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CEREBELLUM'S ROLE IN DUAL TASKING WITH AUTOMATICITY OF
MOVEMENTS

by

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ABSTRACT OF THE DISSERTATION

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People perform dual task performances involving cognitive and motor processes. For example, a skilled typist can type while holding a conversation. The cerebellum plays a key role in allowing individuals to perform these kinds of tasks simultaneously. In the performance of these dual tasks, motor movements are “automatic” or trivial to many individuals and thus, do not require explicit attention. Damage to this brain region may impair the performance of automatic motor tasks. Through neuroimaging, researchers were able to show the importance and involvement of the cerebellum in automation during the performance of two concurrent tasks. However, the specific role of the cerebellum in cognition and true mechanism of automation remains a challenge for future investigations.

Preface

Acknowledgement and/or Dedication

I would like to thank the members of my committee, Dr. Andrew Hill and Dr. Laszlo Zaborszky, for their tremendous support, thorough feedback, and patience when facing many obstacles. Also, I would like to thank friends and families, who have willingly shared their precious time supporting me throughout the entire process. They all made this review possible and I am grateful.

Table of Contents

Topics	Pages
Introduction	1
Understanding the Structure and Adaptive Roles of the Cerebellum	1
Cerebellar-damaged Patients	6
Neural Activity of Cerebellum Associated with Automaticity	13
Insight of Automation Mechanism	20
Importance of Understanding the Nature of Cerebellum and Automaticity	21
Conclusion	23

Introduction:

Automaticity in motor functions is defined as bodily action that can be done with no demand of attention. These movements can be established by a learned behavior by practice or repetitive movements. The cerebellum plays a crucial role in dual tasking by accomplishing automaticity when one practices and accurately perform a desired motor movements. While performing the automatic motor task, a person can pay attention to another task. An example of automaticity can be seen in the everyday act of walking. The control of the body during walking is not mentally taxing to the person in motion because the limb movements involved in walking have already been practiced and learned. The attention of the individual may be directed towards the presence of other nearby pedestrians, vehicles, and street signs. This kinematic of movement of walking is considered to be automatic, requiring little to no attention. During walking, the majority of the cerebellum's output travels to the motor system. The cerebellum never initiates the movements, but modifies the motor commands to make movements more accurate and adaptive.

In this thesis, I will present information showing that the cerebellum is crucial for dual tasking through functional connections related to brain regions and due to its involvement of learned motor movement.

Understanding the Structure and Adaptive Roles of the Cerebellum:

The cerebellum consists of multiple layers; the innermost layer, granule cell layer, is made up of granule cells that are very small, densely packed neurons; the middle layer, purkinje cell layer, is made up of purkinje cells that are

oriented in parallel; and the outermost layer, molecule layers, is made of many cells types, including the dendrites of the purkinje cells and axons of the granule cells. The granule layer receives sensory inputs from the mossy fibers, which, in turn, receives stimuli from sensory neurons. From the granule layer, the signal input goes through the interneurons to the purkinje cells. The purkinje cells will take the modified signal output from the cerebellum to the effector neurons. Along with the mossy fibers, climbing fibers carry information from the spinal cord to the olivary nucleus, projecting synapses with the purkinje cells. All these afferent and efferent neurons are involved in an adaptive process, which allows the brain to initiate learned responses.

The cerebellum learns and adapts signal input and responses through two systems: the feedback and feed forward adaptive system. The feedback system takes in sensory input and constantly compares the desired output to the actual output. The feedback system is ideal for short movements because it constantly compares the desired output to the actual output. If the actual output is faster than the sensory input, the cerebellum will overshoot or undershoot the signals to the effector neurons effecting the movements. In longer movements, such as reaching out for an item, the feed forward system is favored. In the feed forward system, the sensory input is taken and processed through the cerebellum to make an actual output. There is no comparing between the desired output and actual output. This system is based on trial and error. The error signal from the climbing fibers provides teaching signals to the cerebellum for more accurate movements in the future.

In order for a movement to be executed efficiently and automatically, the cerebellum undergoes motor learning. According to Albert et al. (2009), there are changes in the activity level of the cerebellum during the learning of a visuomotor task. The investigators performed a study consisting of two groups, a test group of 12 subjects and a control group of 12 subjects. The visuomotor task required the participant to move a cursor to a defined target. The control group manipulated a joystick which resulted in a cursor moving to a target. The test group had to learn and adapt the cursor's movement because of an internal mechanism in the activity which increased the angle of the cursor by 10 degrees every minute in relation to the joystick movement. Therefore, the test group had to learn to adjust the joystick movement to account for this perturbation.

The investigators determined that the cerebellum increased its input and output signals when the test group did the task. Scans of the brain during the task illustrate that the fronto-parietal and cerebellar circuits are active during the visuomotor adaption and are required in order to retain the motor skill beyond the time of the task itself (Albert et al. 2009). This data illustrates that the cerebellum plays an important role in learning and adapting to a new motor skill.

The adaptation to external stimuli is carried out within the cerebellum in the form of changes in the synapses between neurons. The mossy-fibers provide the major input to the cerebellum as they enter the middle and inferior cerebellar peduncles. A number of the mossy fiber will branch off to make contact with deep cerebellar nuclei. The others will rise into the cerebellar white matter. Here, branches of axons innervate granule cell within numerous folia. These

innervations seem to be illustrated by an adaptive-filter model of the cerebellum depicted by Paul Dean and John Porrill (2008).

The model inputs are split into two components, which are weighted independently. The two components are the parallel fibers and the signal from the synapse between parallel fibers and purkinje cells. Then the two components would recombine to produce an output from the filter in a form of purkinje cell simple spikes. Thus, the central task of the filter is to determine the weight of the parallel fibers' and synapse between fibers and purkinje cells, as the output is dependent on the values of the components' weights. The two independent component values are labeled as teaching weight and learning weight. Teaching weight corresponds to the input of climbing fiber and is related to performance error (Dean and Porrill, 2008). The correlations of these weights determine long-term depression or long-term potentiation, but, if uncorrelated, there will be no change. If the weight of the parallel-fibers is positively correlated with the weight of the climbing fibers, then the output signal weight will be reduced, resulting in long-term depression. If the weight of the parallel-fibers is negatively correlated with the weight of the climbing fibers, then output signal weight will be increased, resulting in long-term potentiation. Dean and Porrill (2008) state that the quantitative form of the weights corresponds to Sejnowski's covariance learning rule. Based on these weights, the cerebellum processes the values and modifies the output signal which results in the desired output movement. The adaptive process may allow the cerebellum to incorporate the consequences of movement

error to guide motor adaptation. After the habituation of a movement, the response becomes automatic.

Automaticity of a single movement requires minimal involvement of the cerebellum. But most actions require the use of multiple movements, which requires more direct involvement of the cerebellum to perform the movements. Aramaki et al. (2010) demonstrated that during bimanual asymmetric movements, more resources of the brain were required to perform the task at hand. Seventeen subjects, age ranging from 25 to 38 years old took part in Aramaki et al. (2010). Ten were males and 7 were females. All of the subjects were right-handed and had no psychiatric or neurological illness. Subjects were asked to perform finger tapping tasks that lasted 30 seconds each. There were four conditions: unilateral sequential, which consisted of tapping with the middle finger and index finger of the right (UR) and left (UL) hands, and bimanual, which consisted of asymmetric (BA) and symmetric (BS) movements. The unilateral condition had 1 hand moving at a time and the bimanual had both hands moving at once. The bimanual symmetric movements were both hands tapping the same patterns simultaneously using the same fingers of the each hand. For example, the left middle finger would tap with right middle finger and left index finger would tap with right index finger. The bimanual asymmetric involved the use of non-homologous muscle, which consisted of left middle finger tap with right index finger and left index finger tap with right middle finger. The finger tapping associated with the both bimanual symmetric and asymmetric involved alternating tapping patterns of the index and middle fingers. The frequency of the

tapping was recorded and an audio was provided to the tapping frequency constant. Each condition was performed separately and lasted for 30 seconds. Furthermore, the subjects were asked to keep their eyes away from their fingers.

The results showed that there were greater levels of neural activity during the bimanual asymmetrical movements than during the bimanual symmetrical movements. This shows that performing asymmetric movements requires more neural regions of the brain. The BOLD responses collected during the study show more cerebellar activation at the left cerebellum, lobule V, during unilateral left-hand tapping. It also shows that the left cerebellum lobule V corresponds to left unilateral movements. On the other hand, the BOLD response for right cerebellum, lobule VI, shows more activation during unilateral right-hand movement. This suggests that the right cerebellum lobule VI corresponds to right unilateral movements. A conclusion to the study illustrates that each individual movement requires activity within various neural regions of the brain along with connectivity to the cerebellum (hereafter defined as activity). This suggests that if a person were to dual task, more activity would be required to commit the movements. Automaticity allows the individual to streamline and prioritize brain resources to more resource-intensive (unhabituated) movements. This idea is more defined in cerebellar-damaged individuals.

Cerebellar-damaged Patients:

A study by Block and Bastian (2012) and another study by Schlerf et al. (2012) conducted experiments involving cerebellar-damaged subjects with different variation of the prism adaptation test in respect to the investigators. A

visuomotor task was given to the subjects and then, visual perturbation was introduced to the subjects via prism goggles while performing the same task prior to the goggles. Results of both studies confirmed that cerebellar-damaged individuals performed poorly in the motor adaptation test. However, healthy individuals are able to adapt to the external changes after several practices (Block and Bastian, 2012). These results confirm that the cerebellum is important to motor modification; and with practice, the movement may become more automatic, requiring less attention. Therefore it allowed for individuals to perform dual tasks more efficiently and grant more of the attention to be explicitly directed towards another stimuli or task that may be present.

It is crucial to be able to perform movements while maintaining attention to the surroundings. In many cases, attention is not explicitly directed towards the kinematic of the external movements. These external movements are automatic because they are commonly made and have already been habituated by the human body, which means that they do not require much attention. The cerebellum allows humans to achieve automaticity, which allows them to perform another task simultaneously.

Catherine E. Lang and Amy J. Bastian (2002) researched the comparison between the performances of subjects with damaged cerebellums against subjects with healthy cerebellums while executing dual tasks. Lang and Bastian (2002) had ten subjects with cerebellar-damage and ten healthy subjects, acting as the control group. The cerebellar-damages were confirmed by MRI and computer tomography before the study was done. The two groups were matched

according to their age. They performed the first task, which consisted of drawing figure-8 motions with a baton around two barriers placed in front of the subject, while standing with feet at shoulders length apart. The cerebellar-damaged subjects were given more trial runs to help their bodies to be adapted to the movement and optimize their chances of perfecting the task. Despite given the extra trials, Lang and Bastian (2002) reported that the figure-8 trials of the cerebellar-damaged individuals had more errors than the control group.

After learning the first task of drawing figure-8 movements, subjects were then given a second task. They had to listen to a 14-letter sequence recording which consisted of the same four letters: A, G, M, and O in random arrangements. At the end of the recording, subjects were asked to state the number of times a targeted letter was presented. After practicing both tasks in a series of single performance, both groups were asked to do them simultaneously as the researchers recorded the results. (Lang and Bastian, 2002).

The number of complete figure-8 motions performed by the cerebellar-damaged subjects (CBL), increased slightly with practice but decreased during the dual task. Not only did the numbers of figure-8 motions decreased but also, the qualities of the motions degraded to the early trials of the experiment. On the other hand, the number of figure-8s performed by healthy control subjects (CNT), increased throughout the experiment with a couple of exceptions, CNT-07 and CNT-10. This may be due to the fact that each subject is different in his or her anatomy and their respective higher cognitive functions. Although CNT-7's and CNT-10's number of figure-8 motions decreased during the dual tasks, the

number degraded just to the late trials of the experiment (Lang and Bastian, 2002). The researchers also showed that even with practice, individuals with damaged cerebellum have difficulty performing dual tasks. The results suggest that practiced physical motions and the cerebellum's cognitive coordination influence movements.

The cerebellar-damaged subjects showed improvements in the figure-8 task alone with practice because they maintained some cerebellar function despite the lesions. However, the result of the paper shows that the performance of the figure-8 movement declines as the second task was introduced to the subjects. This shows that the cerebellum of the cerebellar-damaged individuals may still be able to habituate themselves to the actions of a single task. However, we can speculate that the cerebellar-damaged subject's quality of the figure-8 movement performance declines once the second task was introduced because the attention was taken away from the first task. A study performed by Criscimagna-Hemminger et al. (2009) suggests a way to improve the possibility of achieving automaticity in cerebellar-damaged subjects even when their attention may be demanded by another task. Criscimagna-Hemminger et al. (2009) use different degrees of perturbation to demonstrate this idea.

Thirteen subjects with cerebellar ataxia took part in the experiment. The subjects were divided into two groups, mild and severe ataxia, based on the ratings of the International Cooperative Ataxia Rating Scale (Criscimagna-Hemminger et al. 2009). The subjects were then instructed to reach toward a target in a punching manner while holding a handle of a robotic device. They

were told not to stop at the target after punching. Then, the subjects held a two-joint robotic device that was manipulated by their dominant hand to execute ballistic punching movements at a target. A screen covered the hand holding the robotic device and a small cursor represented the position of the hand was present throughout the experiment. Color feedback was presented at the end of the task indicating whether the speed of the punch was too fast or slow. During the task, two types of perturbation were introduced via the robotic arm. The first was an abrupt perturbation that constrained the trajectory of the reach in a straight path towards the target. The subject's motor output perpendicular to the stiff channel provided by the robotic arm was measured and showed large error results (Criscrimagna-Hemminger et al. 2009). The errors decreased over repetition of the trials. The second type of perturbation, the gradual perturbation conditioning, caused minor errors. Criscrimagna-Hemminger et al. (2009) reported that the adaptation of the cerebellar ataxia patients were significantly impaired during the abrupt conditioning. When they had healthy subjects perform during the abrupt perturbation task, they found that there is a trend of the errors recorded that matches the level of impairment; healthy subjects performed less errors than the mild rated patients and the mild rated patients performed less errors than the severe rated patients (Criscrimagna-Hemminger et al. 2009).

Cerebellar ataxia subjects have difficulty adapting to movement when a perturbation is introduced, but with gradual perturbation and repetition of movements, the cerebellar ataxia subjects in this study made improvements and performed with less errors. Healthy subjects were able to achieve their

movements with less error even with abrupt perturbations, which shows that they have a higher chance of establishing automaticity faster. This study shows that it is not impossible for cerebellar-damaged subjects to eventually reach automaticity with gradual perturbation and greater amount of practice.

The plasticity of the cerebellum during automation of a movement was shown in Balsters and Ramnani's (2011) study. Nineteen right-handed subjects, ages ranging from eighteen to thirty years old, took part in the research. They were placed supine in a MRI scanner with a MRI-compatible headphone on their ears and their right hands were placed on a four button MRI-compatible response box. Stimuli was presented in the back of the machine and reflected off a mirror above the subject's eye, in order for them to see and engage in the directions of the experiment. The first task given was a visual and finger response test. The subjects were presented with a random shape out of five possibilities and were cued on the screen to respond by pressing the correct button that corresponded with the shape. From the beginning of each trial, an instruction cue appears, then the shape stimulus is presented, followed by a delayed period, and finally a trigger cue that prompts the subject to respond with pushing a button. At the end of each run, different lights were flashed: a green light was presented to show the feedback response was correct, a red light showing the feedback response was wrong and a yellow light, showing ambiguous feedback (Balsters and Ramnani, 2011). Furthermore, there were only four buttons for five random shapes. Therefore, the unevenness of shapes to buttons forces motor response learning through trial and error. After practicing the shape task, the subjects were

introduced with a second task. Subjects heard a word through the headphone and then had to respond with a verb that corresponded with word heard. For the second task, Balsters and Ramnani (2011) chose an audio stimulus rather than another visual stimulus to avoid the bottleneck of directing attention in similar stimuli. They also used a different response modality, a verbal one, rather than a motor one. Balsters and Ramnani (2011) assembled their experiment into five sessions. The first (S1) was for training purposes of both tasks. By the end of the trial, subjects were able to run fifteen correct consecutive runs. In the second session (S2) subjects were accustomed to learn the association of instructions and color dot responses. Also, the subjects were split into two categories, high learning (HL) and low learning (LL). Without the subjects knowing, in high learning there was a relevant feedback of green and red dots. In lower learning, there was a fifty percent of relevant feedback and the rest were yellow dots, ambiguous feedback. Third session (S3) involved dual tasks that involved the higher learning and low learning, both sets to have fifty relevant feedbacks so learning was minimized. A fourth session (S4) involved eighty six percent relevant feedback during the dual task. Finally, the fifth session (S5) was scanning after performance of the dual task.

The error rate and response time of higher learning condition decreased more than lower learning condition due to the relevant response. However, the result as a whole, showed improvement of both higher and lower learning condition over the progression of sessions. Thus, proving automation occurs over time and practice.

Balsters and Ramnani (2011) also reported that the greatest activity occurred in Crus I and that region was time locked to the processing of higher learning cues. According to Balster and Ramnani (2011), the BOLD decreased as automation took place. The researchers suggested that decreasing BOLD signal in their study correlates with plasticity of the cerebellum activities during automation. Their study indicates that automation processes occurs in Crus I.

Neural Activity of Cerebellum Associated with Automaticity:

As mentioned earlier, Balsters and Ramnani (2011) chose an audio stimulus rather than a second visual stimulus to avoid attention directing via bottleneck effect. Sigman and Dehaene (2008) explained that humans typically could not perform two tasks at once. They reported that motor and perceptual responses occurred in parallel, and only a central decision stage that directs attention, causes a bottleneck or delay in dual tasking.

Twenty-one right-handed subjects, ages ranging from 20 to 33 years old took part in Sigman and Dehaene's (2008) research. The first task consisted of a value that was randomly selected from the lot of four different values, 28, 37, 53, or 62. The value was presented on the screen for 150 ms and then the subjects had to respond whether the presented number was higher or lower than 45 by pressing a button with their right hand (Sigman and Dehaene, 2008). The second task was an audio task involving the presentation of a sound for 150 ms via headphones. Subjects were asked to respond if the sound was high, 880 Hz or low, 440 Hz by pressing a button with their left hand. The single task block involved 72 number trials and 72 pitch trials (Sigman and Dehaene, 2008). The

trials were randomized and delay time between trials was 2.5 to 3 seconds. In the dual-task trial, there were 160 trials with each task occurring concurrently, 40 runs in each of the four different onset timing of the two tasks. The delay timing of the onset of the two tasks during the dual task trials changes in four different time ranges composed of 0, 300, 900, and 1200 ms (Sigman and Dehaene, 2008). The delay time between each run was 12 seconds.

Sigman and Dehaene (2008) reported that the bottleneck is presented during the overlapping dual task and not during the non-overlapping dual task. The 0 and 300 ms caused the two tasks to overlap one another and attention had to be directed towards one of them. The 900 and 1200 ms causes the second task to be presented as the first task is complete, therefore, attention can be directed towards both task in the order the task is presented. Essentially, when two tasks are performed in a rapid timeframe, processing the first target delays the processing of the second task. The cerebellum may help alleviate the bottleneck in certain dual tasks by means of automaticity. Less or no attention would be needed for the automatic movement and the attention can be directed towards the other task presented.

Studies regarding to the importance of cerebellum and automaticity are not only shown in cerebellar-damaged subjects, but there are studies with healthy subjects that produced consistent reports of cerebellar-damaged individuals. Subjects consisting of 12 right-handed female, ages ranging from 22-29 years old and 12 right-handed girls, ages from 10-13 years old participated in De Guio et. al.'s (2012) study. All participants were healthy and had no history of

neurologic or psychiatric illness. Both groups were to be engaged in a rhythmic finger task. De Guio et al. (2012) stated that the rhythmic finger task was simple enough for the children and adults to execute correctly, thus ensuing a better comparison between neural activations of both groups. Subjects wore headphones and held a four-button response device in their right hand and were instructed to respond with their right index fingers. The test was based on an alternating block design that composed of rest, paced tapping, and unpaced tapping block. During the paced block, subjects were presented with a metronome and a black screen. This block lasted 6 seconds. The metronome produced 12 1-kHz tones for every 500 ms and subjects were instructed to press a button with their right index finger every time they heard a beep (De Guio et al. 2012). During the unpaced tapping session, subjects continued to tap at the same pace as the metronome that was presented earlier in the paced trial while staring at a blank screen. This block lasted for 16 seconds. There was 6 cycles of all the blocks. The purpose of the screen was for giving the subjects a start and stop cue during each cycle. De Guio et al. (2012) reported that two children were excluded from the experiment because their tapping pattern was too fast during 3 unpaced blocks.

Overall both groups performed well with little deviation from the tempo. The adults performed little better than the children, suggesting that the adults maintained a rhythm better than the children. De Guio et al. (2012) reported that both groups performed well on the task and revealed similar neural activation

patterns with difference in intensity. Children produced significantly higher activation than adults.

De Guio et al. (2012) suggested that the children exhibited larger activity in Crus II, a second hand representation, and in the superior vermis, lobule V, which is involved in distinct movement and timing. This shows that even with poorer performance, the children recruited the resource from the superior vermis in order to maintain rhythm due to less automaticity (De Guio et al. 2012). In this study, it can be objectively seen that children can perform simple motor task as well as the adults, but the neuroimages show that children use more resource to deliver the task on par with the adults. It also helps us to lead a theory that children may have more difficulty performing dual task because more resource is demanded to perform a single task.

As we get older our ability to move becomes more impaired. Wu and Hallett (2005) performed a study comparing the automaticity between young and aged individuals. They examined 12 subjects, ages ranging from 57 to 73 years old. The subjects represented the aged group and consisted of eight males and four females. They also investigated 12 subjects, age ranging from 23 to 38 years old. These subjects represented the younger group and also had eight males and four females. All of the subjects were right-handed. None of them reported any history of neurological or psychiatric illness. First, the subjects were asked to perform 2 sequences of right fingers tapping, sequence-4 and sequence-12. Each finger was represented by a number, 1-index, 2-middle, 3-ring, and 4-pinky. These assigned numbers correlates with the sequences.

Sequence-4 was 1-3-4-2 and sequence-12 was 1-4-3-2-2-4-1-3-4-1-2-3.

Automaticity was measured by having the subjects perform a visual letter-counting task concurrently with the sequential task, a dual task. The visual-letter counting task involved random series of the letters A, G, L and O displayed on a screen and subjects were asked to identify the number of time a target letter was seen. They practiced until they could move at a rate of 0.5 Hz (Wu and Hallett, 2005). After the first scan, the subjects practiced until they could perform the sequential task from memory 10 consecutive times and dual task 10 consecutive times accurately. The subjects also performed left index finger tapping at their own pace until they perfected it for scanning. This left index finger tapping task represents the control for the study and scanned after practice. Therefore the researchers can explain whether age-related changes in the brain activity were due to difference of strength. There were no feedbacks for the subjects in the duration of the task and fMRI scans had 2 conditions, rest and active, which lasted 25 seconds each, which repeated 5 times every session (Wu and Hallett, 2005).

One of the activated regions involves the bilateral cerebellum. In young subjects during the automatic stage, the bilateral posterior lobe of cerebellum was not activated. In contrast, the aged subjects recruited resource from the bilateral posterior lobe of cerebellum. Aged subjects needed more time than young subjects for automation to occur and after training, both aged and young groups significantly improved in performance. This speculates that young subjects are able to achieve automaticity more quickly.

There are numerous evidences that have explicitly shown the importance of the cerebellum in automatcity. The effects of damaged cerebellum are clearly observed by the poor performance displayed by cerebellar-damaged individuals. However, implicit evidences show the cerebellum's involvement in dual tasking and other regions of the brain.

Wu et al. (2013) performed another dual task experiment in an attempt to identify any additional cerebellar regions or internal modifications that transpire during dual task. 18 healthy right-handed volunteers participated in their research. The subjects were asked to perform two single tasks and one dual task. Wu et al. (2013) targeted a simple dual task paradigm to avoid neural demands. The single task consists of a visual letter counting task, where a series of A, G, L, and O were shown on a monitor in intervals of 1.5 seconds. Then subject were asked the number of times a targeted letter was presented. The other task involved the subject to tap their right index and middle finger alternatively. Wu et al. took into consideration that timing may be a factor that affects the difference of the error rate and to rid of the potential factor, the timing of tapping interval between the single and dual-task remained the same throughout the experiment. The dual tasks involved both single tasks to be performed simultaneously and through these tasks, fMRI scanning sessions were done.

Wu et al. (2013) reported additional activation of the cerebellum during dual task. There were additional activations shown in the vermis of the right

cerebellum, lobule V of left cerebellum, and precuneus (Wu et al. 2013) and these were consistent prior and after pre training session.

The lobule V and vermis may help provide future neural targets for investigators to identify the natures behind dual tasking with cerebellum. The precuneus is part of the parietal lobe and reported by Wu et al. (2013) to be another activated brain region during dual task.

The additional regions activated in Wu et al.'s (2013) study also provides evidence that the cerebellum plays a major role in dual task and that the cerebellum is changing and shows great plasticity during dual tasking. These regions, the vermis and lobule V had functional connectivity with motor- and cognitive-related regions (Wu et al. 2013). The cerebellum most likely fine tunes these connections allowing for optimal dual task performance.

Wu et al. (2013) found that there were no errors in the single task performed by the subjects during the pre-training session. Errors arose when subjects were asked to perform a dual task and there was a significant difference within performance between the dual-task and the single tasks (Wu et al. 2013). However, after practice, no errors arose. Wu et al. (2013) stated that there was unchanged local activity and strengthened functional connectivity in the cerebellum during the after training session. This suggest that the neural activity of the vermis of the right cerebellum and the lobule V of left cerebellum do not become more efficient, but they adjust both brain motor and cognitive association to be more efficient in order to perform the dual task ideally.

Insight of Automation Mechanism:

The vermis of the right cerebellum, lobule V of left cerebellum are connected to multiple motor and cognitive related networks. Motor related networks would be primary motor, supplementary motor area-proper, contra lateral cerebellum (Wu et al. 2013). Cognitive related networks would be pre-supplementary motor area and cerebellar posterior lobe. The two regions functionally connected to supplementary motor area-proper during tapping and pre-supplementary are while performing counting task. Wu et al. (2013) points out that the supplementary area-proper is primarily involved in movement behavior, whereas pre-supplementary motor area is involved with critical thinking. The additional regions found by the research team also functionally connected to other region of the cerebellum because there are many neural functionally connectivity that connects to the cerebellum involving motor and cognitive skills (Wu et al. 2013). They only connect with areas required for either tapping or counting performances. Wu et al. (2013) report that after training they notice decreased activity of the pre-supplementary and superior parietal lobule, but activity in the vermis of the right cerebellum, lobule V of left cerebellum remained the same. This suggests that automation is taking place because the activity is decreasing and this indicates that fewer neural demands are needed for the execution of the task. When the dual task is performed automatically, Wu et al. (2013) reported that there were not only reduced neural activities but the group of motor area became more tightly packed. This shows that there is also strengthening of functional connectivity between the neural regions and is shown

between the connectivity of the vermis and lobule V to other recruited regions. That change demonstrates the shift in attention demanding state to an automatic one. Wu et al. (2013) also reported that there was no noticeable change in the precuneus, whereas there were multiple changes in the vermis and lobule V. According to the researchers, the precuneus may play a role in monitoring the execution of the cerebellum during automation. Another evidence that demonstrates the importance of the vermis and dual tasking is the fact that majority of the subjects in Lang et al. (2002) experiment had damage to the vermis. The demonstration of automation between two tasks involving cognitive and motor components in the cerebellum is provided by Wu et al. (2013) but the neural activations are specifically linked with the tasks that his subjects were instructed to perform. Future studies would also have to aim for other regions of the brain connected to the cerebellum.

Importance of Understanding the Nature of Cerebellum and Automaticity:

The understanding between the nature of the cerebellum and dual tasking is extremely important in building an understanding linking cerebellum research to dual tasking. The significance of this research topic will help elucidate theories from facts based on empirical experiments. Not only will medical entities benefit, but so will governmental laws and policymakers in which they use the provided research data to help redefine laws referencing the findings of this review. For example, texting while operating moving vehicles or texting while walking across a street. In essence, cerebellum and dual-tasking research could indirectly help save lives.

When thinking about modern, fast-growing societies, one may immediately think of sophisticated technologies, complex infrastructures and multimillion-dollar companies. The advent of vehicles has been so ingrained in our daily routines; we take our driving privileges for granted. Unfortunately, with what we have become greatly accustomed to, it is easy to overlook one of the most dangerous things we do in our everyday lives; driving a car. The cerebellum's involvement in dual tasking plays a vital role in driving. When driving a vehicle, the details of the movements required to apply the brake and accelerate is not pronounced to an experienced driver. The movements are almost reflexive and therefore, the attention of the driver is explicitly directed towards the surroundings. As shown in the previous studies of this review, the cerebellum's involvement with automaticity may alleviate the bottleneck effect caused by central decision on directing attention (Sigman and Dehaene, 2008).

Automaticity may seem convenient and can be utilized effortlessly and efficiently but it also poses hidden risks. For instance, there are many people that text while driving and do not know the potential dangers they are immersing themselves in. Understanding factors that may affect the performance involving the cerebellum gives society a broader perspective of the many possibilities behind dual tasking and the potential dangers that may be involved. While driving and texting, one can be presented with negative perturbation, such as a deer running in the road or an unexpected, abrupt stop by the car in front. One can instinctively react to the perturbation as it appears. On the other hand, the

perturbation may be considered too large of an error size (Criscrimagna-Hemminger et al. 2009) and cause an accident.

Due to these possible dangers, lawmakers have banned driving and texting on a cellular phone. According to the Governor Highway Safety Association (2013), the first state to pass a texting ban was Washington in 2007 and now there are currently 39 states that prohibit texting while driving. Furthermore, texting while walking can also be dangerous for the same reasons. Recently, texting while walking has been banned in Fort Lee, New Jersey (Ngak, 2012).

Conclusion:

People perform multiple tasks involving motor and cognitive functions everyday. The cerebellum plays a significant role in regards to the learning of movements, and is critical in switching learned motor tasks into a more automatic stage through repetition or practice. An essential characteristic of automaticity is the capability to perform a task with minimal or no interference from a second task. It is hypothesized that while performing two tasks automatically the cerebellum's involvement with the cognitive functions is connected with other regions of the brain. Future investigators would have to prove this speculation by researching the functional interaction between the cerebellum and only cognitive regions of the brain during automation.

Reference:

- Albert, N. B., Robertson E. M., & Miall, C., R. (2009). Report: the resting human brain and motor learning. *Current Biology*, 191023-1027. doi:10.1016/j.cub.2009.04.028
- Aramaki, Y., Osu, R., & Sadato, N. (2010). Resource-demanding versus cost-effective bimanual interaction in the brain. *Experimental Brain Research*, 203(2), 407-418. doi:10.1007/s00221-010-2244-0
- Balsters, J., & Ramnani, N. (2011). Cerebellar plasticity and the automation of first-order rules. *The Journal Of Neuroscience: The Official Journal Of The Society For Neuroscience*, 31(6), 2305-2312. doi:10.1523/JNEUROSCI.4358-10.2011
- Block, H. J., & Bastian, A. J. (2012) Cerebellar involvement in motor but not sensory adaptation. *Neuropsychologia*, 501766-1775. doi:10.1016/j.neuropsychologia. 2012.03.034
- Chenda Ngak (2012, May 14). Texting while walking banned in N.J. town. *CBS News*. Retrieved from http://www.cbsnews.com/8301-501465_162-57433581-501465/texting-while-walking-banned-in-n.j-town/
- Criscimagna-Hemminger, S. E., Bastian, A. J., & Shadmehr, R. (2010). Size of error affects cerebellar contributions to motor learning. *Journal Of Neurophysiology*, 103(4), 2275-2284. doi:10.1152/jn.00822.2009
- De Guio, F., Jacobson, S., Molteno, C., Jacobson, J., & Meintjes, E. (2012). Functional magnetic resonance imaging study comparing rhythmic finger tapping in children and adults. *Pediatric Neurology*, 46(2), 94-100. doi:10.1016/j.pediatrneurol. 2011.11.019
- Dean, P., & Porrill, J. (2008). Adaptive-filter models of the cerebellum: computational analysis. *Cerebellum*, 7(4), 567-571. doi:10.1007/s12311-008-0067-3
- Governor Highway Safety Association (2013). Distracted driving laws. Retrieved from http://www.ghsa.org/html/stateinfo/laws/cellphone_laws.html.
- Lang, C., & Bastian, A. (2002). Cerebellar-damage impairs automaticity of a recently practiced movement. *Journal Of Neurophysiology*, 87(3), 1336-1347.

- Schlerf, J. E., Xu, J., Klemfuss, N. M., Griffiths, T. L., & Ivry, R. B. (2013). Individuals with cerebellar degeneration show similar adaptation deficits with large and small visuomotor errors. *Journal Of Neurophysiology*, *109*(4), 1164-1173.
- Sigman, M., & Dehaene, S. (2008). Brain mechanisms of serial and parallel processing during dual-task performance. *The Journal Of Neuroscience: The Official Journal Of The Society For Neuroscience*, *28*(30), 7585-7598.
- Wu, T., & Hallett, M. (2005). The influence of normal human ageing on automatic movements. *The Journal Of Physiology*, *562*(Pt 2), 605-615.
- Wu, T., Liu, J., Hallett, M., Zheng, Z., & Chan, P. (2013). Cerebellum and integration of neural networks in dual-task processing. *Neuroimage*, 65466-475. doi:10.1016/j.neuroimage.2012.10.004