BRAINY – Multi-modal Brain Training App for Google Glass: Cognitive Enhancement, Wearable Computing, and the Internet-of-Things extend Personal Data Analytics

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ABSTRACT

Some of the most exciting trends currently in development and contributing to personal data analytics are wearable computing, the Internet of Things (IoT), and cognitive enhancement. This paper discusses these sectors and their integration as background for proposing BRAINY, a multi-modal brain training application for the Google Glass augmented headset platform. There are over 50 brain fitness training companies, and over 70 Google Glass apps, but there is not yet a brain fitness training app for Glass. BRAINY initially targets the improvement of memory function, and additional cognitive training modules can be added later for attention, processing speed, flexibility, problem solving, and other areas. BRAINY takes advantage of the audio-visual and voice command functionality of the Glass platform to create multi-modal memory games that can be played easily by users during waiting time or other down time. The more advanced memory modules of BRAINY target neuroplasticity and memory updating, and train the brain's fast and slow thinking systems.

1. INTRODUCTION

Two of the most pervasive contemporary trends in personal data analytics linking consumers and computing are the Internet of Things (IoT) and wearable computing. The Internet of Things is the situation that more and more objects are being connected to the Internet. This goes far beyond the usual computing devices to include everyday objects like parking meters and home thermostats, and even toothbrushes and T-shirts. The number of Internet-connected objects is estimated to more than quadruple in five years, from 2013 to 2018, from 2 billion devices to 9 billion [1]. The other big trend, wearable computing, refers to computer-powered devices or equipment that can be worn such as clothing, watches, and quantified self-tracking devices which are often Internet-connected (i.e., part of the Internet of Things). The worldwide wearable device market is estimated to double between 2013 and 2014 (from USD $2.5 billion to $5 billion) and grow to $12.6 billion by 2018 [2].

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2. COGNITIVE ENHANCEMENT

Simultaneous with the development of the Internet of Things and wearable computing, cognitive enhancement is emerging as a sector of considerable consumer interest and adoption, particularly the brain fitness market. A wide variety of potential techniques for cognitive enhancement have been demonstrated in various published studies, however a comprehensive, systematic, and measurable approach to the basics of cognitive enhancement remains to be enumerated. Many interventions are consumer available and continue to be a testing hotbed for quantified self-trackers and others interested in personal data analytics. Computation is no longer a limiting factor in the analysis of these data as the connected device typically uploads data to the cloud when Wi-Fi connected, and which can then be analyzed with machine learning algorithms and other tools to identify meaningful patterns.

One category of purported cognitive enhancement is pharmaceutical interventions like Adderall, Ritalin, Modafinil, Valproate, Steroids, Oxycodone, and caffeine. Another category of enhancement is consumer EEG headsets that can provide inexpensive DIY (do-it-yourself) access to brain activity and be used for neural feedback and neural electrical stimulation. These latter include tDCS (transcranial direct current stimulation (like the USD $249 foc.us (http://www.foc.us/) neural gaming headset)), TMS (transcranial magnetic stimulation), and pulsed ultrasound. Another category is biosensing technologies that can measure the body's signals like pulse, skin conductivity, and physical movement. Physiology and nutrition is another area including sleep quality, relaxation practices, yoga, exercise, micronutrients, specialty diets (like raw food, Paleo), toxin reduction, and intermittent fasting. Finally, one category of cognitive enhancement that has had significant consumer adoption is brain fitness, applications that develop and exercise the brain such as training exercises, games, learning strategies, knowledge and skill acquisition, and affect management.

3. BRAIN FITNESS

The worldwide brain fitness market (brain training and cognitive assessment) was estimated to be $1.3 billion in 2013 [3]. This includes consumer-focused applications like personal cognitive improvement and sports performance enhancement, as well as enterprise-focused applications like pharmaceutical development and clinical trials, public health, academic research, and employers using brain fitness to de-stress workers from companies such as CogState and Brain Resource. Brain fitness programs were initially developed to rehabilitate stroke patients and counter mental pathologies such as cognitive decline. However, widespread interest in cognitive enhancement and mental acuity training triggered the adoption of brain fitness software, applications, and techniques by healthy audiences and learning improvement audiences (i.e.; neurodiversity, autism spectrum, dyslexia) of all ages. There are over 50 companies offering brain fitness training apps for use on mobile devices and other computing platforms according to brain fitness market research site SharpBrains [3]. The leading application is Lumosity from Lumos Lab where as of June 2013 (since launching in 2007), 36 million users had played more than 609 million sessions of cognitive games [4]. The company claims to have the world's largest database of human cognitive performance [5].

3.1 Lumosity Brain Fitness Modules and Research

Lumosity offers brain training in five different areas: memory, attention, processing speed, flexibility, and problem solving. From a personal data analytics standpoint, one critique of Lumosity is that the users do not have access to their own raw cognitive performance data, just overall test scores. This prohibits consumer mash-up of cognitive performance data alongside other quantified self-tracking data streams like EEG read-outs, physical activity, location, blood pressure, stress level, and other biometrics. Lumosity (like 23andMe with genomics), tries to interest the public in brain fitness by reporting finding from their crowdsourced database. For example, Lumosity found that MIT was the smartest university across all five cognitive areas per a review of 60,000 college students using the brain fitness app: "Analysis of World's Largest Database of Human Cognitive Performance Names Massachusetts Institute of Technology Number One [5]."

The cognitive performance database is also used for scientific research projects. As of June 2014, Lumosity cited links to 13 completed research projects and 45 in progress on their website (http://www.lumosity.com/hcp/research) in a variety of areas ranging from cancer therapy recovery to learning preferences in children. Of the completed studies, most are poster presentations by Lumosity staff, and there are three published studies from independent institutionally-based scientists [6-8]. Lumosity is used for different brain training purposes in the studies, and the results and claims of cognitive improvement are typically validated by fMRI and other institutional lab measures.

3.2 Critique of Lumosity/Brain Training

The effectiveness and measurement of brain fitness training apps is contested. There are many claims that intelligence can be trained [9], and Lumosity takes care to describe the detailed science behind their apps in two white papers [10, 11]. The white papers have many supporting references, but there does not appear to have been any independent replication of methods and results. On the other hand, the main opposing claim to brain training is that the only thing that improves is the user's ability to take that specific test or play those particular brain training games, and there is no case for cognitive improvement more generally. Corroborating the opposing view is the example of scientists concluding from a meta-analysis of twenty-three investigations of memory training that the games may yield improvements in the narrow task being trained, but this does not transfer to broader skills like the ability to read or do arithmetic, or to other measures of intelligence [12]. However, it would be difficult to conclude that brain training is useless or harmful (unless over-used), in part because there are no standard terms and measurements for exactly what constitutes cognitive enhancement. Even if cognitive enhancement is not a currently provable benefit, exercising the mind is certainly a worthwhile activity, and many individuals may enjoy using brain training apps.

Figure 1. Google Glass.

4. GOOGLE GLASS AND GLASSWARE APPS

Google Glass is a wearable computer with an optical head-mounted display developed by Google. Glass displays information in a smartphone-like hands-free format, and is equipped with audio, Wi-Fi, and Bluetooth [13]. Users (wearers) interact with Glass by voice command or by light finger taps to the side of the device. Figure 1 illustrates (a) the Google Glass headset device, (b) a wearer and what is seen, and two shots fully from the point of view (POV) of the wearer, (c) accurately depicting the clear but slight fuzziness of the display lens surrounding the information portion of the screen, and (d) the unobtrusive presentation of ambient information through the default home screen which here posts the time (http://en.wikipedia.org/wiki/Google_Glass). Glass was initially available only to software developers through the Explorer program, but as of April 2014 has been available to the public for $1500 (https://glass.google.com/getglass/shop/glass).

As of June 2014, there were just over 70 Glass Apps, according to one Glass application listing website [14], in a wide range of areas (Table 1). Some of the current applications for Glass include picture-taking, video, maps, directions, search, and hangouts; also

points-of-interest 'near me' like parking, hotels, and restaurants, gestures, notifications, news, cooking (SousChef for Glass), and sports (scores and also augmented reality apps that overlay information to live events like baseball pitch speed and player statistics). As one sign of the times, the first market ticker app for Glass is bitcoin quotes not stock market data. Brain fitness apps would be classified in the games category. So far there are 13 gaming apps for Glass, including Ping (an analog to Pong, one of the first video games ever developed), MineSweeper, Space Invaders, Blackjack, Spelling, augmented reality gaming, and others. Although Glass is worn on the head which is the perfect place to take advantage of audio-visual functionality, no apps appear to have incorporated this feature yet. The BRAINY app proposed here makes use of the special characteristics of audio in Google Glass. The speaker is a bone conduction transducer that touches the head behind the ear, and allows sound to be partially transmitted through the skull (bone conduction). This means that users can discreetly listen to sound clips or music without disturbing others. This is perfect for engaging in brain fitness 'games' during down-time, transit time, or other time spent waiting.

Table 1. Google Glass App Categories (crosslisted) [14].

Category	#	Category	#
Productivity	37	Personalization	9
Tools	33	Photography	9
Social	21	Education	7
Lifestyle	18	Shopping	7
Communication	15	Business	5
Entertainment	14	Music & Audio	4
Games	13	Finance	3
Health & Fitness	13	Libraries & Demo	3
Media & Video	12	Widgets	3
Travel & Local	12	Augmented Reality	2
Books & Reference	11	Medical	2
Transportation	11	Sports	2
News & Magazines	9	Weather	1

4.1 Designing Apps for Google Glass

Glass is a completely new and different technology platform. It is not just a 'cell phone for your face,' or another smartwatch or mobile computer, but a true cognitive augmentation platform, and a potential break-through moment in the continuous always-on information climate. There can be a constant stream of information with very little effort on the user's part. The sight and hearing senses are always on and augmented. Passive information can be contributed ambiently to any situation in real-time. However, although augmented headsets and smartwatches are Internet-connected, they are more like lightweight information front-ends than full-fledged computers, and are designed to run as part of the overall personal computing ecosystem that includes the cell phone, the PC/laptop, and the cloud.

5. BRAINY – BIMODAL BRAIN TRAINER FOR GLASS

BRAINY is a proposed cognitive enhancement application for Glass (conceptually like Lumosity for Glass but with adapted and extended functionality). BRAINY brings many fields of contemporary advance together: personal data analytics, quantified self-tracking, wearable computing, IoT, cognitive enhancement, brain training, and Glass as a platform. A primary focus of many current Glass apps is sending simple context-specific real-time notifications to Glass wearers. BRAINY however seeks to make greater use of the capability of the Glass platform through integrated audio-visual functionality. BRAINY is a bimodal (audio-visual) brain fitness app with escalating modules of type and difficulty. In the basic mode, the brain fitness app or 'game' is comprised of two phases, first a training session where the user/Glass wearer is presented with different images and sounds, and then second, a task session where the user is prompted to recall images and sounds from the training session.

The hypothesis presupposed by BRAINY is that multi-modal brain fitness apps may be more effective than single mode apps (because multi-modal training is more effective, and also even just because the user has more personal freedom to experiment with the app and how they wish to use it). Thus far brain training apps have been single mode, targeting the visual sense. Different studies have published results in favor of audiovisual training over single mode training, for example a higher rate of accuracy with audiovisual modality training as opposed to exclusively visual or auditory training conditions [15]. Sensorial multi-modality need not be confined to the auditory and visual senses, another study found that tactile measures have a significant relationship with measures of cognitive ability [16], and other studies found in favor of different kinds of multi-modal learning more generally [17-19].

5.1 BRAINY Specifications – Audio-Visual Platform

BRAINY is designed to be available on multiple platforms, one version for PCs/tablets and one for Glass/smartwatches. The smaller screens of augmented headsets and smartwatches require a different conceptualization of the app. The bigger screens of PCs/tablets can accommodate a more robust form of visual complexity like the twelve-quadrant multi-sized grid in Figure 2. The BRAINY grid extends the complexity of the basic form of the memory game where there are several same-sized rectangles and the objective is to turn over two at a time and match pairs of images. In BRAINY, the grid squares are different sizes, which means that a number of different dimensions of memory can be tested, specifically location, sequence, and content. Location tests where images were presented; sequence, the order in which images appeared; and content different aspects of the content of the images such as presentations of the exact same image, portions of the same image, related images (for example other members of the same sports team), and completely different images; also the

number of times an image appeared. However for the Glass/smartwatch version of the app, the visual aspect must be extremely simple, since the user will be glancing briefly at the Glass screen, or perhaps engaging in a more sustained way for only a short time. Initially just one image will be shown at a time in the Glass/smartwatch version of BRAINY. In later modules, a modified grid system could be introduced with two and perhaps four quadrants. The PC and Glass versions work well together for overall brain fitness as the Glass version tests the brain's immediate-response fast thinking capability (System 1), and the PC version tests the more deliberative slow thinking capability (System 2) [20].

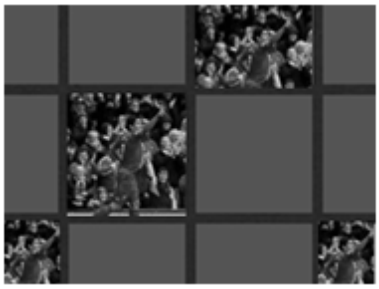

Figure 2. BRAINY 12-Quadrant Grid.

The key feature of BRAINY is linking audio and visual input for brain fitness training. In the basic mode, the user is presented with a series of combinations of images and sounds (a beep, sound, or song clip) during the training session. Then in the test session, the user can be queried at three levels of chosen complexity (Figure 3). First, in a single mode, an image or a sound is replayed for the user to identify a reoccurrence from the training session. Second, an image-sound combination is replayed which is either an exact repetition from the training session, or both image and sound are completely different. Third, an image-sound pair is presented for the user to identify if only one (image or sound) appeared in the training session. Given the difficulty of remembering a specific image-sound pairing (more challenging than remembering two images, which is already difficult), users may prefer to begin with the basic testing mode.

The audio functions similarly in both the PC and Glass versions of BRAINY, although the integrated audio-visual (plus voice command) functionality of Glass, and its being designed for mobile use suggests the potential value of easy-to-use audio-related apps. Users may find the audio-only mode of the brain trainer most accessible and fun while on the go, and experiment with exactly the personalized testing permutations they prefer. Complexity can be added to the audio dimension, for example, pitching audio into one ear or the other, or if directional audio functionality were to be included in Glass, pitching the sound direction to both up/down and right/left. Completing the loop of users communicating back with the app, the Glass and smartwatch app versions are controlled by voice command and/or touch, and the PC and table app versions are controlled by touchscreen and/or mouse click. With audio-visual brain fitness, BRAINY tries to take full advantage of the fact that the best interaction with Glass is light communication that includes intermittent visual glances, together with the possibility of more intense ongoing audio and voice command interactions. Side modules of BRAINY could include a 'name that tune' app, an app for recognizing perfect pitch, a choir practice app, and a 'singing for those who cannot sing' app, and music learning apps in a suite of 'Musical Brain Training with BRAINY on Glass.' Since Glass users are connected through the Google+ social network (Glass requires logging in with a Google+ account), BRAINY can be social, allowing users to compete or share with other players in general or within the user's own social network.

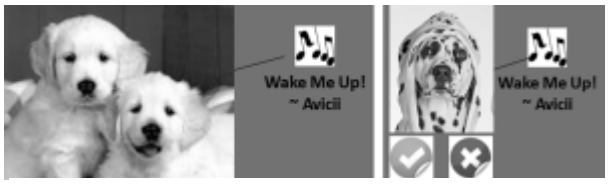

Figure 3. BRAINY for Glass: Training and Testing.

5.2 BRAINY Advanced Memory Module: Neuroplasticity and Memory Updating

One advanced memory module for BRAINY helps to train neuroplasticity. Leading memory researchers have posited that memory updating capability is one of the most important factors in having a high-functioning memory apparatus [21]. Memory updating (like Bayesian updating) is the ability to take into account new information about reality and update the precise and relevant memories to which the information applies. It is fairly straightforward to develop a test for memory updating. The key structural aspect is that there are multiple sessions, and the recall of images and sounds pertains to only the most recent training session. Thus, the memory updating challenge becomes more difficult as sessions ensue as it is much easier to identify a seen/heard image/sound today than one experienced specifically in the latest training round. A citizen science study in collaboration with the University of Geneva covering memory-updating is currently seeking participants [22].

The science behind memory updating is that the brain is able to adapt to the unexpected using an inbuilt network that makes predictions about the world and monitors how those predictions turn out later. The orbitofrontal cortex at the front of the brain plays a central role, and studies have shown that patients with damage to this area confuse memories with reality and continue to anticipate events that are no longer likely to happen. The brain's ability to react adaptively is crucial for survival in the face of potential danger [23]. The brain's reward system is also geared to keep thought and behavior in phase with reality [24].

5.3 BRAINY Advanced Memory Module: Fast and Slow Thinking

Another advanced memory module for BRAINY helps to train fast and slow thinking. It is known that there is a range of cognitive biases endemic to human cognition. Two recent thinkers discussing the issue and potential solutions are Daniel Kahneman [20] and Nicholas Nassim Taleb [25]. The key themes for both

authors are citing reasons why humans are bad at thinking statistically, describing the heuristics employed as a result, claiming that too much confidence is placed in human judgment, and proposing alternative solutions. Kahneman discusses a number of cognitive biases such as loss aversion, over-optimism, anchoring, availability, and sunk-cost. He segments two modes of thought, the immediate gut response (System 1, fast thinking) and the slower more deliberative response (System 2, slow thinking). One of the biggest issues with System 1 is that it associates new information with existing patterns as a shortcut, rather than creating new patterns for each new experience. An example is someone faced with a hard question like "Should I hire this person?" may automatically convert it to an easier (but possibly irrelevant and inaccurate) question such as "Do I like this person?"

The challenge is knowing when to distrust the quick gut response and invoke serious research and thought. Organizations manage this by requiring certain protocols and checklists that call for System 2 analysis. Individual professionals (like athletes, firefighters, and pilots) often use training to make their System 1 intuition extremely expert in acting swiftly on a wider range of signals and options than amateurs can handle. Technology can help, for example, the way a heads-up display makes it possible for pilots to notice what is most important for them to act on even in an emergency. The Internet can also help because it makes research easy and looking things up exposes alternatives that triggers thinking in new ways.

BRAINY is in some sense already geared to fast and slow thinking in that the PC/tablet version targets System 2 deliberation over whether and how an image-sound pair has been presented in the training session. The Glass/smartwatch version on the other hand targets System 1 immediate gut-response thinking. A more challenging module for BRAINY can be developed to attempt to train System 2 deliberations into System 1 actions. First in the image-sound pairs presented in the test session, the Internet-lookup function Kahneman mentions could be stimulated by showing the user new types of image-sound pairs that closely conform to the training round but not quite, and do not conform via previously unpresented attributes. This could disturb the shortcutting tendency of System 1 and force thinking in new patterns. Also, separate modules and crowdsourced best practices could help to train the user on the techniques of high-scoring individuals (which are likely to be System1-System 2 integrations), what they do to identify whether previous image-sound pairs have appeared, for example quickly shifting through different dimensions of attributes. Even the awareness that there are different techniques pushes thinking into System 2, considering not just the task, but a higher order of abstraction about different ways to execute the task.

5.4 BRAINY - Future Implications

In addition to the basic modes of operation envisioned for BRAINY and the advanced Neuroplasticity Memory Updating, and Fast and Slow Thinking modules, there may be a host of future additions for a multi-modal cognitive training platform like BRAINY. Since BRAINY primarily targets the cognitive improvement of memory, one next obvious step would be designing analogous modules for Glass from the other four Lumosity coverage areas (attention, speed, flexibility, and problem solving). Another addition could be modules to address the other cognitive biases cited by Kahneman like over-optimism, and loss avoidance. A current citizen science study is currently investigating some of these aspects fast and slow thinking per Kahneman [26].

In the farther future, it is imaginable that subsequent generations of brain fitness apps could extend into a much wider spectrum of functionality. For example, in memory-related exercises, apps might not be confined to creating and testing new immediate short term memories, but designed to work with a user's own memories. For example, applications that help facilitate a user being able to remember and interlace their own life experience memories for enjoyment (the *'Proust module'*) or psychoanalysis (the *'Freud or Lacan module'*), working with repressed memories and reconfiguring negatively-charged memories. For Alzheimer's patients, memory dysfunction aiding apps could replay built-in but hard to access memories of simple tasks like going to the store or walking and navigating in a hospital or doctor's office just before a user undertakes the action.

6. CONCLUSION

One of the most exciting emerging areas in personal data analytics is the consumer use of applications related to cognitive enhancement. Cognitive performance tracking and optimization may continue to develop and mature particularly as the underlying enablers, wearable computing and the Internet of Things, also continue to expand. This paper discusses the integration of these trends and proposes BRAINY, a lightweight multi-modal (audio and visual) cognitive training app for the Google Glass augmented headset platform. The app presents users with sound clips and images in a training session that are later queried for recall in a test session. Cognitive enhancement apps could be just the first step in the construction of monitoring and augmentation platforms for the optimization of all mental activity.

7. CONFLICTS

One or more of the authors are involved with the citizen science memory updating and fast and slow thinking studies mentioned in this paper.

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