Serious Games for Active Aging

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What Can Be Done about Cognitive Decline?

- **Good news**
  - Neural plasticity at all ages
  - New drugs to delay cognitive decline

- **Potentially good news**
  - Monitoring computer interactions may detect decline earlier
  - Development of cognitive exercises to delay decline and possibly remediate
The brain is composed of a number of specialized regions serving distinct functions. Our life and productivity depend on a variety of brain functions, not just one. There is nothing inherently fixed in the trajectory of how brain functions evolve as we age.
### Myths vs. Facts

<table>
<thead>
<tr>
<th>Myths</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Genes determine the fate of our brains.</td>
<td>Lifelong neuroplasticity allows our lifestyles and actions to play a meaningful role in how our brains physically evolve, especially given longer life expectancy.</td>
</tr>
<tr>
<td>2. Aging means automatic decline.</td>
<td>There is nothing inherently fixed in the precise trajectory of how brain functions evolve as we age.</td>
</tr>
<tr>
<td>3. Medication is the main hope for cognitive enhancement.</td>
<td>Non-invasive interventions can have comparable and more durable effects, side effect-free.</td>
</tr>
<tr>
<td>4. We will soon have a Magic Pill or General Solution to solve all our cognitive challenges.</td>
<td>A multi-pronged approach is recommended, centered around nutrition, stress management, and both physical and mental exercise.</td>
</tr>
<tr>
<td>5. There is only one “it” in “Use It or Lose it”.</td>
<td>The brain is composed of a number of specialized units. Our life and productivity depend on a variety of brain functions, not just one.</td>
</tr>
<tr>
<td>6. All brain activities or exercises are equal.</td>
<td>Varied and targeted exercises are the necessary ingredients in brain training so that a wide range of brain functions can be stimulated.</td>
</tr>
<tr>
<td>7. There is only one way to train your brain.</td>
<td>Brain functions can be impacted in a number of ways: through meditation, cognitive therapy, cognitive training.</td>
</tr>
<tr>
<td>8. We all have something called “Brain Age”.</td>
<td>Brain age is a fiction. No two individuals have the same brain or expression of brain functions.</td>
</tr>
<tr>
<td>9. That “brain age” can be reversed by 10, 20, 30 years.</td>
<td>Brain training can improve specific brain functions, but, with research available today, cannot be said to roll back one’s “brain age” by a number of years.</td>
</tr>
<tr>
<td>10. All human brains need the same brain training.</td>
<td>As in physical fitness, users must ask themselves: What functions do I need to improve on? In what timeframe? What is my budget?</td>
</tr>
</tbody>
</table>
### Brain Functions

<table>
<thead>
<tr>
<th>BRAIN FUNCTION</th>
<th>SKILLS INVOLVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception</td>
<td>Recognition and interpretation of sensory stimuli.</td>
</tr>
<tr>
<td>Attention</td>
<td>Ability to sustain concentration on a particular object, action, or thought. Ability to manage competing demands in our environment.</td>
</tr>
<tr>
<td>Memory</td>
<td>Short-term memory (limited storage). Long-term memory (unlimited storage).</td>
</tr>
<tr>
<td>Motor</td>
<td>Ability to mobilize our muscles and bodies. Ability to manipulate objects.</td>
</tr>
<tr>
<td>Language and Auditory Processing</td>
<td>Skills allowing us to differentiate and comprehend sounds and generate verbal output.</td>
</tr>
<tr>
<td>Visual and Spatial Processing</td>
<td>Ability to process incoming visual stimuli. Ability to visualize images and scenarios.</td>
</tr>
</tbody>
</table>
| Executive Functions       | Abilities that enable goal-oriented behavior, such as the ability to plan, and execute a goal. These include:  
                             • Flexibility  
                             • Theory of mind  
                             • Anticipation  
                             • Problem-solving  
                             • Decision making  
                             • Working Memory  
                             • Emotional self-regulation  
                             • Sequencing  
                             • Inhibition |
Problems with Current Cognitive Assessment Methods

- Assessments done only after concern on the part of the patient or caregiver – usually late
- Repeated assessments infrequent – yearly at best
- Large day-to-day variability in cognitive performance with onset of dementia
- Unwanted variability in assessments due to education, language, motivation, etc.
Traditional Cognitive Tests

- Verbal Fluency
- Word List Learning
- Constructional Praxis
- Trail Making Test
- Symbol Digit Modalities Test
- Letter-Number Sequencing
- Finger Tap Test
How does computer game performance relate to cognitive functions?

Adaptive Cognitive Computer Games
Spry Learning / OHSU (NIST grant)
Example: Spry Learning Adaptive Cognitive Computer Games

- 30 users (all cognitively healthy)
  - Average age 81.5 yrs (standard dev= 6.04 yrs)
  - 13% male, 87% female
- 9 Interactive games developed with Spry Learning as part of NIST grant
- Evaluated in local elders’ residences
- Neuropsychological data was collected at baseline, 3 month, 6 month, and at a planned 1 year period
Older Adults’ Use of Computers

- Growth in computer use by elders rose 47% since 2000 – fastest growing group
- 70% use email
- 59% Web browsing
- 35% play computer games (similar to general population rate of 39%)
In-Home Monitoring of Computer Interactions

- Frequent data → trend detection
  - Individual as their own control
  - Less influenced by
    - Educational background
    - Language
    - Cultural differences
- Dynamic algorithms to model user performance
- Inexpensive → screening, coaching
**Objective:** Develop metrics that reflect cognitive capability and function of the players

For Each Game

**Ideal Player:**
Develop framework capturing the information processing resources and capabilities required by an ideal player

**Cognitive Models and Limits:**
Describe ways that a human player may differ from an ideal one

**Specific Metrics:**
Characterize the required cognitive processes by a small set of parameters
Word games:
- Word length
- Word complexity
- Speed of word generation
- Total number of words

Compare to:
- Verbal Fluency
Letter Generation Rate as a Game Metric

Total Time to Guess Words (Each Game) vs Number Letters Guessed Correctly (User 1020)

Regression Equation:
$$y = 2.31189x + 13.2406$$
$$r = 0.866714$$
Shorter words are guessed more frequently than longer ones

Exception is 7 letter word

- Try harder because it’s the goal
- Have to use all letters
- Hence not necessarily most difficult
Neuropsychological Scores vs. Proportion of Word

Neuropsych Average Total Fluency vs Game Difficulty

\[ y = 0.522433 x + 40.2374 \]
\[ r = 0.403347 \text{ (with outliers)} \]

\[ y = 0.687054 x + 31.3083 \]
\[ r = 0.659844 \text{ (w/o outliers)} \]
On the Flip Side – Memory Game

Memory games:
• Short-term memory
• Working memory
• Spatial memory
• Abstract reasoning
Characterize Memory Capacity as a Function of:

- Intervening number of events
- Intervening time
- Memory load

Simple Memory Model: Discrete Buffer
Results

Subject 1020, N = 8687

Probability of Correct Intervening Number of Events

Probability of Correct Intervening Time [sec]
Examples of Other Fits

Subject 1021, N = 387

Subject 1024, N = 892
Weekly Tracking of Working Memory Buffer Size

Subject 1021, N = 120

Time [Days]

Relative Buffer Size
Estimation of Working Memory Capacity

![Bar Chart]

- **X-axis**: Subjects
- **Y-axis**: Square Root of Buffer Size

The chart illustrates the distribution of square root of buffer sizes across different subjects.
Assessment of Neuropsychological Test Scores

TRAILS-B Scores vs. Predicted Scores from Flipside

- Trail-Making Test B: R = 0.60
- Digit Span: R = 0.36
21 Tally (2-D Black Jack)

Dual Task games:
- Divided attention
- Working memory
- Spatial memory
### Evaluation Metrics

<table>
<thead>
<tr>
<th>Double Bust</th>
<th>Single Bust</th>
<th>Accept</th>
<th>Single Win</th>
<th>Multiple Win</th>
</tr>
</thead>
</table>

**Bust-Win**

\[
q(t) = N_{\text{win}}(t) - N_{\text{bust}}(t) + \alpha
\]

\[
Value(\text{loc} | c, b(t)) = q(\text{loc} | c, b(t)) + Eq\{b(t + 1)\}
\]

\[
Eq\{b(t + 1)\} = \frac{1}{N_{\text{loc}}} \sum_{\text{loc}} \sum_{c} p(c) \cdot q(\text{loc} | c, b(t + 1))
\]
Response Time vs Quality of Move

Subject ID: 1020

α = 3 in quality function

Value of subject move / value of ideal move

Response Time per move (sec)
Reference Players

- **Ideal Player**
  - uniform card distribution
  - look a single move ahead
  - choose ‘loc*’ where
    \[
    Value_c(loc^*) = \min(\text{Value}_c(loc_i)), \ i = 1 \ldots \#
    \]
    empty loc
    \[
    Value_q(loc^*) = \max(\text{Value}_q(loc_i)), \ i = 1 \ldots \#
    \]
    empty loc

- **Chance Player**
  - place card randomly
  - all locations are equally likely
Modeling Subject Reaction Time

\[ p_0(N_o) = e^{-\left(\frac{N_o}{a}\right)^b} \]

**Parameters:**
- \( a = 9.9886 \)
- \( b = 38.4971 \)
- \( T_o = 1.284 \) s
- \( T_e = 0.683 \) s
- \( RT_{\text{min}} = 2.9397 \) s

**Equation:**

\[ RT(N_o) = RT_{\text{min}} + p_0(N_o) \cdot T_o \cdot N_o + (1 - p_0(N_o)) \cdot T_e \cdot (16 - N_o) \]

**Graph:**
- **Prob Searching Occ Loc**
- **Avg RT per move**

**Legend:**
- Data
- Model

**Note:**
- "Serial Processing of locations"
Modeling Subject Reaction Time

![Graph](image)

- Top graph: Probability of searching occupied locations as a function of the number of occupied locations.
- Bottom graph: Average response time per move as a function of the number of occupied locations.

Legend:
- Circles: Data
- Line: Model
# Modeling Subject Reaction Time

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>a</th>
<th>b</th>
<th>T_occ</th>
<th>T_emp</th>
<th>T_min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1020</td>
<td>10.7166</td>
<td>13.3114</td>
<td>1.2583</td>
<td>0.4043</td>
<td>3.3855</td>
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<tr>
<td>1021</td>
<td>14.1551</td>
<td>1.1685</td>
<td>1.8104</td>
<td>0.2804</td>
<td>1.2226</td>
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<tr>
<td>1022</td>
<td>11.8667</td>
<td>3.834</td>
<td>0.9403</td>
<td>0.9704</td>
<td>2.9144</td>
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<tr>
<td>1023</td>
<td>0.9</td>
<td>12.769</td>
<td>0</td>
<td>1.6135</td>
<td>0.9237</td>
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<tr>
<td>1024</td>
<td>37.9464</td>
<td>12.248</td>
<td>1.0</td>
<td>0.6830</td>
<td>2.9397</td>
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<td>1025</td>
<td>38.4971</td>
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<td>0.8088</td>
<td>0.2773</td>
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<td>1026</td>
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<td>1027</td>
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<td>1.0</td>
<td>0.5736</td>
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<tr>
<td>1028</td>
<td>1.2249</td>
<td>9.9950</td>
<td>0.1127</td>
<td>0.0385</td>
<td>2.137</td>
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<tr>
<td>1029</td>
<td>11.5338</td>
<td>4.6529</td>
<td>1.2456</td>
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<tr>
<td>1030</td>
<td>8.7695</td>
<td>12.867</td>
<td>0.5714</td>
<td>0.0385</td>
<td>2.137</td>
</tr>
<tr>
<td>1031</td>
<td>12.8849</td>
<td>21.9481</td>
<td>0.6782</td>
<td>9.9996</td>
<td>2.9198</td>
</tr>
</tbody>
</table>

- **Took more time looking at...**

- **Model shows these subjects don’t spend time searching empty locations**
Cost and Benefits of Divided Attention

Forced Bust

Unforced Bust

Forced Bust-Win
Pyramid Builder – Color / Shape Matching

Shape / color games:
- Divided attention
- Speed / accuracy
- Visual search
- Planning
- Working memory
Response Time vs. Move Number

- Response time (move duration) increases with the complexity of the game.
  - Average move duration increases with move number.
  - Variance increases with move number.

File: tst3.mouse
Example: Response Time Distribution
(Data from a Single Game)

Multimodal distribution suggests

- Fast responses to known or easy decision
- Medium requiring some search and decision
- Long – pondering and planning of execution
Resulting Search Efficiency

Correlation with Trail-making B

$R = 0.49$

Move Times [sec]

Number of Distractors

slope = 24 ms/item
Rapid movement games:
- Motor speed
- Visual search
- Set switching
- Speed of processing
- Divided attention

Compare to:
- Finger Tap Test
- Trail Making Test
FreeCell – Planning Game

Strategy games:
- Planning
- Visual search
User Performance Metrics

- Difficulty
  \[ D_t = \sum_{\tau=1}^{t} f(d_{\tau} - d_{\tau-1}), \]
  \( d_t = \) number of moves to solution at time \( t \)

- User Performance
  - Reduction in difficulty
    \[ \eta_t = d_t - d_{t+1} \]
  - Outcome of game
  - Time to completion
FreeCell Performance Curve

- Actual
- Expected

subject

solver
<table>
<thead>
<tr>
<th></th>
<th>Average (Individual Ave(Perf))</th>
<th>St Dev (Individual Ave(Perf))</th>
<th>Average (Individual SD(Perf))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normals</td>
<td>0.58</td>
<td>0.12</td>
<td>0.38</td>
</tr>
<tr>
<td>Mild Cognitive</td>
<td>0.27</td>
<td>0.72</td>
<td>0.55</td>
</tr>
<tr>
<td>Impairment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Benefits of Cognitive Computer Games

Improvements over standard techniques:

- Daily monitoring (not yearly, after-the-fact)
- Individual as their own control
- Adaptive measurement – more sensitive measure
- Understanding of variability, trend detection
- Unobtrusive, more representative performance

- Potential for remediation
Demonstrations – after Break
Serious Games for Active Aging: Market Overview

Alvaro Fernandez, CEO & Co-Founder, SharpBrains market research.
www.SharpBrains.com
An introduction to SharpBrains

- SharpBrains is a Market Research and Consulting firm. SharpBrains doesn’t develop or sell products. www.SharpBrains.com

- Source of standard Industry data and clinical validation analysis for the field, media and other analysts

- Clients: Kaiser Permanente, Intel Corporation, Procter & Gamble, Johnson & Johnson, Technology Partners, most Major Developers of cognitive non-invasive tools

- Strong research focus: network of dozens of neuroscientists and psychologists
More than meets the eye

1. Number of Allstate’s policy holders engaged in research project to improve elder drivers’ safety?
2. Estimated # residential communities?
3. Investment in Centre for Brain Fitness at Baycrest?
4. Investment of insurer OptumHealth in cog. assessment for clinical decision-making?
5. US Army: how many have taken computerized cognitive assessment so far?
Market Discussion Today

1. State of the Market 2009
   - Market data and growth drivers
   - Competitive landscape
   - Consumer feedback
   - Category bottlenecks

2. The Future
The State of the Brain Fitness Software Market 2009

Key question: How much value will computerized cognitive assessment and training tools deliver in the real world?

No "silver bullet": Neurosoftware Products

Who is taking action?
- 700 Retirement Communities
- Allstate
- Gov't of Ontario
- OptumHealth
- The Conference Board
- U.S. Army
- USA Hockey League

Market snapshot:
- Areas of Opportunity:
  - 2010
  - Mental Health
  - Party Act
  - Athletic Performance
  - Driving Safety
  - Lifelong Learning

In Numbers:
- $5 Billion to $1 Billion
- Estimated Annual Revenue (USD): $100M, $225M, $265M, $45 Million
- 38% CAGR from 2005 to 2008
- 95% surveyed see Brain Health as a healthcare priority
- 65% don't know what to expect from products
- 39% state that Public Awareness is the most important problem

Also in the report:
- 2,000+ decision makers and early adopters surveyed
- 12 scientists discuss research and implications
- 21 competitors profiled
- Trends in 4 customer segments


DESIGNED BY / PAUL VAN SLEBRUCK www.paulvanslebruck.com
Top 10 Highlights from 2009 Market Report

1. Sustainable Growth – if problems are addressed
2. Increased interest and confusion
3. Growing investment in R&D
4. 700 residential facilities
5. Customer satisfaction
   1. “got real value for $”: Lumosity > Puzzle Books > Posit Science > Nintendo
   2. “seen the results I wanted”: Posit Science > Lumosity > Puzzle Books > Nintendo
6. Growing adoption of assessments
7. Compelling clinical evidence, but “who needs what when”
8. Distracting controversy, with two misleading extremes
9. Market & Research Momentum: 4 Leaders, 8 High Potentials, 3 Crosswords 2.0, 6 Wait & See
10. Increased differentiation

© SharpBrains
Figure 1.1: Brain fitness market by segment

Source: SharpBrains analysis
Figure 1.3: Brain fitness growth drivers

**SCIENCE**
- Neuroplasticity
- Cogn. training
- Cogn. reserve

**DEMAND**
- Baby boomers
- Seniors housing
- Insurance companies
- USA Hockey League

**SUPPLY**
- Venture investments
- Acquisitions
- Research pipeline

**POLICY**
- US Army cog screening
- New Center at Baycrest
- Mental Parity Law

Source: SharpBrains analysis
Market Discussion Today

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2. The Future
Figure 3.1: The Research-Market Momentum Matrix

- **HIGH POTENTIALS**
  - Applied Cognitive Engineering (ACE)
  - Cogmed
  - CogniFit
  - Houghton Mifflin
  - NovaVision
  - Scientific Brain Training (SBT)
  - Scientific Learning
  - TransAnalytics

- **LEADERS**
  - Brain Resource
  - Cognitive Drug Research (CDR)
  - Lumos Labs
  - Posit Science

- **WAIT & SEE**
  - Advanced Brain Technologies (ABT)
  - Brain Center America
  - CNS Vital Signs
  - CogState
  - Learning Enhancement Corporation (LEC)
  - Vigorous Mind

- **CROSSWORDS 2.0**
  - Dakim
  - Nintendo
  - Vivity Labs

Source: SharpBrains analysis
Figure 1.6: Level of clinical validation: product and domain

Source: PubMed, SharpBrains analysis.
Figure 1.7: Type of customer and delivery vehicle

Source: SharpBrains analysis, company websites
Market Discussion Today

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2. The Future
Figure 2.8: Customer Satisfaction for four top products

In regard to the product you just named, how much do you agree or disagree with the following statements?

I have seen the results I wanted

![Bar chart showing satisfaction levels for Posit Science, Puzzle Books, Nintendo, and Lumosity.com for seeing the results they wanted.]

I think the price is appropriate

![Bar chart showing satisfaction levels for Posit Science, Puzzle Books, Nintendo, and Lumosity.com for the price being appropriate.]

I got real value for my money

![Bar chart showing satisfaction levels for Posit Science, Puzzle Books, Nintendo, and Lumosity.com for getting real value for their money.]

Source: SharpBrains’ survey January 2009
Market Discussion Today

1. State of the Market 2009
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   - Consumer feedback
   - Category bottlenecks

2. The Future
Figure 2.9: Most Important Problem

Finally, what is the most important problem you see in the brain fitness field and how do you think it can be solved?

Source: SharpBrains’s survey January 2009
#1: Public Awareness (39%)

- "Getting people to understand that heredity alone does not decide brain functioning."
- "An expectant public will first want to believe that a "miracle" drug is to be soon available (to prevent Alzheimer`s Disease)."
#2: Navigating Claims (21%)

- "How to separate marketing hype from stuff that really works?"
- "The lack of standards and clear definitions is very confusing, and makes a lot of people skeptical."
#3: Research (15%)

"Determining what activities are most beneficial to the user with the minimum level of effort or most overlap of the already existing efforts."

© SharpBrains
“Integration within existing healthcare infrastructures - this will require research, education, and culture change. If brain fitness remains a niche alternative approach for the well-healed, we will have failed.”
"Lack of development of standardized and easily accessible assessments of cognitive status that could be used by individuals and organizations to test the efficacy of cognitive improvement methods."
“Lack of information and products available to people - perhaps a drive to get the products and information in public libraries would help.”
Market Discussion Today

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   - Market data and growth drivers
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   - Category bottlenecks

2. The Future
Do you agree or disagree with the following statements

1. Addressing cognitive and brain health should be a healthcare priority
2. Technology can significantly complement other behavioral interventions
3. I would personally take an assessment every year as a mental check-up
4. I would advocate for widespread annual "mental check-ups" after 55
5. I don’t really know what to expect from products making brain claims
6. Products available today do not work. They are a waste of money
7. We will soon have a cure for Alzheimer’s so why care about all this

Source: SharpBrains’s survey January 2009
Figure 6.3: Comparison of intervention options

- **Cognitive Therapy**
  - Low degree of insurance coverage
  - No evidence, not covered by insurance

- **Software**
  - Low degree of insurance coverage
  - Evidence, no insurance

- **Pharma Drugs**
  - High degree of insurance coverage
  - Covered by insurance

Source: SharpBrains analysis
Figure 9.1: Range of Projections for 2015

Source: SharpBrains analysis
Future Directions 2008-2015

Ø Brain Fitness goes Mainstream
  ▪ Increasing focus on brain maintenance
  ▪ Better integration of physical and mental exercise
  ▪ Broad government initiatives

Ø Leveraging Better Tools
  ▪ Wide use of cognitive assessments as baseline
  ▪ More and refined computer-based programs
  ▪ Low-tech options to play increasing role

Ø A Growing Eco-System
  ▪ Need for professional development
  ▪ Insurance companies will introduce incentives
  ▪ Transfer from military research and applications
  ▪ Corporate wellness will add a brain component

© SharpBrains
New Culture: from Magic Pills to Addressing Lifestyle and Bottlenecks

**Lifestyle**
- Balanced diet
- Aerobic exercise
- Stress management
- Mental activity/exercise
- Medication management
- Sleep

**Bottleneck**
- Emotional self-regulation
- Visual/auditory processing
- Attention
- Executive functions
- Working memory
- Long-term memory

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More Information on Market Trends

1) Market Report questions, email Alvaro, afernandez@sharpbrains.com

2) To order report with 50% discount before October 31\textsuperscript{st}: http://www.sharpbrains.com/, using discount code: blueocean

3) More information:
   1) Free monthly eNewsletter
   2) http://twitter.com/AlvaroF
Future Research – after Break