An Inquiry into the Neural Plasticity Underlying Everyday Actions

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How does the brain change with respect to how we live our daily lives? Modern studies on how specific actions affect the anatomy of the brain have shown that different actions shape the way the brain is oriented. While individual studies might point towards these effects occurring in daily actions, the concept that morphological changes occur throughout the numerous fields of neuroplasticity based on daily actions has yet to become a well established and discussed phenomena. It is the goal of this article to view a few fields of neuroplasticity to answer this overarching question and review brain imaging studies indicating such morphological changes associated with the fields of neuroplasticity and everyday actions. To achieve this goal, a systematic approach revolving around scholarly search engines was used to briefly explore each studied field of interest. In this article, the activities of music production, video game play, and sleep are analyzed indicating such morphological change. These activities show changes to the respective areas of the brain in which the tasks are processed with a trend arising from the amount of time spent performing each action. It is shown from these fields of study that this classification of relating everyday actions to morphological change through neural plasticity does hold validity with respect to experimental studies.

Abbreviations: EEG – Electroencephalogram; REM – Rapid Eye Movement; SWS – Slow Wave Sleep; PET - Positron Emission Tomography

Key Words: Voxel-Based Morphometry; Music; Video Game Play; Sleep

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Introduction

Over the past 100 years, innovative technologies have allowed the prospects of neuroscience to stand among the natural sciences. While neuroscience can be found in many fields of study, as seen in medicine, education, and neuromarketing, neuroscience has also played an active role in defining the neural mechanisms that establish a better efficiency for daily routines. Some of the most prominent and unusual of these findings have been derived from the concept of neuroplasticity, or the reorganization of synapses within the brain. Due to neuroplasticity's consistent appearance in neurology, neuroscientists and neurologists have actively sought out how environmental activities affect the anatomical structure of the brain and how cognition is affected by these changes. Such investigations have led to copious amounts of experiments that demonstrate the effects that certain demographic groups have acquired due to prolonged environmental stimulation.

Studies on adult neuroplasticity have found numerous daily activities that people partake in that show how the brain physically changes shape with respect to each action. While there may be many areas of interest within the modern study of neuroplasticity, the actions looked at in this analysis are pertaining directly to environmental stimulation and learning and arise from music production, video game play, and sleep. These three actions have been explicitly selected due to their defining characteristics, involving changes in the physical shape of the brain with respect to the time spent performing each action (Gaser and Schlaug, 2003; Han et al., 2012; Morrell et al., 2010) and having very distinctive attributes that can be associated with each action. Due to the variety of different neural substrates spanning the central nervous system for proper action functionality, many underlying pathways could intersect (Janata and Grafton, 2003; Lestou et. al., 2008) showing similar morphologies for like pathways. For instance, while all three actions being studied allude to the processing of movement, the way these neural circuits process movement is drastically different, revolving more so around sound for music production (Gaser and Schlaug, 2003; Sergent et al., 1992), more so around a visual stimulus for video game play (Li et al., 2009), and more so around memory consolidation for sleep (Peigneux et al., 2004). However, that example is only one of the many existing networks and the problem is of much higher dimensionality. It is most likely due to these high dimensional neural circuit interactions that these actions have not been highly correlated with each other. The answer to that question, though, is well beyond the scope of this article, as will be elaborated. The observation that these changes occur with respect to daily actions gives rise to the important observation that they are indeed related, from which further conclusions could be made upon. Other very prominent areas of study were also considered, like that of language or kinesthetics, but due to an overabundance of relevant research, only these select few were thoroughly analyzed.

The goal of this article is to span the gap between these different and very distinctive fields of neuroplasticity and show that they can relate to the broader view that morphological changes in the brain occur in a daily setting in unique ways. Currently, as previously elaborated, these fields do not share common ties due to their unique underlying results and thus are studied independently of one another. Grouping them together with an emphasis on daily change allows for a more applicable way to view neuroplasticity in terms of a real-world application problem. To study related literature on the three topics of music, video game play and sleep, keyword searches in Google Scholar and WorldCat's search engine were used in conjunction with the related topic: "Voxel-Based Morphometry," “Morphologies," "Gray Matter," and "White Matter." Relevant sources were also found referenced in other search results in which further investigation elapsed.

The Basis of Neuroplasticity

Neuroplasticity was first formally recognized by Santiago Ramón y Cajal in 1914, but due to lack of evidence and a poor common consensus at the time the concept would be forgotten and labeled as a lapse in judgment by the proclaimed father of neurology (Stahnisch and Nitsch, 2002). Findings of adult neuroplasticity did not prevail until 1969 when Geoffrey Raisman found anatomical structural changes in trained adult rat brains (Fuchs and Flügge, 2014). Since that discovery, the prospects of adult neuroplasticity have grown exponentially, but the enigma still awaits comprehensive scientific answers. Neuroplasticity has been found to change neural structures and functions under various conditions, i.e. learning, stress, growth factors, drugs, environmental stimulation, aging, etc. (Fuchs and Flügge, 2014). With so many different methods as to how neuroplasticity can occur, finding a single definitive answer as to how neuroplasticity functions can become difficult. To simplify the criteria to the purpose of this article, only environmental stimuli and learning will be considered for analysis, in which neural anatomical morphologies will be the main signature of change.

When classifying how environmental stimulation changes the anatomy of the brain, neuroscientists and neurologists rely on a pre-established map of the cortical regions of the brain. This map has effectively been defined through experimentation and processes like that of aphasia to signify which sections of the cortex perform specific actions. These experiments and maps have found generic properties of the cortex to establish which areas generically perform specific processes. For instance, on the macro scale, the right side of the cortex in right-hand dominant patients is typically associated with broad functionalities, while the left side of the cortex is typically associated with specific functionalities (Ehrenwald, 1984; Shepard, 1994). As one specifies further within the two hemispheres, the individual processes become more specific and distinctive but follow the same basic characteristics given to each respective side.

Specifying further, neurons have thousands of different shapes and forms that can be used to best fulfill their function, but in the cortex, the most prominent cell is the pyramidal neuron. As emphasized by Pulvermüller on the works of DeFelipe and Farinas as well as Braitenberg and Schüz (respectively), the pyramidal neuron has about 50,000 afferent and efferent synapses that constitute approximately 85% of the 10^{10} to 10^{11} neurons of the cortex (Pulvermüller, 2002). To analyze such scales, methods of analyzing the overall structure of the system have been developed to help alleviate the assortments of data.

Since neurons can be distinguished by their color, a method has been established to help indicate how groups of neurons are relatively connected. White matter is primarily on the inside of the brain and gets its white color due to myelin sheath surrounding the axon, which allows rapid long-distance communications with other groups of cells. Gray matter is primarily located on the outside of the brain, in the folds, and lacks the myelin sheath; thus, it is established as being connected to local neurons for short distance communication and computation. To determine how developed a functional section is, the concentration of gray matter can be analyzed, in which a high ratio of gray matter to white matter indicates a highly developed section of the brain. The most common analytical device for performing this kind of analysis is known as voxel-based morphometry, which analyzes specific features of the brain to create generalizations on how its shape differs from normal anatomical representations. These representations have been pre-established as an average in any given voxel-based morphometry program (Ashburner and Friston, 2000). The resulting ratio can then be taken as a statistical means of measurement, with respect to the ratio of change found in any particular area of the brain, to then signify how the synaptic connections within a given region are established through synaptic plasticity. Voxel-based morphometry is the primary means of measurement for morphological changes as well as the primary method of classification throughout this article.

While neural circuit computation is also a vital process in this context, the computation of circuits associated with the cortex goes beyond the scope of this article. As mentioned in the introduction, the reasoning behind why neuroplasticity has most likely not crossed over the various fields of study is most likely due to the complexity of neural circuit computation. It is simply too difficult, even with modern technology, to try and predict how circuits in the brain will process information, nonetheless to accommodate for factors such as environmental change. For this reason, the study of neural circuit computation on the level of mass neural circuitry will not be covered in this review, although its importance should be emphasized. While large-scale circuitry may be beyond the scale of this article, single synaptic plasticity is still within range, as will be seen in the consolidation of memory with respect to the action of sleep.

Synaptic plasticity between cells is often associated with the postsynaptic density located on the dendrites of neurons (Kim and Eunjoon, 2011). The postsynaptic potential on the dendrite end of the neuron works with a threshold value that can change according to use. When the threshold value of the potentials for the excitatory and inhibitory postsynaptic densities have been summed and established as greater than the threshold value, the neuron then becomes activated. This process allows the entire neuron to stimulate adjoining neurons and repeat the process for the following cells that are connected to it. To allow for faster connections and communication between cells, it is well established that the more two neurons activate, when the postsynaptic threshold is reached, the quicker and more defined the connection between the synapse and postsynaptic region becomes. This process allows for more efficient connections between the two cells and is termed Hebbian plasticity (Pulvermüller, 2002). Simply put, faster and more defined links between adjoining neurons allow a more efficient computational network for specific neural tasks to arise.

The last generic piece of information to consider about plasticity would be its fundamental position in the nature vs. nurture debate. This debate is undeniably one of the oldest biological debates that is still disputed despite being conceptually simple; revolving around the question, “to what extent does the environment affect the growth development of human beings?” Modern evidence for this debate is heavily dependent upon genetic studies, mainly surrounding twins, but still has a very split perception as to one view or the other (Polderman et al., 2015). Neuroplasticity, by definition, is a concept that offers evidence for the nurture side of this argument and is commonly considered in neuroplasticity studies (Hyde et al., 2009).

The concepts and findings of environmental neural plasticity, despite the long-standing debate of nature versus nurture, have taken root as fundamental properties of neuroscience. While the concept as a whole is by no means resolved, it is a prominent enigma that is under constant investigation in the field of neuroscience and has years of scientific research supporting it.

Changes in the Brain: On Music Production

Music has been a cornerstone case study in the field of neural plasticity for decades (Bever and Chiarello, 1974; Münte et al., 2002). Due to the unique occupational practices professional musicians partake in, the fields of neuroplasticity and music have overlapped to answer the question of how the brain processes music. Many studies have been produced to help indicate what morphological changes occur within the brain due to music’s unique disposition. The study of music production in terms of neural plasticity and daily living offers a wide variety of evidence indicating such morphological changes, giving the topic a nice foundation to build upon. However, before proceeding further towards the studies indicating such morphological change, the importance of where music is processed in the brain should also be emphasized.

The study of active neural processing has given insight into the very nature of how activities are processed within the brain. With respect to music, positron emission tomography (PET) gives direct feedback as to the processing of music in the studied areas by signifying which areas become active during the processing of a task. Focusing on the processing of live information acquisition, in 1992, Sergent et al. studied the real-time processing of subjects while reading and playing music using PET. The main resulting active areas, after studying several musical activities, were the inferior parietal lobule of both hemispheres, both superior parietal lobules, the premotor cortex, and the left inferior frontal gyrus (Sergent et al., 1992). In the experiment, the results suggested that all four cortical lobes and the cerebellum were active while sight reading and playing the piano. While the study only covered a limited number of musical skills (in limited quantity), the study does offer insight into the neural processes of playing and reading music as a fundamental notion. Most significantly in the context of this article, it is shown that music is not processed solely in one area of the brain; music offers the unique stance of being highly distributed in the brain despite the brain being highly restrictive on a macro scale to regional interactions (as will be covered in more detail).

Accordingly, music processing in the brain requires an immense system in order to function properly, especially for musicians. Classical musicians follow a unique life of consistent practice to meet the expectations of their field. Professional classical musicians practice hours a day, spending a fair majority of their time focusing on the fundamentals of music production; practicing techniques such as scales, chords, arpeggios, rhythm, positioning, absolute pitch, bowing, etc. on top of their current pieces of music. Due to their rigorous occupational practices, musicians have been found to be a desired candidate for studying the effects of environmental neuroplasticity in adult patients (Müte et al., 2002; Schlaug, 2001). The eminent effects of neural plasticity in musicians, due to their rigorous occupational practices, have been shown to morph areas of the brain to become better suited for musical processes.

Classical music, as a practice, requires a detailed oriented approach to effectively perform complicated pieces. Due to this approach, some areas of music processing in the brain, such as melody perception, have been shown to switch hemisphere dominance (Bever and Chiarello, 1974). The theoretical reasoning behind the hemispheric shift is primarily related to the declarative association of sound processing. The right hemisphere is often associated with both pattern recognition and auditory processing due to their natural ambiguity, but the left hemisphere is associated with specific associations (like that of semantic processing; Shepard, 1994). The effects of analyzing music in an auditory analytical perspective (also known as the process of "ear training") gives the explicit functionality of pattern recognition a definitive association to instantaneous changes in sound (in music connotation known as "intervals" which are comprised of individual "steps"). Due to these definitive associations arising, investigative studies on gray and white matter morphologies have shown more prominent morphologies occurring on the left rather than the right hemisphere in musicians (Gaser and Schlaug, 2003). These findings support the theoretical notions of interhemispheric morphologies in musicians as established by Bever and Chiarello in 1974, who emphasized shifts due to explicit functionality differences, as previously stated. While specific functionalities of music may cause changes in hemisphere dominance, that does not entail that all processes are associated with the left hemisphere.

As previously stated, music has been found to incorporate all four cortical areas and the cerebellum (Baeck, 2002; Sergent et al., 1992). Due to the extensive nature of music processing, communication from all four cortical areas is vital for its overall performance, but music processing is hindered because of regulatory devices subsiding communication between the four cortical regions. To negate these effects, changes in the communication structures within the brain, such as the interhemispheric nerve bundle known as the corpus callosum (Schlaug et al., 1995), have been shown to develop more substantially in musicians. This finding indicates that neuroplasticity is working to increase connections across the hemispheres of the brain for the processing of music while also showing that musicians have a higher functional efficiency in interhemispheric communication. It should be noted that interhemispheric communication is also often recognized as being a sign of higher intelligence, having a greater aptitude in relating right side dominant broad functionalities with left side dominant specific functionalities (Ehrenwald, 1984; Men et al., 2013). While the corpus callosum seems to be a major functional factor in establishing how neuroplasticity plays into the actions of music, many other areas of the brain have also been shown to morph with long-term musical practice.

Emphasizing on the works of others, Gaser and Schlaug undertook a study that compiled years of anatomic morphological research on musicians and analyzed the specified areas in relation to musicians and non-musicians in their own study (Gaser and Schlaug, 2003). Working on the notion that an overall examination had not been studied on the specified areas, Gaser and Schlaug performed an experiment, showing how the brain structures as a whole change between musicians, amateur musicians, and non-musicians to accommodate for the special skill set of musicians. Using Voxel-Based Morphometry, Gaser and Schlaug found primary structural morphologies in the "perirolandic regions including primary motor and somatosensory areas, premotor areas, anterior superior parietal areas, … inferior temporal gyrus bilaterally … left cerebellum, left Heschl's gyrus, and left inferior frontal gyrus" (Gaser and Schlaug, 2003). The analysis showed a direct correlation to gray matter density increasing directly with a musician's status, and it was noted that no significant decrease in gray matter or white matter was observed in the study. The larger correlated areas emphasize more developed regions in the functionalities of systems relating to motor control, spatial orientation, visual processing, auditory perception, and decision-making. All of the related functional areas are highly correlative to the specific functional abilities of music production. This study offered compelling evidence to coalesce the mass collection of studies before it into a single observation.

These prominent findings of morphological studies in music have sparked great interest in the field of neuroplasticity, but still fall in the long-standing controversy of nature verses nurture. To study this long-lasting debate, Hyde et al. conducted a long-term study to depict if the morphologies can occur in six-year-olds over a 15-month period after private keyboard lessons (Hyde et al., 2009). As expected, structural morphologies of increased gray and white matter volumes were found using voxel-based morphometry in the right precentral gyrus, corpus callosum, and right primary auditory region (specifically in the Heschl's gyrus) after the 15-month period. Both findings in the right precentral gyrus and Heschl's gyrus can be directly matched to the findings of the previous study by Gaser and Schlaug (Gaser and Schlaug, 2003). It should be noted that while it is not emphasized in the main findings from the study listed above, the left and right precentral gyri were also correlated with musician status by Gaser and Schlaug (Gaser and Schlaug, 2003). The corpus callosum, as previously stated, has been found to change under the environmental stimulation of music and was considered as a potential experimental error in the study by Gaser and Schlaug (Schlaug et al. even reported findings indicated such changes; Schlaug et al., 1995). This study effectively showed evidence for the nurture argument in the ongoing nature verses nurture debate.

Music has shown to be one of the most prominent sources of adult neuroplasticity, primarily due to the extensive nature of a musicians practice. Music offers a unique perspective into how years of practice can shape one's cognitive abilities. Through these studies and similar ones, it is seemingly clear that the daily practice of music can offer cognitive reform that can affect a multitude of areas that preside outside the realm of music. While it is unclear whether these areas affect the resulting daily activation of such regions, a strong presumption could be made that emphasizes an overall shift in aptitude in the given functional regions.

Changes in the Brain: On Video Game Play

As a second case study, video game play has been an emerging field of study in neuroplasticity since the invention of video games in the early 1970’s. The most notorious reason for this is the semi-false assumption, which arose shortly after video games were invented, that video game play weakened the cognitive abilities of the kids playing them. Due to this ill-founded assumption, countless studies have been produced showing the effects that video games induce on populations. Due to this field being immensely developed, showing a large variety of both studies and influenced fields of study, a brief elaboration on the effects across these studied disciplines will be elaborated here.

To help alleviate the assortment of experiments and to help point towards a consensus, thorough investigations into the findings of such experiments have been conducted to find trends among the assorted data via analyzing hundreds of studies. One such analysis was carried out by Powers et al., which analyzed 687 experiments and found a positive correlation between the studies on video games and increased cognitive ability (Powers et al, 2013). Despite having an assortment of amplitudes of effect (ranging from small to large change), the analysis concluded that the overall direction of studies indicated an increase in cognitive function. The standing view of video games is trending away from the long-held belief of negative effects occurring on cognition due to video game play. Although, it should be emphasized that certain societal and neurological decline has been seen due to the explicit use of video games in specific circumstances, as will be covered. Despite these findings, the eminent effects of video games on a mass audience may not be as prominent as other media sources, as seen in statistical population studies.

Even though video games have a large base audience, they are not played in long durations on average. A statistical study found that the average daily play time of video games in the United States in 2010 for individuals between the ages 8 to 18 was only a little above one hour (Rideout et al., 2010). Despite the marginal play time, it was also reported that within the age group, 93% had access to a computer and 87% had access to a gaming console. The more prominent findings of the statistical study showed an emphasis on television content, music, and computer usage. Congruent with the statistical findings of Rideout et al., PricewaterhouseCoopers (one of the world's largest accounting firms; also known as PwC) reported the activities of 18-year-old to 59-year-old consumers at around an hour and a half per day (found by taking the total of the averages of multiple ways of playing video games in hours per week as reported and dividing by seven; PricewaterhouseCoopers, 2010). While the time spent playing video games has trended upwards, and is predicted to trend upwards hereafter, it is clear that other sources of media are still more prominent. When relating these findings to the studies observing video game play on cognitive functions, the average play durations are typically longer than the statistical average to signify results (excluding studies that take this variable into account as means of population analysis). This indicates the amplitude of effect may be smaller than what is found in most studies, but may still be vaguely prominent.

Furthermore, due to the copious amounts of research provided for video game studies, numerous types of video games and play styles have correlated to a variety of different functional enhancements. Working on the same basis as Powers et al., but with the distinction of classifying effects, Latham et al. reviewed the effects that have been reported and the distinct differences between them. Latham et al. reported findings indicating that depending on the type of gaming, increases in cognition were found in "hand-eye coordination and reaction time, spatial visualization, visuospatial attention, visual anticipation and visual search strategies, temporal dynamics of sensory attention, exogenous and endogenous attention, task switching, [the] fundamental properties of the visual system, [and] visual perception and use of sensory evidence…" (Latham et al., 2013). Individual studies demonstrating these specific results can be seen carried out by Kühn et al. (Kühn et al., February 2014), Kühn et al. (Kühn et al., March 2014), Dye et al. (Dye et al., 2009), and Li et al. (Li et al., 2009), in which the different types of effects are shown. Latham et al.'s review continues the trend of showing the positive effects that video games have been accruing over the past 30 years, concurrent with Powers et al.'s analysis. Despite both groups questioning the validity of the observed experiments, it is clear through the findings of Powers et al. and Latham et al. that a global trend is indeed shifting towards the notion that video games offer a positive association to cognitive enhancements.

Keeping with the notion of general population dynamics, video game play has also been observed to show negative effects in particular situations, hence the "semi-false assumption" as mentioned above. One such negative consequence that has arisen from video game play is related to internet addiction. As emphasized by Weng et al. in a study on video game addiction, it was elaborated that around 14.1% of China's youth (about 24 million people) experienced symptoms of internet addiction in 2010, notably being tied to online gaming addiction (Weng et al., 2013). Such studies can help bring to light the nature of how the brain changes with respect to the extreme environmental stimulus of video game play.

Internet addiction has sparked the interest of countries worldwide, in some cases even being labeled as a behavioral disorder (Han et al., 2012). In a study to depict the morphological differences in online gaming addiction (a subsequent form of internet addiction) versus intense video game play, Han et al. elaborated on a group of online gaming addicts that were chosen and had shown unproductive societal behaviors (Han et al., 2012). They elaborated that the group had poor daily functions, extreme decreases in their school and work efforts, had been expelled from school due to theft or absence, or even had extreme debts. These scenarios seem to be consistent among studies pertaining to online gaming addiction; some have even proclaimed that the neural morphologies and behaviors depict that of substance abuse (Weng et al., 2013). Despite the standing cultural downfalls of online gaming addiction, Han et al. studied how anatomical morphological effects differ between what is seen in professional video game players, verses what is seen in online gaming addicts.

Han et al.'s experiment showed online gaming addicts as having "increased gray matter volume in the left thalamus, and decreased gray matter volume in the right inferior temporal gyrus, right posterior cingulate gyrus, right middle occipital gyrus, left inferior occipital gyrus, left inferior occipital gyrus, right middle occipital gyrus, and left inferior temporal gyrus" (Han et al., 2012) compared to the healthy control. Concurrently in the corresponding group of professional gamers, only three morphologies were found when compared to the healthy control: an increase in gray matter in the left cingulate gyrus and decreases in gray matter in the left middle occipital gyrus and right inferior temporal gyrus. Such findings, like that of increased gray matter in the thalamus, provide further support for Weng et al.'s claim of showing evidence similar to substance addiction. Additionally, in both gaming addiction patients and professional gamers, regions within the occipital cortex had a decrease in gray matter volume, which was emphasized could be a result of harmful visual stimuli and not explicit video game play cognition (Han et al., 2012). As the main finding of this study, it was clearly shown that video games depict a direct correlation towards how the games were played and not the duration of time played. This study is an excellent example of the published works surrounding internet addiction as it pertains to online gaming addiction and explicit changes between two different forms of video game play.

As the last major field of significant importance in video game play morphologies influenced by neural plasticity, medical science has begun taking a keen interest in the positive effects that video games can induce on the brain. Through evaluating studies like those of Han et al.'s experiment on online gaming addiction, it is seemingly clear that the way video games are played establish different means of cognition upon the user. Through these observations, video games like Project EVO are being created to help the fight against neurological diseases and disorders like Alzheimer's, ADHD, autism, and depression, as well as to help improve multitasking functionalities (Akili, 2016). Project EVO is currently being fiscally backed by several major companies including Pfizer and is effectively being implemented. As a basis of explanation behind the video games' involvement in Alzheimer's, as well as its overall theoretical construct, recent developments have started to associate the acquisition of Alzheimer's to a lifestyle of diminished intellectually stimulating activities, like that of watching television (Lindstrom et al., 2005), also notably another potential daily action that could be studied in more depth. The effective means of improvement from Project EVO are primarily derived from the video games' intellectually stimulating environment that is brought to the player, as oppositely seen in Alzheimer's patients. While Project EVO is dedicated to explicitly bringing a stimulating environment to its audience, consumer video games have also entered the study of medical practice, showing promising results in the field of neuroplasticity in a similar fashion.

In a pilot medical study by Li et al., the effects of playing consumer video games were tested on patients with amblyopia (Li et al., 2011). The neurological disorder of amblyopia is also commonly referred to as "lazy eye" and treatment for this disorder takes a long time to take effect due to the nature of the disorder. The pilot study conducted was established to detect if neural plasticity could be induced through playing hours of video games with the amblyopic eye. The authors were aware of the audience's presumed bias towards the negative effects of video games on individuals, as discussed with the common concerns against video games. Thus, participants were split into groups and performed tests with both a violent video game and a non-violent video game, under the presumption that "playing action video games may not be ideal for [all] patients with amblyopia, particularly children" (Li et al., 2011). The effects of playing an action video game increased the average LogMAR letter chart rating by 1.6 lines after 40 hours of video game play, which showed an average improvement of about 31%. The patients in the non-violent video game improved nearly to the same degree as the violent video game, with an average improvement of 1.5 letter lines and an improvement of about 28%. It was noted that while the experiment was still a small-scale pilot test, the results that were shown would take around five times longer to stimulate improvement to that extent with conventional treatment. It could be said that the results were acquired through straining the eye in both a rewarding process, as well as an environmentally stimulating/stressful process, which could have stimulated the effects of neural plasticity based on the desired need for adaption. Despite the marginal effects between the types of video games played in this study, it is also emphasized in older studies by Li and others that the type of video game played can also impact cognitive change (Li et al., 2009), which is congruent with Latham et al.'s findings as previously emphasized (Latham et al., 2013).

While the field started with an extreme bias as to the effects that video games can have on cognition, over the past several decades, video games have begun to show positive results. Even though there have been negative effects, like that of online gaming addiction, video games have shown, through many studies and evaluations, to have an overall positive effect on populations. Video games may show positive results, but it may still be questionable whether other popular means of entertainment could still be better for populations, such as playing a musical instrument. Regardless, as shown with Lindstrom et al's analysis (Lindstrom et al., 2005) concurrent with statistical findings of the Kaiser Family Foundation (Rideout et al., 2010), video games seem to be a better fit than many other forms of media in modern society, like watching television, and should be considered for potential neural development.

Changes in the Brain: On Sleep

As the third and final case study for neuroplasticity in everyday actions, sleep offers a unique stance into the daily essential tools plasticity provides. The modern theories surrounding sleep are primarily based on memory consolidation, which implies the direct need for plasticity to occur to form and order synapses. Evidence supporting this claim comes from copious amounts of research collected over the past 60 plus years (Diekelmann and Born, 2010; Walker and Stickgold, 2006; Shepherd, 1994). The earliest recorded studies of neural activation on the sleeping brain could date back to 1929, when Hans Berger reported on his findings of the electroencephalogram (EEG), but dealings and related findings surrounding the modern concept of neuroplasticity would not come until 1935 (Wang et al., 2011). To provide a brief outlook on the generic mechanisms of sleep in this context of memory consolidation and plasticity, a short explanation of the properties of sleep will be elaborated.

The findings of Berger in 1929 on EEG would spark an investigation into the concept known today as EEG rhythm. In sleep, the EEG rhythms that are observed mainly arise in the form of alpha and delta waves occurring during the sleep stages 1 and 2 and stages 3 and 4, respectively. Found distinctively during rapid eye movement (REM) sleep, alpha waves have a consistent pattern ranging from 8 to 12 Hz with small amplitudes. Opposite of REM sleep, slow wave sleep (SWS) is distinctive towards delta waves, which have a consistent pattern ranging from 1 to 2 Hz with large amplitudes (Shepherd, 1994). The two different types of sleep are considered to have two explicitly different functions. REM sleep occurs later in the sleep cycle and is often related to emotion and procedural memory tasks, while SWS is earlier in the sleep cycle and is often related to declarative and explicit memory tasks (Diekelmann and Born, 2010; Wang et al., 2011). Due to the ambiguity of sleep, there is heavy debate over the functionality of the two processes, but a consensus does elaborate on the two being functionally unique. The ambiguity also stimulates debate between the distinct stages of sleep and how they relate to memory consolidation, the two most prominent being the synaptic homeostasis hypothesis and the active system consolidation hypothesis. The synaptic homeostasis hypothesis works under the notion that consolidation is produced from global synaptic downscaling, while the active system consolidation hypothesis works under the notion that consolidation is actively ensured through the reactivation of memories (Diekelmann and

Born, 2010). It is duly probable that the two work in tandem to fulfill the functions of sleep.

The reasoning as to why this brief explanation holds relevance in the context of plasticity is due to the processes of memory consolidation. Due to memory consolidation being noticeably split into these two district patterns of brain activity, SWS and REM sleep, this creates a perception that plasticity is occurring in these patterns to help accommodate for these processes in different ways. The functional role of sleep in memory retention has been heavily studied at the scales of SWS and REM sleep (Bernardi et al., 2016; Peigneux et al., 2004; Wang et al., 2011; Diekelmann and Born, 2010); thus, in this context, we can see two different forms of plasticity occurring in a short time scale for daily actions through this field of study. The direction of this article will focus on organizing the studies related to the amount of time required to see effects. SWS and REM sleep studies only occur over an hourly time span, but, as will be shown, their absence for long durations of time can stimulate long-term morphological effects.

With respect to daily functional capabilities, the quality of sleep in terms of SWS and REM sleep can play a critical role in how one retains memory. Through an investigative study with naps this is shown clearly. SWS and REM sleep can be divided into two different stages in the sleep process; SWS occurs within the first 60 minutes and REM sleep occurring roughly from the 60 to 90 min range for adults (Mednick et al., 2003; Shepard, 1994). To study the consolidation of visual memory, Mednick et al. performed a simple experiment taking advantage of these two neurological findings (Mednick et al., 2003). The experiment was comprised of three groups, a control (group A), a 60 min nap group (occurs during SWS but not REM; group B), and a 90 min nap group (occurs with both SWS and REM; group C), along with a test that measured visual texture discrimination. To measure overall performance and how the groups differed, the three groups were tested before the nap as a baseline, later that day in the evening after the nap but before a night's sleep, and then once again the next day after a night's sleep. The three groups at the end of the first day before a night's sleep showed that A was significantly worse at the texture discrimination test than their base; B showed neither a significant improvement nor diminishment, but seemed to return to the beginning state, while C showed extreme improvement. The following morning's test showed that A gained improvement in the test over their base, B improved marginally over the control, and C improved significantly over the control (both nap groups improving more so than the non-nap group). The experiment elaborated on the fundamentals of how memory consolidation, and thus the accounting form of plasticity, is expressed in the different stages of sleep. It was depicted that SWS can revert the brain back to the state of cognition before the test was presented, and REM sleep seems to establish a greater form of memory consolidation. It could be said that the SWS was a form of recuperation for the synapses to slow down to normal pace, while the true consolidation was through REM sleep. Shortly the concept of recuperation/global downscaling of neural activation will be covered and elaborated through an experiment that explicitly studied the phenomena, but it is also established that SWS has been shown in the process of consolidating memory and is not explicit to recuperation.

As discussed in the active system consolidation hypothesis, restimulation of neural pathways that were present during wake could be a means of memory consolidation (Wang et al., 2011; Diekelmann and Born, 2010; Peigneux et al., 2004). Known as replay, the reactivation of neural pathways occurs mainly during the SWS portion of sleep, falling between the first 15 to 30 minutes of sleep onset (Peigneux et al., 2004). The process has been mainly studied in trained rats, but some studies have attempted and been successful in studying the phenomena in humans. Experimenting to discover if spatial memory is elaborated in the human hippocampus, Pelgneus et al. simultaneously studied the problem of reactivation of neural ensembles in the hippocampus as seen in rats (Pelgneus et al., 2004). The study discovered two key findings: one being that the hippocampus is involved in spatial navigation and second being that the reactivation of neural ensembles is demonstrated in humans, as seen in rodents during SWS. Despite the evidence pointing towards consolidation occurring in SWS, it is also primarily believed that SWS has a more important role in maintaining the homeostasis of synaptic connections rather than having an emphasized importance in memory consolidation.

During the waking hours of the day, synapses are consistently in a high state of activation, which when related to Hebbian plasticity, results in synaptic connections becoming more globally intense (Wang et al., 2011). The resulting cause of the high states of activation establishes high postsynaptic density regions that lose efficiency. As neural regions reach a high postsynaptic density the mean diffusivity, the water diffusion of a region based on tissue density, drops (Giulio et al., 2016). The reasoning for this is presumed to be a decrease in the volume of the extracellular matrices as the synaptic densities become more established and move closer together. Using this method, short time scale measurements of plasticity can be seen in real time. Giulio et al. performed an experiment to test the resulting method to study the extent to which the mean diffusivity can drop and if and how the mean diffusivity can restore the areas back to their prior condition (Giulio et al., 2016). They found the resulting methods work to measure small-scale plasticity and that sleep restored the brain to the prior conditions after 12 and 24 hours of extensive training, but did not find any correlation between the enigma and EEG studies (SWS and REM). The study looked at the EEG waves to find abnormalities in the SWS and REM sleep, but did not seem to correlate SWS and REM sleep to the mean diffusivity phenomena. It may still be likely that the mean diffusivity was restored primarily during the SWS or REM processes exclusively without showing abnormal EEG effects, as the mean diffusivity was not measured during this period. Despite the evidence not showing SWS or REM sleep correlating to the enigma, the results do tailor to the synaptic homeostasis hypothesis and show how sleep restores states of high neural activity in a process similar to what would be found in the concept of homeostasis.

The resulting studies have given a perception to the way neuroplasticity occurs in the daily routine to allow the process of long-term plasticity to occur, but viewing sleep in periods of long-term plasticity is a difficult task. The most prominent findings, indicating morphologies in the anatomy of the brain due to long durations of sleep states, are commonly tied to neurodegenerative disease. This, in and of itself, is an issue when relating the problem of sleep, due to the known phenomena that neurodegenerative diseases disturb the process of sleep while also causing abnormal morphologies (Wang et al., 2011; Raggi and Ferri, 2010). Some common ways to successfully study the effects of sleep on the anatomy of the brain originate from extreme environmental conditions of learning (Giulio et al., 2016), mass analysis of a population's sleep habits (Kuperczkó et al., 2014), and studying diseases that are not neurodegenerative that inhibit sleep (Morrell et al., 2010).

As a point of common ground for most human beings, people typically do not prefer being sleep deprived for extended periods of time. Finding patients to perform imaging studies and tests on when relating to impaired sleep is typically challenging, but with recent studies, patients with sleep apnea have been deemed to fit this description. Sleep apnea is a disorder defined by actions of repeated pauses in breathing during sleep. Sleep apnea is not a neurodegenerative disease but results in insomnia, hypersomnia, and sleep deprivation, conditions looked for when analyzing how the brain reacts to an excessive lack of sleep over long durations of time. Even though sleep apnea may be linked to neurodegenerative diseases (Raggi and Ferri, 2010), it itself is not considered neurodegenerative. Obstructive sleep apnea has been related to impairments in working memory, planning, cognitive flexibility, and semantic fluency (Morrell et al., 2010). Working under the premise that the experiments regarding morphological changes in the brain due to sleep apnea were unreliable, Morrell et al. analyzed apnea patients in a new study taking the concerns into account. While other studies have shown various regions of the brain being affected by sleep apnea, Morrell et al. only found two distinct areas with significant changes in their study, that being the loss of gray matter in the right middle temporal gyrus and left cerebellum. Morrell et al. emphasized that loss of gray matter in the pertaining regions could lead to impaired motor control, attention deficits, and working memory (Morrell et al., 2010) as previously seen. The studies on sleep apnea patients lead to evidence relating the extreme effects of lack of sleep over long durations of time, but results in an extreme not typically found in daily living. While these effects may be seen in extreme cases, the implications in the studies surrounding sleep apnea would indicate that these are generic effects relating to a quasi-linear relationship between effects seen and time spent sleep deprived.

To study the effects of long-term sleep habits, Kuperczkó et al. studied college students to determine how the hippocampus changes with respect to the different aspects of daily sleep. Studying 90 university students, Kuperczkó et al. showed evidence for bedtime significantly affecting hippocampal volume (Kuperczkó et al., 2014). Due to the risks of analyzing subjects with the potential of having sleep disorders or sleep problems unknowingly, the group of 90 students was carefully selected to control for sleep related problems. A variety of different variables such as bed time, wake up time, and sleep duration were analyzed to clearly match the results to the provided data. The experiment showed significant results pertaining to bed time and the relative volume of the hippocampus; showing early bed time as having the highest hippocampal volume and late bed time having the lowest, being linearly correlated. Interestingly the results pertaining to sleep duration showed a peak in relation to hippocampal volume at a medium sleep duration (about 7-8 hours). Having a peak at the medium sleep duration could allude to the idea that there is an optimal amount of sleep that the brain can attain. This experiment indicates that plasticity is occurring over a long duration of time based on the daily decisions of when and how long to sleep.

The study of sleep can directly and almost immediately impact one's way of living. Sleep is a prime example of how analyzing the daily and long-term effects of neuroplasticity can directly affect the way the brain is oriented. While the effects of plasticity are seemingly hidden in the underlying terminology and mechanisms of sleep, the studies indicating such plastic effects can be seen in the studies by Mednick et al. (Mednick et al., 2003), Peigneux et al. (Peigneux et al., 2004), and Giulio et al. (Giulio et al., 2016).

Conclusion

This article explored the notion that daily actions influence the way the brain is oriented. As provided with the plastic tendencies of music production, video game play, and sleep, several highly studied areas of neurology offer significant evidence to support this notion. As emphasized, with the complication of having a plentiful amount of relevant studies, sources, and topics, only a limited number of fields were thoroughly studied. Further neurological review regarding this topic could be seen with respect to the neural effects of social media, religion, language (specifically reading and bilingualism), kinesthetic learning, and surely many more, spanning the entirety of the economy and human well-being. As the main point of this article, future research should emphasize and relate the findings indicating daily actions affecting the way the brain is developed in a variety of situations.

Through knowing and understanding the modern findings surrounding the neurology of daily actions, insight into the diagnosis and treatment of neurological disorders and diseases could be gained to support patients. Such findings have already begun to take place in specific niches of neurology, as seen with the diagnosis and treatments provided with respect to Alzheimer's (Lindstrom et al., 2005; Akili, 2016), amblyopia (Li et al., 2011), and sleep apnea (Morrell et al., 2010). Past direct clinical interests, public knowledge of how daily actions affect the brain can help prevent neurological deficits, like that of online gaming addiction, and may even promote changing the way one lives to explicitly change the way people think and perceive the world around them. Such actions have even been deemed a necessity for economic structures by the management philosopher Peter Drucker. These conclusions are an essential part of his core philosophy in improving employees' mental wellbeing and are made periodically throughout his book *Management: Tasks, Responsibilities, and Practices* (Drucker and Maciariello, 2008).

Thus, the resulting importance on the study of daily actions with respect to neuroplasticity has been shown in this article to have supporting evidence for the role of neuroplasticity in everyday life. Even though neuroscience can be found in specific domains, such as medicine, education, and neuromarketing, it can be seen through these studies and others that neuroscience and neuroplasticity specifically are more entangled in everyday living than what may be expected. Among those lines, how we go about using this newly acquired information could influence our daily function as human beings and as a society.

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References

Akili (2016) A different type of medical product. In: akiliinteractive.com [Internet].

Ashburner J, Friston KJ (2000) Voxel-Based morphometry—The methods, Neuroimage 11:805–821.

Baeck E (2002) The neural networks of music, Eur J Neurol 9: 449-456.

Bernardi G, Cecchetti L, Siclari F, Buchmann A, Yu X, Handjaras G, Bellesi M, Ricciardi E, Kecskemeti SR, Riedner BA, Alexander AL, Benca RM, Ghilardi MF, Pietrini P, Cirelli C, Tononi G (2016) Sleep reverts changes in human gray and white matter caused by wake-dependent training, Neuroimage 129:367–377.

Bever TG, Chiarello RJ (1974) Cerebral dominance in musicians and nonmusicians, J Neuropsychiatry Clin Neurosci 21: pp 94–96.

Diekelmann S, Born J (2010) The memory function of sleep, Nat Rev Neurosci 11:114–126.

Dye MW, Green CS, Bavelier D (2009) Increasing Speed of Processing With Action Video Games. Curr Dir Psychol Sci 18:321–326.

Drucker PF, Maciariello JA (2008) Management. New York, NY: Collins.

Ehrenwald J (1984) Anatomy of genius: Split brains and global minds. New York, N.Y: Human Sciences Press: 3-18.

Fuchs E, Flügge G (2014) Adult Neuroplasticity: More than 40 years of research, Neural Plast.

Gaser C, Schlaug G (2003) Brain structures differ between musicians and non-musicians. J Neuro Sci 23:9240–9245.

Giulio B, Luca C, Francesca S, Andreas B, Xiaoqian Y, Giacomo H, Michele B, Emiliano R, Steven R K, Brady A R, Andrew LA, Ruth MB, Maria FG, Pietro P, Chiara C, and Giulio T (2016) Sleep reverts changes in human grey and white matter caused by wake-dependent training, Neuroimage.

Han DH, Lyoo IK, Renshaw PF (2012) Differential regional gray matter volumes in patients with on-line game addiction and professional gamers. J Psychiatr Res 46:507–515.

Hyde KL, Lerch J, Norton A, Forgeard M, Winner E, Evans AC, Schlaug G (2009) The effects of musical training on structural brain development: A longitudinal study. Ann N Y Acad Sci 1169:182–186.

Janata P, Grafton ST (2003) Swinging in the brain: shared neural substrates for behaviors related to sequencing and music. Nature Neuroscience 7:682-687.

Kühn S, Gleich T, Lorenz RC, Lindenberger U, Gallinat J (2014) Playing Super Mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game. Mol Psychiatry 19:265–271.

Kühn, S, Lorenz R, Banaschewski T, Barker GJ, Büchel C, Conrod PJ, Flor H, Garavan H, Ittermann B, Loth E, Mann K, Nees F, Artiges E, Paus T, Rietschel M, Smolka MN, Ströhle A, Walaszek B, Schumann G, Heinz A, Gallinat J (2014) Positive association of video game playing with left frontal cortical thickness in adolescents. PLoS One 9:5–10.

Kuperczkó D, Perlaki G, Faludi B, Orsi G, Altbacker A, Kovács N, Dóczi T, Komoly S, Schwarcz A, Clemens Z, Janszky J (2015) Late bedtime is associated with decreased hippocampal volume in young healthy subjects. Sleep Biol Rhythms 13:68–75.

Latham A, Patston LLM, Tippett LJ (2013) The virtual brain: 30 years of video-game play and cognitive abilities. Front Psychol 4:629.

Lestou V, Pollick FE, Kourtzi Z (2008) Neural Substrates for Action Understanding at Different Description Levels in the Human Brain. J Cogn Neurosci 20:324-341.

Li R, Polat U, Makous W, Bavelier D (2009) Enhancing the contrast sensitivity function through action video game training. Nat Neurosci 12:549–551.

Li RW, Ngo C, Nguyen J, Levi DM (2011) Video-game play induces plasticity in the visual system of adults with amblyopia. PLoS Biol 9.

Lindstrom HA, Fritsch T, Petot G, Smyth KA, Chen CH, Debanne SM, Lerner AJ, Friedland RP (2005) The relationships between television viewing in midlife and the development of Alzheimer's disease in a case-control study. Brain Cogn 58:157–165.

Mednick S, Nakayama K, Stickgold R (2003) Sleep-dependent learning: a nap is as good as a night. Nat Neurosci 6:697–698.

Men W, Falk D, Sun T, Chen W, Li J, Yin D, Zang L, Fan M (2014) The corpus callosum of Albert Einstein's brain: Another clue to his high intelligence? Brain 137.

Morrell MJ, Jackson ML, Twigg GL, Ghiassi R, McRobbie DW, Quest RA, Pardoe H, Pell GS, Abbott DF, Rochford PD, Jackson GD, Pierce RJ, O'Donoghue FJ, Corfield DR (2010) Changes in brain morphology in patients with obstructive sleep apnoea. Thorax 65:908–914.

Münte TF, Altenmüller E, Jäncke L (2002) The musician's brain as a model of neuroplasticity. Nat Rev Neurosci 3:473–478.

Peigneux P, Laureys S, Fuchs S, Collette F, Perrin F, Reggers J, Phillips C, Degueldre C, Del Fiore G, Aerts J, Luxen A, Maquet P (2004) Are spatial memories strengthened in the human hippocampus during slow wave sleep? Neuron 44:535–545.

Polderman JC, Benyamin B, Leeuw CA, Sullivan PF, Arjen VB, Visscher PM, Posthuma D (2015) Meta-analysis of the heritability of human traits based on fifty years of twin studies. Nat Genet , 47,7: 702-709.

Powers KL, Brooks PJ, Aldrich NJ, Palladino M a, Alfieri L (2013) Effects of video-game play on information processing: a meta-analytic investigation. Psychon Bull Rev 20:1055–1079.

PricewaterhouseCoopers (2010) The evolution of video gaming and content consumption. Retrieved from in: pwc.com [Internet].

Pulvermüller F (2002) The Neuroscience of Language: on brain circuits of words and serial order. New York, NY: Cambridge University Press:12-13, 18-19.

Raggi A, Ferri R (2010) Sleep disorders in neurodegenerative diseases. Eur J Neurol 17:1326–1338.

Rideout, Foehr, Robersts (2010) Generation M2: Media in the Lives of 8- to 18-Year-Olds. Kaiser Family Foundation. In: kff.org [Internet].

Schlaug G (2001) The brain of musicians. A model for functional and structural adaptation. Ann N Y Acad Sci, 930:281–299.

Schlaug G, Jäncke L, Huang Y, Staiger J, Steinmetz H (1995) Increased corpus callosum size in musicians. Neuropsychologia 33:1047–1055.

Sergent J, Zuck E, Terriah S, MacDonald B (1992) Distributed neural network underlying musical sight-reading and keyboard performance. Science, 257(5066), 106–109.

Shepherd G (1994). Neurobiology. New York: Oxford University Press: pp 550-551, 539-561, 557, 679

Stahnisch, F, Nitsch R (2002) Santiago Ramón y Cajal’s concept of neuronal plasticity: the ambiguity lives on. Trends Neurosci 25:589–591.

Walker M, Stickgold R (2006) Sleep, memory, and plasticity. Annu Rev Psychol 57:139–166.

Wang G, Grone B, Colas D, Appelbaum L, Mourrain P (2011) Synaptic plasticity in sleep: Learning, homeostasis and disease. Trends Neurosci 34:452–463.

Weng C, Qian R, Fu X, Lin B, Han X, Niu C, Wang Y (2013) Gray matter and white matter abnormalities in online game addiction. Eur J Radiol 82:1308–1312.