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The Effects of Neurochemical Changes on Language Development*

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Park, Soonhyuck. 2012. The Effects of Neurochemical Changes on Language Development. *Linguistic Research* 29(1), 261-279. There have been evidence that age-related changes in language processing during childhood, adolescence, and even up to elderly period. A very exciting data under consideration rely on the changes that occur throughout the life span that influence the development of language comprehension system. Children appear to employ some tools in their language performance that adults no longer adopt. This paper aims to provide an account of language development in terms of the brain development in magnetic resonance (MR) spectroscopy. With the ability to focus on multiple metabolites in one MR spectroscopy session, this paper scrutinizes the complex biochemical cycles involving counteracting neuro-transmitters and apply the experimental results to the empirical data that the children produce. In doing so, we can hypothesize that language develops as the brain matures in a way that it is reducing the number of unnecessary neurons, such as nerve cell bodies, while maximizing the number of axons that consists of myelinated nerve cells. Prunning of neurons with aging is recognizable by the decrease in the ratio of GABA to glutamate and the seemingly increased neuron-to-neuron connection is detected by greater amount of white matter. **(Pukyong National University)**

Keywords neurochemicals, language performance, early child English, GABA, MR spectroscopy, brain development, myelinated nerve cells, language processing, brain maturation

1. Introduction

The 43th Annual Meeting of the Psychonomic Society, which was held in Kansas City, 2001, is regarded as a very intriguing event in two respects: one respect is that

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it explores the cognitive domain using multiple, perhaps infinite, paths across various disciplinary boundaries. The other respect is that it focuses mainly on cognitive changes that occur throughout the life span. Given that the adult system is not static, changes continue to occur in the language system as it progresses toward older age. Sometimes the maturation process is accompanied by declines due to wear-and-tear on the system or by declines due to pathology. In short, the language comprehension system is dynamical in nature and is always adjusting to the environment and our summative experience.

This idea is in fact initialized by Grodzinsky (2000), who proposes that the linguistic and the neurological perspectives go hand in hand into the future. The research program set up by different areas can and should eventually be combined. There is enormous progress in our understanding of language systems, their acquisition, implementation, and neural representation. The study of the neurology of language is the leading area of these developments (Geschwind 1979; Caplan, et al. 1999; Zurif 1995). Given that language resides in a dedicated cerebral locus, distinct from those supporting other cognitive functions, linguistics and neurology thus go together to see the details of cerebral mechanisms for language through the use of imaging methods when constructing our stimuli.

Recently, there have been a wide cross section of neuropsychological tools, including fMRI, electrophysiological measures, hemispheric laterality, eye movement monitoring, and the examination of patients with pervasive or localized brain damage. Many of these tools are applied to our understanding of the component processes that contribute to language comprehension and production. Neuroimaging researches show that older adults exhibit recruitment or increased activation of brain area while performing various cognitive tasks.

Brain functional organization for cognition shows an age-related reduction of the functional asymmetries typically found in young adults. Kahlaoui et al. (2007) shows comparable performance between the two age groups. For both younger and older participants, they reveal significant hemispheric differences between the word and pseudo-word conditions with increased blood oxygenation patterns observed in pseudo-word conditions across both hemispheres. By comparison to younger participants, however, older adults activated a larger bilateral network, involving both frontal and temporal regions, during the lexical decision task, suggesting that the substrates for semantic processing of words change with aging. This result implies

that the involvement of both hemispheres is part of the brain's compensatory mechanisms subtending the preservation of language abilities in successful aging.

One of the most striking fact results from the neuroscientific experiment using MR spectroscopy, which noninvasively samples concentrations of neurochemicals of living tissues and allows scientists to study mutagenic evolution of subjects in vivo. Given that there is an intricate association between structural brain development and changes in levels of metabolites, data acquired from MR spectroscopy reveals metabolic framework of the sampled tissue, and is anticipated to help understand and identify normal patterns of metabolites.

The earlier generalization of brain with respect to age is that brain no longer undergoes changes after childhood. Paus et al. (2001), however, reports that the volume of human cortical gray matter is decreasing with age, whereas the white matter continues to steadily increase from birth to around 20 years of age by about 12%. While the white matter percentage is significantly increasing with age, the gray matter percentage is decreasing.

Baslow and Gulifoyle (2007), based on the direct method of measuring tissue condition, finds the decrease in ratio of GABA and glutamate to the reduction in gray matter percentage. Her finding is based on the assumption that if there are certain chemicals or neurotransmitters that change with age, these changes can be related to volumetric changes determined in gray matter and white matter. The ratio of GABA to glutamate levels also decreased with aging, and this resembles a similar relation to the results shown from the gray matter changes.

The goal of this paper basically follows what the papers mentioned above intended to perform in their works: an interdisciplinary approach to language processing throughout the life span. To investigate the nature of language is an interesting and intriguing issue, which linguists have long been engaged in. Equally interesting is to see how language develops throughout the life span. Children appear to rely on some tools in their language performance that adults no longer adopt. Unlike Baslow and Gulifoyle (2007), who focuses only on the ratio between GABA and glutamate during the pediatric period, this paper aims to provide an account of language development in terms of the brain development from the pediatric up to elderly period in magnetic resonance (MR) spectroscopy. With the ability to focus on multiple metabolites in one MR spectroscopy session, this research scrutinizes the complex biochemical cycles involving counteracting neurotransmitters such as GABA

and glutamate by using the ratio between them and apply the experimental results to the empirical data that the speakers ranging from 10 to 65 years old produce throughout the life span.[1] In doing so, we can acquire better understanding of their linkage to changes in gray matter percentage in the dynamic human adolescent brain development and the changes in language processing. Based on the biochemical differences over the span of adolescent brain maturation, this paper hypothesizes that language changes as the brain matures in a way that it is reducing its number of necessary neurons, such as nerve cell bodies, while maximizing the number of axons that consist of myelinated nerve cells. Pruning of neurons with aging is recognizable by the decrease in the ratio of GABA to glutamate, and the seemingly increased neuron-to-neuron connection is detected by greater amount of white matter.

2. Age-related Performance

There have been evidence that age-related changes in language processing continue during childhood, adolescence, and even up to elderly period. A very exciting data under consideration rely on the changes that occur throughout the life span that influence the development of an adult's language comprehension system.

Radford (2004) provides an interesting fact observed in the early stage of English acquisition.

(1) What do you think what Cookie Monster eats?
(2) How do you think how Superman fixed the car?
(3) Who do you think who the cat chased?
(4) Why did the farmer didn't brush his dog?[2]

In (1) through (4), the wh-phrase and the auxiliary verb are duplicated at the

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[1] As two anonymous reviewers pointed out, this research has not yet developed to the extent that it can clarify how and why the ratio change of neurochemicals has effects on language development What this research indicates, however, is that the transition from easy performance to minimizing computation in language development might be dictated by the ratio of the grey and white matter which is dependent upon the neurochemical change.

[2] Felser (2003), Du Plessis (1977), and Reis (2000) also provide evidence from adult English speakers that show the morphological realization of the embedded *wh*-phrase.

intermediate position in the long distance dependency. A similar pattern is found in adults, as in (5) and (6) where the resumptive pronoun *him* and the relative pronoun *which* are unnecessarily pronounced, but it is very rare or even considered to be ungrammatical.

(5) He is someone who I don't know anyone that likes him.
(Pesetsky 1997)

(6) It's a world record which many of us thought which wasn't on the books at all. (Radford 2004)[3]

It is not clear why children often produce the sentences like in (1)-(4), but it is likely that the memory span of children is not long enough to retain the relationship between the displaced *wh*-phrase/auxiliary and their original positions.

It is generally known that duplication in this period is to help processing in an easier and faster way. Duplication, however, is a tool that should be barred in the current linguistic theories of Minimalist Program, in that it violates minimal computation. The multi occurrence of computation contains unnecessary, thus, ungrammatical contents in the derivation, thereby resulting in 'crash' in the interfaces. Duplication generally disappears when children are closer to adolescence.

Age-related evidence has been reported since early 1960s. Chomsky (1969) tests the minimal distance principle to see whether children acquiring English as a first language would rely on surface distance of nouns and verbs in processing, or they would use underlying syntax in processing. Her assumption is that children might interpret the noun closest to the verb as the subject of the verb in the sentences in (7)-(9).

(7) The doll is easy/eager to see. (predicted error: doll does all the seeing)

(8) Bozo asked/promised Mickey to sing. (predicted error: Mickey does all the singing)

(9) Ask/tell Bozo what to eat. (predicted error: Bozo does all the eating)

Her findings show a progression with age-older children completed the tasks

[3] As a anonymous reviewer points out, the sentences in (5) and (6) are expected to disappear in the adults.

much more accurately than younger children. The youngest children use 'nextness' as a way of assigning noun-verb connections, and are not as accurate in locating pronoun referents, as in 'He found that Mickey won the race (he≠Mickey).'

Many other experiments have also shown how the speakers disregard word order and use content words to build propositions that make sense. Clark and Clark (1977) finds that when children are given toy animals to play with and asked to show you, they usually pick up the first mentioned toy and make it kiss the second in both (10) and (11).

(10) The horse kissed the cow.
(11) The cow was kissed by the horse.

This is very similar to the observations from Broca's aphasia. What is interesting here is that adults are more likely to begin with the content words and try to construct propositions that seem logical based on the real world and the immediate context.

The differences between children and adults in language processing are also found in so-called SOE (slips of the ear) and TOT (tips of tongue). When we hear the utterances of slips of tongue, they go unnoticed because they are converted by 'slips of the ear,' back to what the speaker really intended to say.

(12)	Slips of the tongue	Slips of the ear
	a. The man bit the dog.	The dog bit the man.
	b. John ironed and washed his shirt.	John washed and ironed his shirt.

Bond (1999), following linguistic and psycholinguistic views of Meringer (1908) and Meringer and Mayer (1895), points out that listeners apply strategies based on their knowledge of the structure of their language, when they are faced with a phonetic stream of a rapid and inconsistent, full of assimilations, deletions and many other kinds of reductions. By doing so, most of the time, listeners untangle the rumble speech and recover listener intentions. SOE and SOT imply that we can arrive at propositional meaning, even though we cannot easily process the syntax. Clark and Clark (1977) reports that older adults more likely to perform SOE than

children and young adults to comprehend languages, not only by working from word recognition, but by using good background information and adequate knowledge of world.

Another evidence related to aging is TOT, which is tips of tongue. TOT is caused by a more accessible word but incorrect word that comes to mind first and suppresses the target word, preventing its retrieval. Jones (1989) provides evidence that questions presented with phonologically related alternate words produce more TOTs than questions presented with an unrelated word.

Cross and Burke (2004) further finds that older adults produce more TOTs not because they have greater knowledge related to the target word than young adults and this greater knowledge produces competitors that interfere with target retrieval. They instead suggest that when participants fail to produce the answer to a question, presentation of a semantically related word compared to an unrelated word reduced correct responses and increased TOTs as the participant try to respond to the question (Meyer and Bock 1992; James and Burke 2000).

Another interesting research is to explore the relationship between mastication and cognition, with a special focus on aging and dementia, and its possible underlying mechanisms. Since the relationship between mastication and cognition is not yet firmly established, and is investigated in the context of a number of different disciplines, a comprehensive overview will contribute to our knowledge. The results of animal and human experimental studies suggest a causal relationship between mastication and cognition. Furthermore, correlations exist between mastication and activities of daily living and nutritional status. These findings have compelling implications for the development of prevention strategies by which medical and nursing staff may optimize their care for the frail and elderly, suffering from dementia. There is a causal relationship between mastication and cognition in animals; (i) there is a correlation between cognition and oral health status in elderly humans. (ii) Several possible underlying mechanisms for these relations have been identified. (iii) Several brain areas are activated during mastication, such as the prefrontal cortex. And (iv) nutritional status and ability to maintain oral hygiene might play a mediating role.

Dementia is a growing concern for all health professionals because of the rapid increase in the elderly population and the increased prevalence of older people living with neurodegenerative disorders. Dementia is traditionally defined as a decline in

intellectual ability from a previous level of performance, causing impairment in everyday activities in a setting of unimpaired consciousness. There are multiple reversible and irreversible causes of dementia in the elderly. The prevalence of edentuousness is declining, and therefore dental professionals will face a greater burden of maintaining and preserving dental health in older adults who develop dementia. This overview of dementia and oral health summarizes the epidemiology, etiology, signs and symptoms, diagnosis, and medical management of dementing illnesses, particularly AD, and provides a brief overview of the stomatological findings and dental management of these patients.

3. Neurochemicals

The magnetic resonance (MR) spectroscopic provides an account of why children give preference of performance to competence and how their preference changes as they grow. Adolescent and elderly brain development is a 'novel' field in that before the availability of MR imaging and MR spectroscopy, scientists could only conduct post-mortem studies. They could not organize longitudinal studies of development or relate brain changes to behavior. MR spectroscopy noninvasively samples concentrations of neurochemicals of living tissues, and allows scientists to study disease processes and mutagenic evolution of subjects in vivo. Researchers strongly agree that there is an intricate association between structural brain development and changes in levels of metabolites, which are organic compounds used or produced by metabolism.

MR spectroscopy is commonly used in clinical settings for psychiatric and neurological studies to provide greater understanding of brain diseases based on metabolite changes. Data acquired from MR spectroscopy reveals metabolic framework of the sampled tissue, and is anticipated to help understand and identify normal patterns of metabolites. That is, MR spectroscopy creates quantitatively precise metabolite maps, depicted in Figure 1 (McLean et al. 2000).

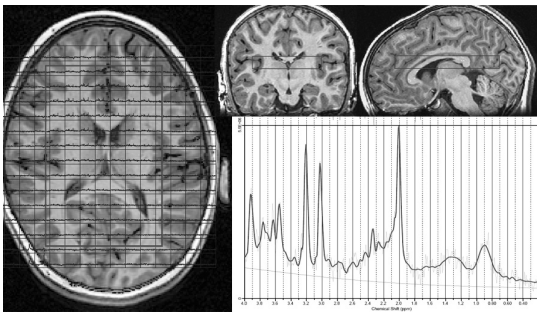

Figure 1. Sample MR spectroscopy spectrum averaged over the whole slice (bottom right) and top, front, and side views of signal volume of Chemical Shift Imaging (left to right). Each blue square detects signals of neurochemical measurement.

Recent neuroimaging researches show that older adults exhibit recruitment or increased activation of brain area while performing various cognitive tasks. Brain functional organization for cognition shows an age-related reduction of the functional asymmetries typically found in young adults. This research aims to examine the normal brain development by characterizing metabolite patterns and to provide a MR spectroscopic account of why speakers give preference of performance to competence during this particular stage in life.

MR spectroscopy is a tool that might prove to be useful in studying the topic. It is possible that MR spectroscopy is a reliable, analytical tool for classifying developmental progresses of individuals. From graphical plots of several metabolites' signal areas versus observation frequencies demonstrated by proton MR spectroscopy, the most obvious peak is NAA. The peak also includes levels of N-acetylaspartyl glutamate, glycoproteins, and amino-acid molecules in peptides (Barkovich 2005). NAA, Cho, Cre, GABA, and glutamate are the metabolites to be tested. NAA is stored in neurons, and will help measure how dense neurons are in particular regions. NAA is commonly regarded as a marker for neuronal activity. Cho is a part of neural membranes, and opens a way to examine cell myelin density. Cho levels indicate membrane condition. An increase in Cho level is a sign that myelin has broken down. Cre is representative of cellular energy storage. Previous research results suggest that abnormal Cre levels induce Cre deficiency syndromes, stroke, tumor, and trauma (Cecil and Jones 2001). Lastly, the ratio of GABA and glutamate yields a direct method of measuring the overall tissue condition, where as NAA,

Cho, and Cre are indirect markers of neuronal activity. This measurement will be used as an important reference that represents the overall number of cells in the tissue. Additionally, individual concentration levels of GABA and glutamate are considered as well.

GABA and glutamate are neurotransmitters that control synaptic activities; GABA is a major inhibitory neurotransmitter and glutamate, a precursor to GABA, is an important excitatory neurotransmitter. Petroff, et al. (2002) demonstrated that glutamatergic neurons activate GABA transporters, and GABA-nergic neurons can take up extracellular glutamate during glutamate-GABA cycle. This process suggests that GABA and glutamate are dependent on each other for metabolic transcription and expression. Consequently, the ratio of these two neurotransmitters can give insight into the overall relationship between functional imaging signal and extent of neurotransmission and energetics. GABA can interact with a vast number of tissue regions in central nervous system, including sites that are not known to be GABA receptors but physiologically relevant. Therefore, measuring GABA concentrations can indicate physiological, behavioral, and biochemical regulations in the developing brain. Jensen et al. (2005) proposed that higher GABA concentrations are found in cortical gray matter than white matter in six healthy human subjects (three male, three female, 27±7 years). The authors also detected increase in white matter and decrease in gray matter with aging.

Previous studies have reported both consistent and conflicting findings in the levels of specific neurochemicals depending on their selection of subject age groups. Kreis (2004) performed MR spectroscopy in 21 normal infants in 28 sessions, and concluded that brain maturation plays a role in the remarkable increase in total NAA, Glu, total Cre, and Tau. Similarly, Kato et al. (1997) observed a large increase from in vivo levels of NAA as infants matured. Another study found an age-related increment of total chemical concentration, particularly in the prefrontal and sensorimotor cortices, in 19-31-year-olds. This was a cross-sectional study including young adults and middle-aged groups. The authors conducted correlation analysis using GABA, Glu, and Gln, which were discovered to yield the greatest differences in concentrations between young and middle-aged subject groups. Interestingly, these chemicals were positively correlated with ages of the subjects, but there was weaker relationship between NAA/Cre levels and aging.

Results from previous invivo studies show an increase in NAA concentrations in

whole brain or occipital lobe from early childhood to adolescence and decrease of NAA/Cre in SMC with brain maturation. On the contrary, the authors acknowledge that recent reports show results in which NAA did not change across different age groups (Grachev and Vania 2001). A probable interpretation is that the metabolite levels increase then decrease again with aging, and only particular age ranges go under certain chemical level changes. It is also possible that conflicting results are obtained from limitations in acquiring reliable detectors for chemical differences, and also in part to lack of understanding how to accurately interpret chemical volume in relation to specific brain regions and aging process.

The overall purpose of this paper is to elucidate age-dependent and region-specific neurochemical changes by analyzing data collected from 10-65-year-old healthy speakers using brain imaging technology, proton MR spectroscopy. This paper hypothesizes that investigating the biochemical differences over the span of adolescent brain maturation can provide precise answers to why such spatial and chemical volume changes in the brain occur. To accomplish this, statistical brain imaging techniques and analyses are applied to detect how much of certain neurochemicals are present in particular brain regions. Along with the neurochemical measurements, percentages of white and gray matters are examined to evaluate the results obtained from Jensen et al. (2005).

This paper anticipates that identifying a solid pattern of changes in neurochemical levels and relative ratios during the developmental period by utilizing MR spectroscopy can benefit the medical field by providing reports that show what is happening as apart of normal pediatric brain development. This knowledge is crucial in order to help the medical community understand developmental disorders and efficiently diagnose pathological diseases. Specific deviations in biological chemicals could help detect detrimental pathologies, such as tumor, infection, and inflammatory progresses, caused by abnormal metabolic responses in the brain.

Evaluation of results obtained from MR imaging and MR spectroscopy may provide further understanding for lesser known brain disorders, as well as identify undiscovered medical complications. Further understanding and utilization of MR spectroscopy method over the course of brain development and aging may provide quintessential and accurate interpretation, as well as effective and non-invasive treatment plans for brain disorders, such as Alzheimer's disease, amyotrophic lateral sclerosis, and Parkinson's disease. Eventually, knowing current brain chemistry might

help physicians decide what treatments and dosages to use in different situations. In this study, ratio of GABA and glutamate levels is measured along with other metabolites during pediatric brain maturation. Accordingly, another implication is that knowing when GABA systems are maturing in the brain during normal development can possibly shed new light on when adolescents should be allowed to take GABA-nergic drugs such as valium or alcohol.

Subjects

Subjects for this experiment consist of 30 healthy speakers in the range of 10 to 65 years of age with two subjects per each year of life. Subjects in this particular age group are selected in order to measure the adolescent brain development. The study excludes individuals with a history of psychiatric disorders or abnormal biological health factors. All 30 speakers are asked to complete IQ tests and questionnaires that characterize how they have socially developed. This step determines whether or not the subject is psychologically and behaviorally representative of a typically developing person at the age level.

MR Spectroscopy Session

Each subject receives one MR spectroscopy session. During the session, a single-voxel PRESS sequence is applied to successfully produce a spectrum with excellent line width, which allows better resolution in the frequency dimension of the spectrum. Safriel, et al. (2005) mentioned that PRESS provided “improved signal intensity-to-noise ratio and a simpler spectrum with less peak interference.” Ideally, high field strength of 3T is acquired to produce peak distributions of neurochemicals. At the same time, short echo time is used to record chemical signals with time efficiency. Short echo time is a way of getting stronger signals from less abundant chemicals such as amino acids and neurotransmitters. Finally, spectra are created from different sections of the brain. In the case of right-hemisphere amygdalae, TE = 35 msec, TR of 1500 msec, and 256 averages of 4096 data points are used. Proton MR spectroscopy detects concentrations of neurochemicals by plotting metabolite signal area versus an observation frequency. This is corrected for field strength, which converts measurements to parts per million (ppm). Chemical metabolites are then able to be recognized on scanners functioning at different field strengths by the frequency correction. Metabolite ratios are then used to make feasible region-specific

comparisons.

Chemical Shift Imaging

Chemical Shift Imaging (CSI) is technologically one of the newest types of MR spectroscopy, and images from CSI are illustrated in Figure 1. The figure shows a top view, a front view, and a side view of the signal volume, from left to right respectively. The top view shows each square that allows signal detection and measurement.

LCModel

Another technological necessity is the LCModel, which is used to analyze resultant brain spectra. This is a software package that automatically evaluates spectra obtained from CSI. Skoch et al. (1983) used this technique to combine measured and stimulated peaks of neurochemical compounds acquired according to the LCModel manual. In a different study, McLean et al. (2001) used single PRESS-excited volume to measure chemical levels in right and left hippocampi of healthy subjects, in the age range from 19 to 30 years old.

To evaluate metabolites measured, Cre is used as an internal control for comparing any changes in chemical volume, as it is assumed that Cre is stored in about the same concentration in all cells. This allows amount of metabolites or number of cells to be measured, and measurements become less sensitive to water or scar tissue, as well as other factors involved in the signal volume. The LCModel software will generate a linear function that is instantaneously deduced from resonances of multiple protons of a specific neurochemical. An adapted computer software is used to separate grey matter and white matter, so that age-related differences in brain chemistry in these tissues can be measured. Dechent et al. (1999) utilized the software as an adequate method to obtain absolute concentrations of metabolites such as NAA, Cre, Cho, Glu, Gln, Tau, and GABA.

The model is particularly useful in that it gives a more precise data than results from single-peak analyses. Because there is no control subject group in the research, the data collected will not be able to be compared to a set of control data. However, data acquired outside of the research lab will be monitored to formulate a general trend in the levels of certain chemicals in relation to regional and age differences

(Figure 2).

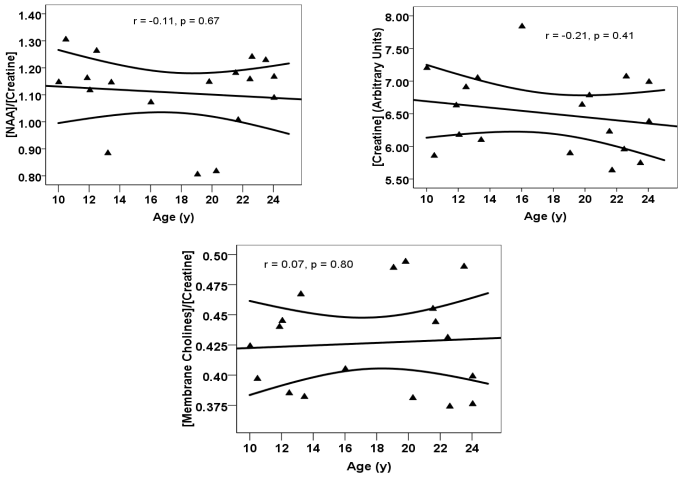

Figure 2. There is no significant correlation between concentration levels of NAA, creatine, and choline and brain maturation.

The pilot test shows that white matter percentage of Chemical Shift Imaging (CSI) is increasing with age (r = 0.50), while the gray matter percentage of CSI is oppositely decreasing with age (r = -0.51). As the p values are 0.04 for the results obtained from white matter percentage of CSI and 0.03 for the gray matter percentage of CSI, both of these patterns with brain development are statistically significant. On the other hand, concentration levels of NAA, creatine, and choline did not yield a strong statistical correlation with brain maturation (Figure 3). The data set for concentrations of NAA (r = -0.11, p = 0.67), Cre (r = -0.21, p = 0.41), and Cho (r = 0.07, p = 0.80) did not provide a clear trend to be correlated with aging, as indicated by the regression lines.

Another pilot test depicted in Figure 3 below clearly shows the decrease in the ratio of GABA and glutamate with aging (r = -0.64, p = 0.004), a result consistent with reported literature values in human invivo J-resolved spectroscopic imaging study. However, concentrations of GABA (r=-0.47, p=0.07) and glutamate (r=0.04, p=0.86) measured alone do not express significant correlations with adolescent brain development. Table 2 shows values of statistical correlations for the ratio of GABA and glutamate, as well as for the concentrations of GABA and glutamate measured

separately. As Petroff (2002) had reported, the ratio between the inhibitory (GABA) and excitatory (glutamate) neurotransmitters provide strong evidence that in vivo GABA and glutamate systems are changing.

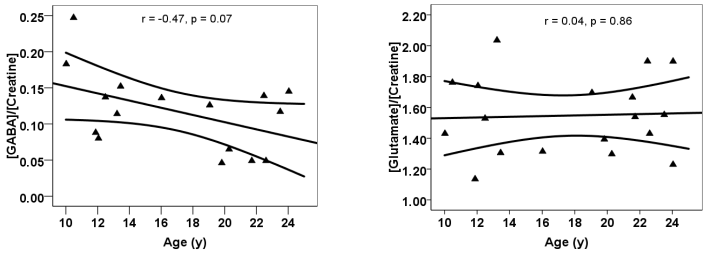

Figure 3. The ratio of GABA and glutamate is decreasing with aging (top graph). However, concentrations of GABA and glutamate taken alone do not seem show a significant correlation with aging.

Overall, the typical indirect method of measuring brain tissues did not form a significant correlation with age, while the direct method of measuring tissue condition suggested an interesting relationship of the decrease in ratio of GABA and glutamate to the reduction in gray matter percentage. This implies that as the brain matures, it is reducing its number of unnecessary neurons, such as nerve cell bodies, while maximizing the number of axons that consist of myelinated nerve cells. Pruning of neurons with aging is recognizable by the decreased gray matter, and the seemingly increased neuron-to-neuron connection is detected by greater amount of white matter. Interestingly, the ratio of GABA to glutamate levels also decrease with aging, and this resembles a similar relationship to the results shown from the gray matter changes. On the contrary, measurements from concentrations of GABA and glutamate alone show no correlation with pediatric brain development. As a result, thorough and holistic interpretations of continuous neural adaptations and modifications that occur during normal adolescent aging may be reached until neurochemical levels are compared with one another. Since the ratio of GABA to glutamate is decreasing, the GABA levels are decreasing whereas the glutamate levels are increasing over the span of brain development. With the ability to focus on multiple metabolites in one MR spectroscopy session, further MR spectroscopy studies can begin to scrutinize the complex biochemical cycles involving counteracting neurotransmitters such as GABA and glutamate by using the ratio

between the two.

4. Conclusion

Recent experiments in neuroscience have been conducted to show the differences in the brain area activated while performing various cognitive tasks between different age groups. A series of researches on the ERP (N400 and P600) data from children, the most common feature of the N400 component, which reflects semantic processing, is its tendency to be greater in amplitude, more delayed in latency, and more widely distributed in terms of scalp location than that observed in adults. For the P600, which reflects syntactic processing, there is a tendency for this component to be greater in amplitude and more delayed in latency as compared to that observed in adults.

Another interesting facts have been observed from the neuroscientific experiments. Given that there is an intricate association between structural brain development and changes in levels of metabolites, the data of MR spectroscopy reveals metabolic framework of the sampled tissue, anticipating to help understand and identify normal patterns of metabolites. The earlier generalization of brain with respect to age is that brain no longer undergoes changes after childhood. It has, however, been reported that the volume of human cortical gray matter is decreasing with age, whereas the white matter continues to steadily increase from birth to around 20 years of age.

Baslow and Gulifoyle (2007) finds the decrease in ratio of GABA and glutamate to the reduction in gray matter percentage and claims that there are certain chemicals or neurotransmitters that change with age and these changes can be related to volumetric changes determined in gray matter and white matter. This paper conducts a similar experiment, but added to the experiments the subjects whose ages range from 10 to 65 and the neurochemicals other than GABA and glutamate. It is hypothesized from the experiments that as the brain matures, it reduces the number of unnecessary neurons, while maximizing the number of axons that consist of myelinated nerve cells. Pruning of neurons with aging is recognized by the decreased gray matter, and the seemingly increased neuron-to-neuron connection is detected by greater amount of white matter.

There are multiple paths for exploring the cognitive domain that cross various disciplinary boundaries and provide unique perspectives on language processing. The effort to incorporate the linguistic perspectives with neurological ones has just started to improve our understanding of cerebral mechanisms for language through the use of imaging methods and chemical changes.

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