercial.

DUAL-N-BACK

The single training method that is arguably attracting the most attention at present is "Dual-N-Back." In its canonical version, Dual-N-Back tasks present a subject with an auditory stimulus (a voice reading letters from the alphabet) and a 3 X 3 spatial grid.[4] Individual squares in the 3 X 3 grid (never the center square) are successively illuminated, and while each is being illuminated, the voice reads an individual letter. The subject is instructed to press a particular computer key if the square that is lit matches the one that was lit N iterations ago and a different computer key if the letter read matches the one that was read N iterations ago. (These keys are never varied.) So, for instance, suppose the subject is playing Dual 3-back, and a round begins with spatial stimuli BC (bottom center), BR, TR, TL, CL and auditory stimuli A, T, U, V, S. If the next spatial stimulus is TR, the subject will hit the appropriate spatial stimulus key. If the next auditory stimulus is U, the subject will hit the appropriate auditory stimulus key. If it is both TR and U, the subject will hit both keys. If it is neither, the subject will hit neither key. (The typical length of a round is 20 + N stimuli of each type—giving the subject 20 chances with each stimulus type—lasting roughly 1 minute.)

Its proponents believe that the Dual-N-Back method has a number of favorable qualities to recommend it. One is that it requires divided attention, and this is thought to provide a more rigorous and profitable form of training than tasks which do not require such division. Another is that difficulty can be varied for subjects with more or less skill/experience—it can be increased as subjects improve in the task and decreased if subjects suffer setbacks or cannot sustain previous high levels of performance. (For instance, a subject might begin with a Dual-3-Back task, and as performance improves—as measured by coming in lower than a maximum threshold for number of errors in a particular round—the subject can move to a Dual-4-Back task, and so on.) This is thought to reduce (partially boredom-related) plateauing (the boredom presumably resulting from reaching a point where effortless high performance becomes second-nature), training fatigue, and reliance on narrow task-specific heuristics, all of which threaten the ultimate benefits of the training.[5]

At present, the jury remains out on the effectiveness of Dual-N-Back training—there are some promising preliminary results, but also a fair bit of skepticism. In addition, Dual-N-Back trains a fairly narrow range of cognitive abilities, and for it to serve as a "be all, end all" training method (as some proponents seem to suggest), it would need to produce impressive far-transfer effects. The question of whether there is any good evidence for such effects (or even for somewhat narrower effects) remains unresolved. In addition to a modest amount of data, there appear to be methodological problems (or at least methodological questions) surrounding some of the assessment measures used by Jaeggi (the apparent inventor of Dual-N-Back) and her colleagues as part of their case that Dual-N-Back improves fluid intelligence—the experimenters appear to have administered timed tests in unorthodox ways that may have ruined their ability to measure what they are designed to measure. (See especially Moody (2009) on this.)

LUMOSITY

Another training method (or, more accurately, suite of training tasks) that has been attracting attention are the games provided by the for-profit cognitive training company Lumos Labs, on their website lumosity.com, which currently has upwards of 10 million members.[6] At last count (on 5/20/11), Lumosity provides subscribing users with 40 different training games and, for users that prefer a structured regimen, offers different combinations of these games in a variety of "courses" that generally last for several dozen 15-20 minute sessions (intended for daily or near daily use). The games on the website aim to train a host of different cognitive abilities. Categorized roughly, the cognitive abilities are spatial orientation, visual information processing (for speed and accuracy), visual field processing, working memory, spatial recall, general information recall (e.g., putting a face with a name), focus, task switching, response inhibition, verbal fluency, arithmetic/quantitative reasoning, and logical reasoning.

Rather than running through all the games, we will provide a brief description of a representative game or two in each category (most categories have several games in them, with individual games often training what appear to be subtly different specific skills). The "Penguin Pursuit" game is a paradigmatic game in the spatial orientation category. The game display consists of a two-sided maze which is symmetrical about a vertical axis, with two penguins (one representing the player and the other a computer opponent). The object of the game is to reach the end point of the maze before the computer opponent does. The challenge of the game comes not just from negotiating the maze, but also negotiating various random rotations of the maze (when the maze rotates, the control arrows rotate as well, forcing the individual to mentally reorient the arrows). As the player proceeds through the levels, the mazes become more elaborate and the rotations more rapid, and in addition the computer opponent speeds up. (By the time a player reaches level 25, it is impossible or virtually impossible to move perfectly enough to defeat the computer opponent.)

Visual information games typically test and train one's ability to judge quickly and accurately that some presented visual stimulus is the same as or different from one presented just previously. An example is "Speed Match," one of Lumosity's oldest games. In this game, there is a succession of images that flow across the screen (in some rounds, these images are uniformly colored solid shapes, in others composite diversely colored shapes, and in still others Chinese characters). The player must indicate with a key press whether the displayed image is the same as the previous one. The player also controls the speed with which new images are displayed—not until the player provides a response does a new image appear. Individuals are scored for both speed and accuracy, with heavy bonuses provided for long strings of accurate responses that are not excessively slow.

Visual field processing games, on the other hand, tend to test one's ability to respond accurately to very quick visual stimuli, particularly stimuli on the periphery and in the midst of distracters. A paradigmatic example is Lumosity's oldest game, "Birdwatching." The display for this game consists of a large scenic photograph of a natural background. In the center of the screen is a small window. Letters flash in the window at the same time that tiny birds appear instantaneously at random places in the periphery (in higher levels, distracters—in the form of tiny blue dots—appear as well). After the stimuli have disappeared, the player must move a small camera beam (roughly the same size as the bird) directly over top of the spot where the bird appeared. (The player scores no points if the camera beam fails to shine on any part of the spot where the bird was, and scores increasing points based on how centrally placed the beam was.) If the player is able to shine the beam over some part of the spot where the bird appeared, he/she is asked to select the letter that flashed from among a group of possible choices. If the player guesses correctly, the letter appears "Wheel of Fortune-style" in a word display that spells the name of a bird. If the player guesses the bird name correctly, the player scores more points (based on the length of the name and the sparseness of letters that have been filled in).[7]

Many of the working memory games focus on spatial working memory[8], but some do not. A paradigm example of one that does is "Monster Garden." In this game, the player is a girl aiming to negotiate her way from a starting point to an ending point (represented by a flower). The game is played on an N X N grid (with the N varying based on the level selected at the beginning of the game—4 for lower levels and 5 for higher ones). A number of monsters are then revealed for a brief time, one by one, with each taking up a square in the N X N matrix.

(The number of monsters is again determined by the level.) The object is to go from the starting point to the finishing point without colliding with any monsters. Each playing of the game has ten rounds, presuming that one is able to complete them without running out of lives (one of which is lost each time the player collides with a monster). An example of a game that does not focus on spatial working memory is "Memory Match" and its sibling "Memory Match Overload." The display for and feel of these games is virtually the same as for "Speed Match" (described above), except that the player must decide whether the stimulus currently displayed matches the one 2 back (for "Memory Match") or 3 back (for "Memory Match Overload"). Again, as with "Speed Match," heavy bonuses are applied for long strings of accurate responses that are not excessively slow.

Spatial recall games typically require one to remember the positions of numerous items that are presented briefly. A good example of such a game is "Memory Matrix." In "Memory Matrix," one begins at the lowest level with a 3 X 3 matrix. In that matrix, 3 squares are briefly lit up, and then one must identify them subsequently without making any errors. If one performs the task successfully, one then continues to a slightly larger grid where 4 squares are illuminated. Mistakes on any but the last unidentified square result in reduction by one level (though never lower than the original 3 square illumination level), while mistakes on the final unidentified square (so long as one does not make mistakes in two successive rounds) results in a replay of the same level. Each playing of the game consists of 15 rounds, so one can advance to a 6 X 6 grid with 17 illuminated squares if one performs perfectly on the first 14 levels. Scores increase exponentially with successful completion of higher levels.

There are also general information recall games on the site, with recalling face/name combinations receiving primary emphasis. An example of such a game is the aptly titled "Name Tag" game, probably loosely based on the Milton Bradley children's game "Memory." In this game, one turns over cards, the visible side of which marks them as either a name or a picture. At the beginning of the game, one is introduced to two photographs, each of a person, and each associated with a name. One then attempts to match the name cards with their respective photos. (All names and photos appear in every level, though the positions are shuffled from level to level. Usually most of the individuals pictured differ fairly significantly in race, ethnicity, hair color, hair style, etc., though typically some are similar in appearance.) If one does this in an appropriately small number of tries (generally averaging no more than two turn-overs per card), one advances to a higher level where an additional name and face is provided.

In the task switching games, one must constantly adjust the rule one is following based on some cue provided by the game. An example is "Brain Shift." In "Brain Shift," one is presented with a game display with a top half and a bottom half. (The feel of the response mechanism is similar to that of "Speed Match" and "Memory Match," described above.) Combinations of a letter and a number are then randomly displayed on either the top half or the bottom half (e.g., E5 on the top half, followed by S2 on the bottom half, followed by 3B on the bottom half, etc.). If the combination appears on the top half and the number is even, one hits the right arrow. If the combination appears on the top half and the number is odd, one hits the left arrow. (So the combination being on the top half is a signal that evenness/oddness of the number is salient.) If the combination appears on the bottom half and the letter is a vowel, one hits the right arrow, whereas if the letter is a consonant, one hits the left arrow. (So the combination being on the bottom half is a signal that vowel/consonant status of the letter is salient.) Scoring patterns are similar to those of "Speed Match" and "Memory Match," with sizable bonuses being given for long strings of accurate and reasonably quick responses.

In the focus training exercises, one attempts to maintain focus in the face of somewhat serious obstacles to continued attention. An example is the "Playing Koi" game. The display for the game is an overhead view of a Japanese fish pond, where numerous qualitatively identical fish swim around randomly in the midst of lily pads that partially obscure the player's view of the pond (and wholly obscure the player's view of particular fish at some times). The fish—particularly in higher levels (where there are more lily pads and more fish)—often swim near (and in fact overtop of) other fish. One must then "feed" the fish by clicking on each of them without clicking on the same one twice. (After each click, there is a waiting period of several seconds before the next click is permitted, presumably to prevent the player from clicking so fast that it is easy to keep track of which fish is where.) Perfect rounds allow one to move up levels, with each level adding one fish (as well as new lily pads). (The starting level of this game is determined by previous performance, and each playing consists of 5 rounds.)

The response inhibition exercises emphasize censorship of and control over instinctive responses.[9] The paradigmatic game here is "Color Match," which appears to be based on the classic Stroop Task. In Color Match, the display is divided into a left half and a right half. On the left half is the name of a particular color, always in black font. On the right half is the name of a color that is itself in a particular colored font (which may or may not correspond to the name--e.g., 'YELLOW' or 'BLUE'). If the name on the left side matches the color of the word on the right side, the player hits the right arrow, whereas if these don't match, the player hits the left arrow. Each round seems to be divided up between fairly straightforward trials (where, e.g., the two names are identical, and the color of the font and the word on the right match—for instance, RED RED) and more difficult ones (e.g., BLUE GREEN or RED RED). Again, the scoring scheme and game feel are quite similar those of "Speed Match" and "Memory Match."

The verbal fluency games focus on one's ability to generate words that start with a particular succession of letters. A good example is "Word Bubbles," which Lumosity advertises as its most popular game. Each playing of the game consists of three one minute rounds. At the beginning of each round, the player is presented with a 3-letter prefix, and the object is for the player to come up with as many words as possible during the minute, with the caveat that only three words per length unit are permitted. (There are ten length units—the word lengths of 4 letters to 13+ letters inclusive.) (The first correct word of any given length scores 30 points, the second 60 points, and the third 90 points.) (Clearly, games such as this test and train knowledge of vocabulary and familiarity with heuristics for generating cognate words—e.g., by systematically using all possible conjugations of verbs—as much as they test and train any underlying verbal fluency ability.)[10]

Arithmetic and quantitative reasoning are trained with games that involve some form of explicit basic arithmetic.[11] The classic example of an arithmetic game—again, one of Lumosity's oldest games—is "Raindrops." "Raindrops" presents the player with a display where there are a number of slow-moving "raindrops" falling from the top of the screen to a body of water at the bottom of the screen. Within each raindrop is a simple addition, subtraction, multiplication, or division problem involving two one or two-digit numbers. When the player types in a correct answer to the problem in any particular raindrop, that raindrop disappears. The goal is to avoid allowing any of the raindrops to hit the body of water at the bottom of the screen. (As the game progresses, the raindrops move faster and faster and, in addition, more and more raindrops appear simultaneously. Wrong answers are penalized by losing the value of one correct answer, and correct answers become more and more valuable as the game progresses based on the number of previous correct answers.)[12] The main quantitative reasoning game is "Chalkboard Challenge." "Chalkboard Challenge" has a screen setup which is divided into right and left halves. Different simple arithmetic problems (in the lowest levels—one begins every game playing at the lowest level—just numbers) appear on each side of the screen, and the player must indicate (by hitting either the right arrow or left arrow) which problem has the higher number as answer. (Sometimes, the two will be equal, and this is indicated by hitting a different key.) Much as in many of the earlier games already discussed, no new stimulus is presented until a response has been given for the current stimulus. One difference with Chalkboard Challenge, however, is that rather than the game having a set temporal length, there is a timer which runs down more quickly when a wrong answer has been given, but which is augmented by bonuses after every fifth correct answer. (Hence, the timer can be refreshed indefinitely. At the highest levels, though, the problems involve enough operations that it is difficult to prevent the timer from gradually winding down.)[13]

The final training area, logical reasoning, is comprised of two games that are very similar to one another—"Word Sort" and "By the Rules."[14] Both require the player to sort objects into categories based on whether the objects follow a particular rule (in "By The Rules," the objects are cards; in "Word Sort," they are words). (The player is not told the rule, and hence the object is to discover the rule by inference from trial and error.) Once the player sorts six consecutive cards correctly, points are added to the player's score (based on how quickly the rule was discovered) and the rule is replaced. Level is determined entirely by previous performance, and difficulty is increased by increasing the possible range of features that might be salient for the rule. For instance, the highest level of "By the Rules" has rules that focus on the status of one of six salient features—card outline (solid, dotted, or dashed), striped pattern across the card (horizontal, vertical, or unstriped), number of objects on the card (one, two, or three), shape of the objects on the card (triangle, circle, or square), color of the objects (red, blue, or green), and nature of the coloring of the objects (solidly colored, shaded, or colored only along the edges). So, for instance, a particular rule might be "green." Another might be "2 objects." (The rules are always simple in this way—they are never conjunctive or disjunctive.)

At present, questions about the effectiveness of Lumosity remain largely unresolved. Although Lumosity promotes itself as being based on the latest scientific research and boasts numerous prominent psychologists and neuroscientists on its advisory board, published research confirming the effectiveness of Lumosity has been sparse thus far. But, on the other hand, so has published research claiming to demonstrate the ineffectiveness of the games on the site. Because Lumosity has such a diverse suite of games, it may very well be that the results are complex, with some games showing more promise than others. (In fact, it seems like the primary way that the results would wind up not being complex in this way is if none of the games wind up showing promise. This is because a number of the games seem clearly ineffective. We do not believe ourselves to be in the position to evaluate this issue further, however.)

Lumosity does have a number of general issues that are worthy of note. It is fairly easy (and requires a relatively minimal time investment) to all but max out performance in some of the games. In addition, in a number of the games (e.g., "Memory Matrix" and "Penguin Pursuit") time is wasted because every playing of the game begins at the most basic level, a level that is unchallenging to all but the most novice and unskilled players. Hence, a player spends the majority of the game working through the basic levels in order to arrive, near the end of the playing, at a level which provides some serious challenge. This is an inefficient training regimen, even if the games have promise in principle. Also, heuristics can be readily applied to many of the games (e.g., "Monster Garden," where with repeated playings one will begin to memorize the possible placements of monsters).[15] Although the usefulness of explicit heuristics and factual knowledge varies from game to game (e.g., very useful in "Monster Garden," much less so in "Color Match"), the effectiveness of games where performance is heavily improved by heuristics is likely to be suspect, particularly where those heuristics are narrow and highly task specific, as well as in ones where the heuristics largely replace the need for exertion of mental effort. These games may be testing and training explicit knowledge or familiarity with heuristics more than they are testing and training some underlying fundamental ability or abilities, or even general knowledge that is likely to be broadly useful in real-life intellectual activities.

VIDEO GAMES

In recent years, several studies have been done by psychologists and neuroscientists strongly suggesting that the playing of action video games (games such as “Grand Theft Auto,” Halo,” and “God of War”) increases the speed with which visual information is processed, and may also increase players’ aptitude at rotation of visual objects, effective division of attention, and even visual memory.[16] Although to our knowledge these gains have not been shown to extend to any cognitive activities not closely associated with the visual modality, action video games may ultimately be an important component in an overall cognitive training regimen.

As yet, little is known about the benefits (or lack thereof) of non-action video games, except that they do not seem to have any significant visual processing speed benefits. However, many do require reasoning, planning, and complex decision-making, and in addition provide feedback in the form of success or failure at the game. Consequently, they too may hold some promise—particularly the sophisticated games available today—but we have yet to evaluate any relevant evidence or even learn whether there is any such evidence available.

LOW TECH AND LONG AVAILABLE TRAINING ALTERNATIVES

There are also numerous low tech training options available. These include the children’s game “Memory,” crossword puzzles, chess puzzles, and Sudoku. While some of these clearly reward and (to some extent) teach the acquisition of task-specific heuristics and explicit propositional knowledge, they may have promise nonetheless. (“Memory,” for instance, seems to train similar skills as the Lumosity game “Name Tag.”) We have yet to search the existing literature for evidence that relates to these methods.

There are also some slightly higher tech training options that have been around for decades. Among these are the children’s game “Simon” (available in many free internet incarnations) and the traditional Nintendo game “Tetris.” (“Simon” requires a user to recall a random sequential pattern of illuminated colored spaces. The game display is a circle whose circumference is illuminated by four stationary lights. These lights then illuminate in random order. Correct responses result in the addition of one item to the previous illuminated pattern, and one’s score in the game is the number of illuminated lights in the final successfully completed trial. We won’t attempt to describe “Tetris” due to its complexity and familiarity, but it tests the ability of users to manipulate falling shapes so that they fit appropriately on pre-existing structures.) These tasks may also show promise, though there are questions (dating back to research in the early 1990s by Richard Haier) about whether the difficulty of “Tetris” can increased enough to provide sustained opportunities for cognitive improvement in experienced players. At present, it is unclear (at least to us) how effectively these activities train the respective skills they focus on and (even if the training is effective) how important those skills are to real-life cognitive pursuits.[17] We do not yet have a good grasp of what research exists on the merits of these activities as cognitive training aids.

GENERAL REMARKS—THE PROMISE OF INTENSIVE TRAINING

While (as discussed above) there are still many unanswered questions regarding the effectiveness of most of the training regimens discussed, there is some reason for general optimism about some forms of intensive training. A study done by Schmiedek *et. al.* suggested that, at least in young adults, an online training regimen with tasks at least roughly similar to many of the games on Lumosity could produce at least some impressive near-transfer cognitive benefits.[18] The regimen involved a series of tasks (varying by session) performed over a one hour period. The subjects completed 100 sessions at the rate of roughly one every other day. It remains to be seen, though, how long lasting these benefits are and how intensively one must train to maintain them. (A big source of trouble is that it is difficult to discern from the Schmiedek *et al.* paper what exactly the training regimen consisted in and how improvement was assessed. Often, Schmiedek's descriptions of training tasks are too hasty to allow for a precise interpretation, and the tests used to measure improvement are generally not described in any detail. These are issues we hope to follow up on.)

II. Cognitive Heuristics

What we are calling "cognitive heuristics" are explicit sets of instructions, methods, or procedures that are designed to improve performance on particular intellectual tasks.[19] It goes without saying that there are far too many heuristics available for the wide range of possible intellectual tasks to admit of a broad survey here. Fortunately, some of these heuristics are familiar to virtually every educated person (some to virtually every person *simpliciter*!)—e.g., solving basic equations in symbolic arithmetic by writing down one's work in steps on a piece of paper (rather than trying to store them in one's head) or using repetition to help with memorization. Others are perhaps less familiar, but quite unpromising—e.g., speed reading techniques.[20] We will focus on two particular kinds of heuristics which are at least somewhat promising and far from universally known—mnemonics and speed calculation devices. We will also discuss a versatile memory heuristic (or family of heuristics) that is somewhat widely used, but perhaps not widely enough—chunking.

MNEMONICS

Mnemonics are procedures for making it easier to remember information (easier than trying to nakedly memorize the information on a first go or by using repetition). The most common form of mnemonic is what might be termed an "acronym mnemonic." Many American school children are familiar with one of these—the acronym 'HOMES', which gives the first letter of each of the five Great Lakes (Huron, Ontario, Michigan, Erie, and Superior).[21] While undoubtedly effective and easy to use, such mnemonics suffer from severe limitations. The most notable of these is that one must have a list that can be conveniently fit into a memorable acronym (preferably an acronym that spells some recognizable word), and few lists are so accommodating. In addition, such mnemonics require that one be able to recall a full word just from a first letter coding for that word, which itself may be difficult in some circumstances.

There are other mnemonic techniques, however, that are considerably more versatile. The vast majority of these (perhaps all of them) tend to employ visual imagery in one way or another, and most have been around for thousands of years.[22] (They were especially useful in ancient societies, where large amounts of information might have to be transmitted without ready access to writing materials.) Probably the most famous is the "Method of Loci," sometimes called the "Memory Palace Method" or simply the "Loci Method." The Loci Method requires an individual to have pre-memorized an ordered set of visually represented locations—e.g., rooms in a building, landmarks along a known road, etc. The individual then takes a list of words (which could represent a list of items or keywords that prompt recall of larger bodies of information) and converts them to vivid, detailed visual images that are either semantically or phonologically connected to the respective word. (An example of a semantic connection—the word is 'dog', and one pictures a dog. An example of a phonological connection—the word is 'context', and one pictures a written text sitting on top of a traffic cone.) One then places these images in their respective "niches" in the pre-memorized set of visually represented locations, preferably in a zany or otherwise striking way.[23] (So, e.g., if the first word is 'dog' and the first niche is a specific house along a familiar road, I might imagine a dog jumping out of a window in the house.)

A somewhat less versatile but easier variation on the Method of Loci is the "Peg Method." The Peg Method requires an individual to pre-memorize an ordered list of items (usually roughly 20). The items in this list using have some ready connection to the number they represent in the list. (Some versions, for example, just have individuals remember giant numerals or objects that look similar to the numerals—e.g, a hook for the number 5 or pen for the number 1. Other ones have people remember lists of items that have cultural connections with the numbers the respective items represent—e.g., having an image of a cat represent the number 9, since cats have "nine lives." Still others have individuals memorize items that have phonological connections with the numbers—e.g., having an image of a skate represent the number 8, since the word 'skate' rhymes with the word 'eight'.) Once this list of items is memorized, one can then use a mini-version of the Loci Method to store a list of up to as many items as one has pre-memorized. One simply joins new visual images associated with the words to images in the pre-memorized list, just as one would do with the Method of Loci.

A less well-known but similar mnemonic to these is the "Chaining Method" (sometimes called the "Story Method" or the "Story Chaining Method"). The Chaining Method is like the Loci Method (based on creating memorable visual images) except that individuals don't attach the images to pre-memorized loci. Rather, they simply connect one image to another, relying on the succession of action to move them from one image to the next. Here is an example of how it works: suppose a person wants to memorize the words 'red', 'washington', and 'jobs', in that order. The person would conjure up a vivid visual image of (e.g.) a bunch of red washing machines bouncing around a town, with one of the washing machines opening up and a pork chop flying out.[24]

Although less well-known, the Chaining Method has several advantages over the Loci Method. The main one is there is no time investment involved in pre-memorizing a bunch of loci. Relatedly, the Chaining Method is not limited by the number of loci you have pre-memorized—having enough loci to store information permanently can be a real challenge. It is true that in memory competitions competitors almost always use the Loci Method, and that fact does suggest that it probably somewhat easier to store the images if they are fixed to loci.[25] But individuals in memory competitions only care about memorizing things for a short time. Typically, when competitions are finished, these individuals deliberately try to forget the things they have remembered (so they can reuse the loci). It is likely that they would run out of loci if they tried to store information permanently.[26]

The basic principles of these memory systems can be applied more widely than just the memorization of lists of information. The definitions of difficult terms or translations of foreign words can often be memorized more easily with visual images. In trying to remember that the Italian word 'burro' means the same thing as the English word 'butter', for instance, an English speaker might imagine a wild boar being smothered by butter. There are also fairly simple systems for storing numbers as visual images. These systems typically associate each digit '0' through '9' with a particular consonant sound. For example, in one such system, the digit '1' is associated with the sound made by the letter 't' and the digit '2' is associated with the sound made by the letter ‘n’. To remember the number 12, then, the individual forms an image of some object whose name involves a “t” sound followed by an “n” sound, with no intervening consonant sounds. (An image of a tin will work just fine.) As the numbers involve more and more digits (so as to prevent any single image from encoding all of the digits), one simply chains images together that encode the original digits in a way that respects their order.

All of these visual image-based methods take advantage of the apparently near universal psychological fact that human beings remember dramatic, detailed visual images more readily than they directly remember verbal information that is read or heard. (It is not entirely clear how much of the benefits of the mnemonics come from the generation of the images involving activity—as opposed to the passive taking in of information—and how much come from them being dramatic and visually detailed.)

While these mnemonics are demonstrably effective, they do have limitations and weaknesses. Memorizing information via the Chaining or Loci Methods is really not much better than having a list of information inside the head rather than on a piece of paper. The information does not readily “sink in” in the way it would if memorized in a traditional, direct fashion. Consequently, analyzing the information, drawing inferences from it, and generally making “connections” is very difficult without a substantial amount of detailed rehearsal (the rehearsal enabling a form of more direct memorization).[27] With the Chaining Method especially (but also to some extent with the Loci and Peg Methods), there is also the issue that recall of information can be cumbersome. Often (particularly in chains of images that are fairly fresh and have not been rehearsed a great deal) accessing a piece of information will require an individual to work his/her way through an entire chain from the beginning, since one’s recall of each image depends on recalling the image that comes immediately before it. This can be inconvenient in some “real-world” situations where a premium is placed on immediate recall. (This problem is exacerbated in situations where one’s attention is divided, and one cannot spare a great deal of cognitive energy or focus for the recall activity—perhaps one is in the midst of carrying on a conversation, for instance. Recall of information memorized in a direct, traditional way is generally effortless—especially when that information is “fresh in one’s mind”—while recall of information stored via visual mnemonics requires at least a modicum of effort and concentration. Again, though, this problem can largely be solved by rehearsal, but the need for a lot of rehearsal would vitiate one of the primary selling points for these mnemonics in the first place.)

As a general point, it does seem abundantly clear that visual image-based mnemonic devices are heuristics in the sense discussed above—they aim to help individuals employ fundamental, basic intellectual abilities more effectively to perform real-life intellectual tasks rather than aiming to improve the fundamental abilities themselves. Nevertheless, there are issues about the connection between these devices and fundamental abilities which remain unresolved. It is somewhat plausible to conjecture, for instance, that using visual mnemonics will improve one kind of (potentially) fundamental ability—a certain kind of creativity in visualization, or perhaps concentration or an ability to incorporate sharp detail in visual images. (Granted, though, that these are not fundamental abilities that have any intimate connection with the memory skills one would associate with normal, brute memorization.) But does using visual mnemonics help in some indirect way to improve even brute memorization abilities? Could it be, for instance, that people who train with visual mnemonics induce neural changes that help in some fairly straightforward but introspectibly inaccessible way to improve brute memorization ability? To our knowledge, questions of this sort have not been studied, at least in any sort of systematic way. [28]

CHUNKING

'Chunking' refers to any technique for remembering lists of digits, letters, or the like that relies on grouping those objects into smaller sections or "chunks."[29] Chunking is employed by virtually everyone in the process of remembering a phone number, and in fact phone companies often readily provide numbers pre-chunked.[30] For instance, when confronted with the American-style phone number 5527299363, most people would instinctively group the digits into chunks of 3 or 4 (most likely, 552-729-9363). This sort of technique has been shown to vastly improve recall.

While some of the uses for chunking are obvious and widely appreciated, other uses are both less obvious and less widely appreciated. For instance, chunking can be used to remember the positions of illuminated squares in a grid—a common component in exercises that are part of commercially available intelligence tests and intelligence training products. (Dual-N-Back and the Lumosity game "Memory Matrix" are examples. In these games, one can note that some groups of squares form familiar shapes or track geometrically regular paths.)

To pick up on a familiar theme, there remain many unanswered questions related to the effectiveness of chunking in varied situations. It is readily apparent that some kinds of information lend themselves to chunking more easily than others (e.g., the group of digits '12345' is easier to chunk than '72953'), and that chunks of different sizes are more effective than others. (E.g., chunking a phone number into groups of 3, 3, and 4 digits is typically more effective than chunking it into a group of 8 and a group of 2.) But it is far from clear how variable across situations and individuals these effectiveness differences are, and so consequently helpful general guidelines for the use of chunking are not generally available, nor are satisfying theoretical treatments designed to explain the usefulness of chunking. Although considerably more work has been done on the limitations of chunking and its capacity to improve recall, many issues there remain unresolved nevertheless.

III. Meditation

Meditation is one of the most promising of the indirect methods for training intelligence. It has received a fair bit of attention from researchers since the 1970s, and a number of suggestive (if incomplete) findings on its effectiveness are emerging.

To begin, though, we must acknowledge that there are many forms of meditation involving subtly (and sometimes not so subtly) different activities. For our purposes, we can usefully divide types of meditation into those that emphasize concentration and those that emphasis mindfulness.[31] (There are also hybrid examples that integrate components of both types, though often emphasizing one over the other.) Types of meditation that emphasize concentration tend to require the individual to focus attention on some target—a visual image, a sound/mantra, the sensation of deep breathing, etc. Mindfulness meditation, on the other hand, involves striving to maintain an “unattached” awareness of all available thoughts and sensations, including sensations directly produced by environmental stimuli. Although non-metaphorical descriptions of mindfulness meditation are (understandably) hard to come by, meditators are encouraged to note the presence of any thoughts or sensations that arise (and note their rich detail) without focusing or reflecting on them at length. Meditators should simply note their presence and briefly bask in their rich detail, then go back to introspecting in a passive way, waiting for other thoughts and sensations to establish themselves prominently in the mind.

It has been long established that there are stress relief and mood benefits to meditation, as well as physiological changes to the cerebral cortex that appear conducive to more efficient brain functioning (especially in areas of the right interior insula and parts of the prefrontal cortex involved in attention and sensory processing).[32] There has been quite a bit of uncertainty, though, about whether meditation provided direct cognitive benefits, with early experiments purporting to show these benefits suffering from significant methodological flaws.

Recent studies have been encouraging, however, even when the meditation programs are short in duration and the amount of time spent meditating is quite modest. Fadel Zeidan and his colleagues conducted a study of late, for instance, that appears to show that statistically significant cognitive benefits come from following even a very brief meditation program.[33] Zeidan *et. al.* had a group of students with no prior meditation experience follow a guided meditation regimen with an experienced instructor. The program consisted of only four

20-minute sessions, where the subjects performed meditation involving both concentration and mindfulness aspects, while a control group spent the time listening to an audio version of the J.R.R. Tolkien novel *The Hobbit*.[34] There were no statistically significant cognitive differences between the groups prior to the experiment, but shortly afterwards statistically significant differences were observed between the groups in scoring on the "Symbol Digit Modalities Test" (a widely used assessment of ability to memorize and apply various rules that convert numbers to letters) and a verbal fluency test—the meditators did markedly better.[35] (No statistically significant benefit was observed on a computerized N-Back task, however.)

Much work remains to be done in confirming these and similar results, determining how sensitive to exact meditation styles (as well as experience levels, session lengths, etc.) the results are, and understanding how long-lasting the meditators can expect benefits to be. In spite of reasons to be optimistic about short-term programs, it appears that most of the benefits of meditation (including its cognitive benefits) do increase more or less monotonically with time spent in meditation (both in a single session and over the lifetime of the program). Thus, where the motivation for meditation is the hope of tangible benefits, there will likely be questions about the optimal amount of time and effort to dedicate to it. To our knowledge, although such practical motives do drive much contemporary interest in meditation, little work has been done on these issues and consequently little credible advice is available.

IV. Biofeedback

Biofeedback (and in particular neurofeedback) is a topic of growing interest as it relates to cognitive performance. Neurofeedback research has grown out of work done over the last several decades in analyzing electroencephalograph (EEG) readings and their significance. A raw EEG trace includes data about waves of many different frequencies, and the information in the raw EEG can be processed to yield real-time breakdowns of activity at these different frequencies. Beginning in the late 1960s, researchers slowly established that there were a variety of correlations between skill at specific cognitive tasks and activity at particular frequencies (and for that matter correlations between skill at some non-cognitive tasks—like putting a golf ball or shooting an arrow from a bow—and activity at other particular frequencies).[36] This gave rise to a cottage industry of experiments that attempted to discern whether changes to activity in specific frequency ranges could causally impact cognitive performance (and other kinds of performance as well, such as in music, dance, and athletics, though these are not really relevant here). The intent was to provide instantaneous feedback to individuals whose EEGs were being measured about the amplitude of the waves in whatever specific frequency was being targeted (the feedback was sometimes audio, sometimes video, and sometimes a combination), in the hopes that these individuals would associate a particular feedback value with a specific sensation or frame of mind, and then learn to control the amplitude by deliberately inducing that sensation or placing themselves in that frame of mind. Once the values were under voluntary control, their causal effects on cognitive processes of interest could then be studied in detail.

Most subsequent neurofeedback studies have aimed to learn (1) whether individuals can be trained to bring about changes in EEG component readings of specified sorts and/or (2) whether the underlying processes responsible for any changes in EEG component readings (or differences in EEG component readings across persons) causally explain differences in cognitive performance. With respect to (1), there is a consistent track record indicating that individuals *can* change EEG component readings in a wide variety of frequencies (though these changes do not always occur—this has been a recurring problem in studies investigating whether changes in brain wave amplitudes causally affect cognitive processes). With respect to (2), the findings are quite a bit more up in the air. Although crude but fairly definite correlations have been established between amplitude at specific wavelengths and memory, attention, and general intelligence (according to common measures), studies solidly demonstrating a causal relationship from EEG component patterns to any of these abilities have been hard to come by.

In the area of attention, Egner and Gruzelier (2004) did find a statistically significant performance improvement on a range of attentional assessements following a neurofeedback training program designed to increase amplitude of low beta waves (low beta waves have frequency 12-18 Hz). (Both a control group and a group engaged in neurofeedback training focusing on a different frequency range failed to see any improvement on the same assessments.) However, it was later pointed out (by Vernon (2005)) that neither neurofeedback group actually succeeded in changing the amplitude of the waves in their respective target frequencies, leaving the mechanism of improved performance up in the air. (Perhaps the improvement was even due to a mere statistical anomaly.)

A preliminary experiment attempting to show that a neurofeedback training program on low beta waves helps with short-term semantic memory showed significant results (Vernon *et al.* (2003)), but a follow up study failed to confirm these results (Vernon *et. al.* (2004)). Similarly ambiguous results have emerged in studies of neurofeedback training for creativity and spatial rotation abilities (though more encouraging for spatial rotation). Perhaps the most promising findings have been in treatment of learning disabilities and ADHD, but even here the results are preliminary. (See, for example, Tansey (1991).)

Even if neurofeedback training winds up being effective, currently there are numerous practical problems associated with its use. The foremost is that EEGs are expensive and require expertise to set up and use. Most people do not have access to them and, even if they did, they would not be qualified to use them (and it is probably not feasible to train large numbers of people in professional clinical settings). There may be ways to remedy this problem, though, by making safe neurofeedback technology cheaper and easier to use.

V. Nootropics

Nootropics are drugs that aim to improve some aspect(s) of cognitive performance or better a cognitive ability (usually temporarily). It is virtually impossible to survey the broad range of possibilities, so we will instead focus on products that are especially popular, prominently discussed, or promising.

Probably the most common nootropic is also the one that people think of first—caffeine. Caffeine's primary function in the human brain is to block adenosine receptors. (Adenosine is typically released as a byproduct of neural functioning, and hence serves as a rough measure of an accumulated amount of neural activity since the last adenosine "clean up.") This blocking of adenosine receptors cuts off a natural pathway that inhibits dopamine and glutamate activity, allowing dopamine and glutamate to "run wild" in the brain. (When the brain senses the presence of large quantities of adenosine, it triggers resting mechanisms that inhibit dopamine and glutamate.) Both dopamine and glutamate function as stimulants, hence the characteristic feeling associated with caffeine.

Caffeine has a number of beneficial properties where cognitive functioning is concerned, some of which are widely known. It increases energy, alertness, and focus, and also appears to help in short-term memory tasks where the memories required are related to the current train of thought. (Likely not coincidentally, studies have shown increased activity in both the frontal lobe and anterior cingulated cortex after caffeine intake. These areas are important for short-term memory and attention respectively.) However, caffeine may have negative long-term cognitive consequences, albeit relatively mild ones. Preliminary experiments on mice suggest that long-term consumption of low doses of caffeine damages long-term memory and impairs the genesis of new neurons in the hippocampus, a brain region centrally important for memory formation. One study has even suggested that caffeine may increase the likelihood of the "tip of the tongue" phenomenon, where a known word or piece of information resists recall.[37] It must also be said that some of the foods and drinks that contain caffeine also have other ingredients with beneficial or detrimental effects on brain functioning (or general health). (An example is the antioxidants in coffee.) This is obviously also a consideration that must be taken into account in making decisions about the wisdom of long-term caffeine intake through particular foods or drinks.

Another common nootropic is the ADHD and anti-narcolepsy drug Methylphenidate, marketed in many forms under many different names. It is most commonly known by its inventor's original title for it and its trademarked brand name—'Ritalin'. Ritalin's primary function is to increase dopamine levels in the brain by acting as a dopamine reuptake inhibitor. (When neurotransmitters are released into a synapse—neurons use neurotransmitters to communicate with other neurons—after they bind with the postsynaptic neuron they are often destroyed or removed to prevent rebinding with sites on the postsynaptic neuron. A reuptake inhibitor stops this process from occurring, or at least severely impedes it.) Although Ritalin is known to improve concentration and focus in individuals with ADHD, it remains a matter of controversy exactly how it does so. One hypothesis is that the increased dopamine presence makes stimuli more salient and hence easier to focus on and store in long-term memory. (Dopamine is causally involved in the production of many kinds of pleasure.) It also remains controversial just how effective Ritalin is on the brains of individuals who do not suffer from ADHD and do not have conditions which may give them temporary attentional difficulties, such as sleep deprivation. (Although one study did show that average SAT scores of normal students increased by 100 points after taking Ritalin.)[38] In any case, although Ritalin does have the promise of some temporary cognitive benefits, it is a close chemical relative of cocaine and has numerous common short and long-term side effects. It also remains unclear whether long-term Ritalin use contributes to physiological damage later in life that can result in depression and diminished cognitive functioning.

A newer, related nootropic is the ADHD and anti-narcolepsy drug Adderall, released in 1996. Unlike Ritalin, Adderall is actually not a single chemical substance—it is instead a mixture of numerous amphetamine salts. It is believed to work primarily by increasing the amount of dopamine and norepinephrine in the brain, as well as by serving as both a dopamine reuptake inhibitor and a norepinephrine reuptake inhibitor. (These dual roles may be closely related to one another, because preventing reuptake may be an important cause of the increased presence of these neurotransmitters.) It is known to reduce ADHD symptoms and increase alertness, concentration, and focus in both ADHD sufferers and normal individuals, and is typically used for ADHD patients who do not respond to Ritalin or whose responsiveness has worn off. It does, however, carry with it many of the risks and side-effects of Ritalin (often in more pronounced form), including sleeplessness, strongly reduced appetite, and jitteriness. There is also some suggestive evidence that it is associated with increased risk of heart attack and stroke, and it is known to raise blood pressure in some users. The chemical similarities that several of its components have to cocaine and "crystal meth" also make it ripe for serious abuse. It should also be said that Adderall is considerably newer than Ritalin, and so there is still the potential for long-term side effects to emerge that are not currently recognized.

A less widely known relative of Ritalin and Adderall is Modafinil, used primarily to treat narcolepsy (although it appears to be effective also in the treatment of ADHD). (Modafinil, however, is not approved for use by children.) It appears to work by once again increasing the levels of norepinephrine and dopamine in the brain, though the mechanism of its action appears to be different from those of Ritalin or Adderall.[39] It is known to improve both mood and wakefulness, and it appears to have less potential for abuse than Ritalin or Adderall.[40] (It is also banned by many professional sports governing bodies because it is presumed to enhance energy and stamina.) There is no consensus, however, on the extent of its cognitive benefits on healthy, non-sleep deprived individuals. It does seem to help with some aspects of working memory, such as digit span, digit manipulation, and pattern recognition tasks, but its usefulness is less clear for other kinds of tasks, like executive function and spatial working memory tasks.[41] Its benefits may also be more pronounced for those with low IQ.[42] While perhaps somewhat promising as a cognitive enhancer (and general mood and stamina enhancer), there are a number of risks and side-effects users should be aware of. First, as with Ritalin and Adderall, loss of appetite while on the drug is common. In addition, there are rare but serious dermatological reactions that sometimes occur. Overall, Modafinil is still too new to be fully confident that there are no as yet unnoticed long-term side effects. (It first appeared on the market in 1998.)

Modafinil (particularly under the brand name "Provigil") is often associated with another family of nootropics, the ampakines. (Some new ampakines may be mixed with Provigil when they are released on the market.) Although ampakines are stimulants, they do not appear to have unpleasant side-effects common of other stimulants, like sleeplessness. They are known for producing a clear state of mind, and they appear to work by increasing the activity of glutamate (a neurotransmitter centrally involved in many forms of learning and memory) and facilitating its binding to AMPA receptors on post-synaptic neurons, which may be conducive to more efficient communication between neurons at synapses. Little is yet known about any side effects associated with ampakines.

The racetam family of drugs (most notably Piracetam) appears to work in a partly similar way to the ampakines. Although Piracetam's exact mechanisms are not well understood, it does seem to stimulate activity across the corpus callosum. It is also available over the counter in the U.S., and its side-effects are generally mild. (It has also been around since 1964.) Rigorous studies of its general cognitive benefits in normal individuals have been sparse from what we can tell, but one older double-blind experiment suggested that a two-week regimen of Piracetam improved verbal memory in healthy college students (Dimond *et al.* (1976)). There is a sizeable track record of findings indicating that Piracetam improves cognition in dyslexics, severe alcoholics, and stroke victims. It may also help in the treatment of autism and Alzheimer's.

The final nootropic we will discuss is Donepezil, also known by its Pfizer brand name "Aricept." Since its release in 1996, Donepezil has been a very popular treatment for Alzheimer's disease, but some researchers have suggested that it can have cognitive benefits even for normal individuals. Some of the findings, while preliminary, have been suggestive. For instance, Chuah *et al.* (2009) showed a statistically significant correlation between Donepezil intake and episodic memory performance in sleep-deprived but otherwise normal individuals. (It found no such correlation between Donepezil intake and episodic memory performance in normal non-sleep-deprived individuals, though.) Ginani *et al.* (2011) found that Donepezil improved dual task performance, sustained attention, and reaction times (as well as other fairly fundamental abilities) in a small study of normal individuals.

Since Donepezil was not developed with an eye toward use by normal individuals, there has not been a great deal of work done on its long-term side effects for these individuals. It has a number of widespread short-term side effects, however, including abdominal pain, loss of appetite, and bradycardia (abnormally slow heartbeat).

VI. Nutrition

The topic of nutrition and cognitive health is obviously massive, and consequently we will not attempt to provide any sort of comprehensive survey of the terrain here. Rather, we will simply indicate areas where there is especially active nutritional research (as it relates to cognitive functioning) and prominent areas where the existing research at least moderately suggests that there are cognitive benefits (or cognitive detriments) associated with the intake of specific foods.[43]

Blueberries are among the most widely known, and perhaps among the most well-studied, of foods believed to be beneficial. The results of these studies have been quite promising, in fact. Blueberries (along with other dark colored berries like blackberries and cranberries, as well as grapes) contain high concentrations of antioxidants called “flavanols.”[44] Scientists have also observed that flavanols readily cross the blood-brain barrier in rats that consume dark colored berries. And since the blood-brain barrier in rats is very similar to the blood-brain barrier in humans, it is plausible to conjecture that the same process occurs in human brains as well. (It is no coincidence that grapes, dark colored berries, and other dark colored foods—like cocoa—contain flavanols, by the way; flavanols often serve as dark pigments.) In one recent study by Jeremy Spencer (albeit a small one, with only 80 participants—including the control group), individuals consuming blueberry smoothies in the morning showed statistically significant advantages in attention and short term memory tests over controls consuming calorically identical smoothies with no blueberries. (The tests were administered five hours after drinking the smoothies. Interestingly, there were no advantages one hour after ingesting the beverages.) Another small study headed by Robert Krikorian found statistically significant advantages in tests of learning and memory for older adults (average age 76) drinking a specified moderate quantity of blueberry juice for 12 weeks.[45] (It is believed that the flavanoids may be helping both because they are antioxidants and because they appear to be able to improve neural regeneration and neural signaling mechanisms.) There is even some preliminary evidence (using rats as a model organism) that blueberries may help to prevent brain damage from ischemic strokes.[46]

The substance "creatine," while widely known and used as a muscle-building training aid, also appears to have some potential as a cognitive enhancer. A recent study (Rae *et al.* (2003)) indicates that there was a strongly statistically significant correlation ($P < .0001$) between a relatively mild dose of creatine—5g/day—and performance improvements in a common measure of working memory and also one of general intelligence for young adult vegetarians. There have also been studies linking it with improved cognition in the elderly and with better cognitive performance under sleep deprivation. (The mechanism is a matter of some dispute, but appears to be linked to creatine's role in producing more cellular fuel.) Side effects associated with creatine use also generally appear to be mild and relatively uncommon.

Magnesium, while a bit more obscure, shows some promise in its own right. A recent study (Slutsky *et al.* (2010)) indicated that increasing brain magnesium in rats led to enhancement of learning abilities, working memory, and long-term memory. The majority of Americans—61%—actually fail to get the RDA for magnesium as well, suggesting that there may be benefits to be had by increasing intake to recommended levels. At the moment, though, we are unsure about the quantity and quality of detailed findings available about magnesium's role in brain functioning.

We are also unsure of what relevant research has been done on what may be the most commonly known food ingredient thought to impact brain health—omega 3 fatty acids. As far as we can tell, most of the research on omega 3s has focused on benefits other than cognition (with many of the studies focusing on issues other than brain health, like effects on cancer risk and cardiac functioning). There is also the issue that most of the best sources of Omega 3s are fish, and fish—particularly fish higher up on the food chain, like tuna, shark, and swordfish—also contain mercury. Often, the mercury they contain is part of methylmercury, a highly toxic compound ion, and is known to have harmful effects on cognition and brain health more generally. (The reader is reminded of the *Alice in Wonderland* character "The Mad Hatter," a stereotype of a 19th century hatter. Hatters in the 19th century typically used solutions containing mercury in their treatment of felt, and many of them would inhale the fumes or carelessly ingest the mercury by licking the felt as part of the preparation procedure. As a result, they developed chronic—and often serious—cognitive impairments, including severe memory loss. While the dangers of ingesting mercury from fish are not so extreme, there nevertheless appear to be negative consequences, particularly for children and pregnant women.)

A much more obscure (but possibly promising) substance is turmeric, an ingredient in the traditional Chinese medicine Xiaoyao-San. In a study of rats (Xu *et al.* (2007)), turmeric was found to increase regeneration of neurons in the hippocampus (an area of the brain integral to memory formation) in animals under stress. Possibly relatedly, it also appeared to stimulate the generation of BDNF, a protein that helps neurons to survive and also helps in the development of new neurons and synapses.

There are also a number of advocates for various B vitamins and the substance trehalose. We have not had an opportunity to review the evidence yet in enough detail to comment on the prospects for these substances, however.

We would be remiss if we did not include some remarks on hydration in this section. Although it appears to be a matter of some controversy in the scientific community just how much water intake is required for proper hydration (perhaps because it is a matter of some controversy what exact physiological state constitutes proper hydration), relatively subtle deficiencies appear to be associated with at least short-term impairments in processing speed (including visual processing), working memory, and attention.[47] [48]

VII. Exercise

We still need to better explore what the available findings are related to exercise and cognition, but there appears to be a growing body of evidence suggesting that aerobic exercise and aerobic fitness are cognitively beneficial. For instance, a recent study demonstrated a correlation between aerobic fitness and hippocampal size in older adults (aged 59 to 81), and it had been previously established that hippocampal size is correlated with performance in a variety of memory tasks as well as with spatial orientation skills.[49] Another experiment (Gobesky *et al.* (2009)) indicated that neurogenesis in mice was stimulated by cardiovascular exercise, perhaps by stimulating the production of a chemical called (seriously) "Noggin," whose role in the brain appears to be to inhibit the function of BMP, a protein that impedes the development of stem cells in the brain into neurons.

At the moment, we are also unsure whether weight lifting and other non-aerobic forms of exercise have any cognitive benefits. We are unaware of any work on the issue.

VIII. Physical Brain Stimulation

In the last few decades, a number have techniques have emerged that revolve around directly exposing the brain to electrical, magnetic, or sonic stimuli. Respective examples include transcranial direct current stimulation (TDCS), transcranial magnetic stimulation (TMS), and ultrasound. (These, in fact, may be the only technologies of this sort currently in use.) As far as we can tell, research is quite sparse on the potential benefits of these technologies for cognition, though interest seems to be growing and the technologies have been studied in connection with the treatment of conditions such Parkinson's and schizophrenia.

Enhancing Performance in Other Ways

As we mentioned in the introduction, there are also methods of enhancing intellectual performance that do not involve improving any underlying cognitive abilities (or even spurring the acceptance of helpful heuristics or useful information). While we cannot discuss these at length in the current document, it seems advisable to note them so that they can be targeted for future research.

Although not synchronically relevant to the presence of abilities, an important factor in whether an ability is employed effectively (and developed to its full potential) is the level of motivation an individual possesses. Motivation, in turn, can be a function of mood and general "zestfulness." Consequently, developing ways to ensure that individuals are motivated (both in the moment and across time) is a potentially promising way of improving cognitive performance independent of any enhancement to intelligence.

For those interested in enhancing intelligence in the pursuit of good aims, it is also important to ensure that cognitively enhanced individuals are as benevolent (or, perhaps more accurately, as good) as possible. (We have taken the approach in this document that virtuous and vicious people alike can be intelligent or unintelligent and that an increase in benevolence could itself easily be neutral with respect to intelligence.)[50] Insofar as the goodness of the goal aimed at (whether it be in action or theoretical inquiry) is a factor in assessing cognitive performance, training or otherwise motivating people to be benevolent is obviously of great importance. (And even if the goodness of the goals is a matter entirely separate from cognitive or intellectual performance, it is nevertheless crucially important for a general assessment of people's thought and behavior.)

Although at present we do not have much information, the United States Military has also developed (and, as far as we know, continues to develop) technologies designed to present the environment to an individual in a "smart" and easy to interact with way. These may be related to technological devices—like computers and scheduling enhancers—that make it easier for individuals to keep organized and negotiate the demands of daily life.[51]

Some people are also investigating group dynamics in an effort to improve the performance of those groups while the individuals in them work together on cognitive tasks. For instance, it may be that there are ways to get groups to follow rules that enable the individuals with the most insightful ideas to dominate verbal communication at the times when they have the insightful ideas, thus making communication more efficient and (hopefully) improving morale. At present, we do not know much about these techniques and cannot evaluate whether they are promising.

There is also some work being done to study the employment of what might be termed "meta-heuristics." These are essentially heuristics for determining where effective heuristics for performing cognitive tasks might be located! Most of these meta-heuristics focus on encouraging people to place themselves in social environments where they are likely to be exposed to interesting and fruitful ideas, to people with creative and effective ways of solving problems, etc. Again, we have little information on the details here, so we cannot evaluate how likely this sort of work is to yield important insights.

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[1] It may actually be difficult to draw the line in a principled fashion between those methods that truly aim to amplify intelligence and those that merely aim to maximize performance. While there will certainly be clear-cut cases on either side, there will be plenty of borderline ones as well, particularly where the method involved aims to provide the individual with knowledge of an explicit heuristic or algorithm for improved performance, but where that explicit method does not seem to have much noticeable impact on any underlying brain hardware. We will employ a rough-and-ready approach to classifying these methods, generally preferring to err on the side of treating them as methods of real IA.

[2] Some rough provisional commitments are inevitable, though—they are required just to talk about the abilities that might be improved by different methods. Our discussion will aim to remain as conventional and uncontroversial as possible in this regard, albeit with some small concessions to precision. The present document is not the place to discuss any revolutionary proposals for understanding the conceptual terrain of intelligence research.

[3] The effectiveness of these training methods are often assessed via their "near-transfer effects" (effects on performance in tests of cognitive abilities similar to the ones being directly trained) and "far-transfer effects" (effects on performance in tests of cognitive abilities quite different from the ones being directly trained).

[4] Some versions do not present a visible grid (such as the version available on Lumosity—it simply presents lit squares at seemingly random points around the screen). It is unclear whether there is a hidden grid in such versions or if the lit squares really are appearing in random places around the screen.

[5] See the work of Richard Haier (dating back to the early 1990s) on the importance of any training regimen challenging users beyond what is comfortable to them.

[6] There are other for-profit internet training programs available, but Lumosity is by far the most popular and seems to be the most sophisticated at present.

[7] Two comments about this "Birdwatching" game. First, it is clearly not a pure test of visual field processing, since part of the score is determined by one's facility at guessing the names of birds "Wheel of Fortune-style," and this has nothing to do with visual field processing. Second, the sort of visual field processing at issue seems to have little to do with anything that would typically be called "intelligence." In response to this worry, the makers of the game would probably point out that, even if it isn't part of intelligence, it is nevertheless a kind of cognitive processing that is worthy of training. (They claim that it is known to be correlated with reduced risk of automobile accidents, for instance.) In addition, there is some evidence (particularly from studies on the effects of action video game playing) that increased visual field processing speed may be correlated with (or even cause of) increased skill in tasks more centrally associated with intelligence. So, it may be that the makers of the game are hoping for such far-transfer effects. It should also be said that Lumosity has another game—"Top Chimp"—which seems to combine visual field processing training with activities more centrally associated with intelligence in a more organic way. In this game, individuals must remember a series of numbers that flash in random places around the screen and recall them in order.

[8] The distinction (made by Lumosity itself) between working memory (in these spatial instances) and spatial recall is not entirely clear.

[9] There is really only one response inhibition game advertised as such—"Color Match"—and it seems to bear close similarities to the focus game "Lost in Migration." Hence, it really might make sense to collapse the focus and response inhibition categories into one.

[10] It may be that the game is a better measure and trainer of verbal fluency among high performers, all of whom we can presume would already be using near optimal heuristics. Still, though, the extent of vocabulary knowledge is likely to be a major performance factor. (Speed of typing is likely to be another significant factor, since the task is under heavy time pressure.)

[11] The arithmetic/quantitative reasoning distinction is Lumosity's own. Insofar as it is a clear distinction, it seems to have something to do with the complexity of the arithmetical tasks. The games labeled as training arithmetic typically focus on doing large numbers of simple calculations (e.g., adding or subtracting pairs of two-digit numbers), while the quantitative reasoning tasks involve several simple tasks rolled into one (e.g., calculating (2*5) + 4 – 10). The games involving the latter sort of task often reward the use of heuristics—e.g., comparison heuristics in "Chalkboard Challenge," where the two sides differ only in some small but obviously significant way.

[12] Typing speed can often be a significant factor in performance in this game. Obviously, this skill has little or no connection to the central underlying ability that the game is designed to test and train.

[13] Heuristics are clearly useful in "Chalkboard Challenge." For instance, sometimes a good bit of time can be saved by noticing that there is just a slight difference between the two sides—e.g., a problem like "(5*4)/10 + 3" vs. "(5*4)/10 – 3". Also, it often saves time to notice computation-saving patterns—e.g., noticing at a glance that "(8*2)/8" is just 2.

[14] There is actually another area—"Planning"—which consists of just one game. However, this one game ("Route to Sprout") is arguably one of the least promising game on the entire site, so we omit discussion of it and its associated area.

[15] We are including game-specific knowledge under the label 'heuristics'. This includes familiarity with unstated game parameters (as with, e.g., the possible range of rules in "By the Rules"). Some of the games also test (and perhaps train) general knowledge, as of vocabulary in "Word Bubbles."

[16] For a review, see Dye *et. al.*, (2009).

[17] By "skills" here, we mean to speak of improvements due to factors other than growth of highly task-specific empirical knowledge or familiarity with heuristics that are unhelpful in real-life cognitive pursuits. Thus, the relevant improvements will either be improvements to some underlying hardware (involving improvements in some fundamental ability), or consist of learning general information/heuristics or information/heuristics that are readily applicable to some real-life intellectual task (preferably a real-life intellectual task that is important in a variety of settings).

[18] See Schmiedek *et. al.* (2010).

[19] See the note in the introduction to this document about classifying these heuristics as methods of intelligence amplification. Loosely speaking, cognitive heuristics do not aim to improve fundamental cognitive abilities so much as to employ those fundamental cognitive abilities in more efficient and more effective ways to perform real-life intellectual tasks.

[20] It is actually somewhat unclear whether speed reading deserves to be classified as a cognitive heuristic, since mature speed reading may amount largely or wholly to some kind of internalized "know-how" that involves no conscious instruction-following. In any case, there are philosophical issues surrounding "know-how" that we will avoid getting into here, but that may turn out to be important ultimately.

[21] Another famous one is the acronym 'ROY G. BIV', for the successive colors of the visible light spectrum. This one is strangely famous, since 'BIV' is not even a real English word or recognizable name. It seems to work well, though!

[22] There are, of course, many non-visual mnemonics aside from using acronyms. Many of these involve noticing *ad hoc* connections (phonological, semantic, etc.) between things to be memorized, or between things that need to be memorized and things that are already known and can provide useful mnemonic anchors for the new material. These mnemonics are so diverse that it makes little sense to try to survey them here, though many of them are quite useful, at least in specific situations.

[23] Some studies have suggested that the outlandishness or bizarreness of an image may not be a particularly important factor in whether the image is readily recallable. (See, for instance, Senter and Hoffman (1976).) But there is considerable evidence that making images that are interactive with one another is an important factor.

[24] When looking for phonological connections, it is often helpful to be aware of phonological connections between sounds that are often represented with different letters—e.g., the sounds indicated by 'p' and 'b', or by 'j' and 'ch'.

[25] The 2006 World Memory Champion, Clemens Mayer, was able to memorize 1,040 random digits in a half hour using this method, for example.

[26] Although one individual did memorize pi to over 65,000 digits using a system of loci. It is unclear how he had managed to have so many pre-established loci, however. As far as we know, having spaces for 65,000 pieces of information in one's memory palace is highly atypical (even for memory experts).

[27] Although to the best of our knowledge the matter has not been studied systematically, anecdotal evidence suggests that information may "sink in" more quickly and easily when it is directly memorized via rehearsal from stored images instead of via rehearsal from an outside source (written notes, etc.). Crucially, though, this rehearsal must involve not just rehearsal of the images, but a self-reminder of what keywords (and detailed information associated with keywords) are associated with the images.

[28] There has also been scant work done on the usefulness of mnemonics for long-term memory storage and recall. (E.g., there is little work on whether information which is originally learned by a visual mnemonic and then unrehearsed subsequently is easier to recall X number of days/months later as compared to information learned by rote repetition.)

[29] While chunking could easily be categorized as a mnemonic, it is unique enough that it merits its own separate discussion.

[30] Our discussion here will focus on what might be called "active" or "deliberate" chunking. This is to be contrasted with might be called "passive" or "subconscious" chunking—the mind's natural tendency to effortlessly categorize things in efficient ways that allow for easier memory and recall. Passive chunking is probably what allows (e.g.) chess masters to memorize the board positions of actual chess games with astonishing precision, even though it has been demonstrated that chess masters are no better than average non-chess players at memorizing chess boards with pieces randomly placed on them.

[31] This way of classifying meditation is suggested by the discussion in Vernon (2009), 99-100.

[32] See, for instance, Lazar et. al. (2006). Although the correlations are fairly certain and even the causal relationship between meditation and these changes reasonably well established, the exact causal mechanism remains controversial. In particular, it is a contentious issue whether meditation causes these changes directly or instead causes behavioral changes which then in turn cause the thickening of the cortex.

[33] See Zeidan et. al (2010).

[34] Zeidan and his colleagues use the term "mindfulness meditation" to describe the sort of practice their experiment involved, but their description makes it clear that concentration elements were also involved (especially concentration on breathing sensations).

[35] There were also statistically significant differences pre and post-meditation for the meditating group, both after each session and after the entire program.

[36] Some of the correlations are correlations between skill and absolute activity in a particular frequency range and specific region of the cortex, while others are correlations between skill and ratio of activity in a particular frequency range between one region of the cortex and another. (Although it is unclear to us at present, some correlations may even be between skill and ratio of activity in different frequency ranges within the same cortical region.)   See Vernon (2009), 187-188 for discussion.

[37] See Lesk *et al.* (2004).

[38] **I don't have a reference on this—it was in a talk I heard in a neurobiology class in April 2010.**

[39] Specific information on its mechanism of action was hard to come by.

[40] See, for example Myrick *et al.* (2004) and Deroche-Gamoney *et al.* (2002).

[41] **See Wikipedia for more references. (This will eventually be either deleted or replaced by the references.)**

[42] See Randall *et al.* (2005).

[43] We will also bypass areas where nutrition is only thought to *indirectly* benefit cognitive functioning, by making people generally feel more healthy (thus enabling them to avoid health related distractions) or by extending their lives (thereby giving them a longer window to gain knowledge and theorize). (The same goes for indirect harm of cognitive function *mutatis mutandis*.)

[44] Strawberries and raspberries also contain flavanols, but apparently not as high a concentration of them.

[45] See Spencer (2009) and Krikorian *et al.* (2010).

[46] See Sweeney *et al.* (2002).

[47] Lumosity blog post from 7/1/2009.

[48] **Somewhere in the past, possibly on the Lumosity blog, I recall seeing something suggesting that dehydration could result in death of neurons, possibly significant numbers of neurons. I don't see that now, though.**

[49] Lumosity blog post from 3/18/2009.

[50] There may, of course, be complications here. For instance, it may be that intelligent people are more likely *ceteris paribus* to discover the truth about things (and that nothing about intelligence itself makes people unreasonable or deficient in some other way that would vitiate that advantage), and hence that these individuals are

more likely to be good because they are more likely to have discovered the truth about goodness. These complications are quite subtle, though, and can be safely ignored for present purposes.

[51] If one wished to be technical, one could of course place the use of these items in the "heuristics" section, since employing them does, in a sense, involve following a rule-of-thumb or procedure. These procedures are too different from the kinds of heuristics discussed in that section to make that classification helpful, though.