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The Effects of Educational Kinesiology Tasks on Stuttering Frequency of a Pre-School Child Who Stutters

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Abstract: *Purpose:* The purpose of this investigation was to examine the combined effects of educational kinesiology tasks and stuttering treatment on the fluency of a pre-school child who stutters.

Method: This paper details a case study. After the initial diagnosis of a 3-year; 5-month old male with a very severe fluency disorder as indicated by the SSI-4, four months of a modified version of the Lidcombe program for stuttering was completed. After 4 ½ months of receiving this treatment, the participant began receiving occupational therapy services in addition to speech services for two additional months. The occupational services incorporated educational kinesiology tasks. Measures of fluency were obtained throughout the intervention stages.

Results: Fluency measures indicated no significant decrease in stuttered syllable proportions during the initial four-month treatment period. However, significant decreases in stuttered syllable proportions during the combined treatments were documented. The participant's fluency levels were determined to be within normal limits after two months of the combined treatments and he was discharged from treatment.

Conclusion: Although natural recovery is common during the participant's age group, the results of this study indicated that the incorporation of movement-type exercises into fluency treatment might lead to greater gains in fluency. It is possible that these movement tasks recruit and stabilize neural function in regions of the brain such as the cerebellum which has been shown to exhibit signs of dysfunction in people who stutter. Future research should be conducted with larger sample sizes in order to investigate the generalizability of these findings.

Keywords: Cerebellum, kinesiology, lidcombe, preschool, stuttering.

INTRODUCTION

Stuttering is a multifaceted disorder, characterized by oral disfluencies that impede the forward flow of speech. The etiology of stuttering is multi-factorial [1, 2]; as evidence supports differences in personality [3], temperament [4], and neurological functions [5] between people who stutter (PWS) and fluent speakers. Neurological differences that have been documented include hyperactivity of the right hemisphere motor and premotor cortex [6, 7], hyperactivity in the left anterior cingulate cortex during silent reading [8], hyperactivity in the right hemisphere homolog of Broca's area (BA 44) [8], hypoactivity in Broca's and Wernicke's area [9, 10] thalamic dysfunction [11], and cerebellar dysfunction [6, 7, 12, 13, 14]. However, there are many conflicting reports regarding these documented differences. These descrepancies are potentially due to the artifact associated with movement in neuroimaging studies that have relied upon overt stuttering to be present during data collection [15]. More recent research has addressed this issue by utilizing motor imagery instead of overt stuttering during data collection [16]. The motor imagery task, which involves the participants to be scanned while imagining speaking with no disfluencies and also while imagining speaking with disfluencies has been shown to be a reliable measure of the neural activation patterns of those who stutter [16]. Although this methodology is capable of limiting the effects of motoric interference, it has yielded different results than many of the previous research protocols. However, a common finding between these types of studies is the similar pattern of activation in the cerebellum [6, 7, 12, 13, 14, 16].

A second explanation for the variability that has been revealed among these studies is a result of the white matter structural anomalies among PWS which can potentially contribute to physiological abnormalities as well [17, 18]. In addition, it has been suggested that these conflicting results could be due to the group design of the less recent imaging studies. Wymbs *et al.* [19] claim that group imaging studies may mask substantial and potentially important individual differences in the brain activation patterns of those who stutter. In order to address this concern, the authors conducted a study which utilized an individual-participant approach using event-related functional magnetic resonance imaging during the production of audible fluent words, audible stuttered words, imagined fluent words, and imagined stuttered words. The authors found little

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consistency when comparing each individual's profiles to the rest of the group. However, they did find that overt stuttering, once again, elicited abnormal cerebellar activation patterns [19].

The cerebellum is thought to play a vital role in motor control, contributing to timing and sensory acquisition [20]. It has also long been hypothesized to be involved in the control of both the laryngeal and respiratory mechanisms during speech [13, 21]. Furthermore, it has been demonstrated that the cerebellum's contribution to motor speech production consists of being a regulator of the temporal real-time sequencing and the adaptation of overlearned speech movement patterns into linguistically larger units such as words and connected speech during routinized speech movements [20]. Individuals with cerebellar damage can exhibit disturbances in accuracy and the coordination of speech production. Specifically, the speech of individuals with cerebellar damage is often categorized as an ataxic variation of dysarthria characterized by slurred, irregular, and laborious speech [22]. Functional neuroimaging studies have demonstrated the importance of the cerebellum in the pre-articulatory stage of silent speech [23] and during internal speech [24] as well, indicating a critical role in the articulatory sequencing of speech movements. The overall findings of the cerebellum's role in speech production indicate that the cerebellum plays a vital role in the development and maintenance of automatic fluent speech. Automatisation of the speech mechanism leads to effortless, forward moving speech, which is the polar opposite of how stuttered speech can be described. Stuttered speech may consist of the production of whole and part word repetitions, prolongations of speech sounds, silent postural fixations, and frequent interjections. These disfluencies disrupt the forward flow of speech.

Stuttering has often been characterized as a dyscoordination disorder with both sensorimotor and cognitive linguistic processes being affected [8, 13]. De Nil *et al.* conducted a treatment study using positron emission tomography (PET) which investigated the role of the cerebellum in these processes [13]. The authors utilized thirteen stuttering and ten nonstuttering male adults between the ages of 20 and 45 years as participants who had not received stuttering treatment in the previous 5 years. All participants who stuttered were scanned before receiving treatment, immediately after 3 weeks of intensive stuttering treatment, and one year after treatment. Immediately following the treatment phase, each PWS had significantly reduced their level of stuttering as measured by stuttered syllable proportions. In both the pre-and immediate post-treatment scans, the PWS exhibited increased levels of cerebellar activity which the authors claimed represents the presence of increased sensory or motoric monitoring of the ongoing movements associated with lower levels of automaticity (p. 79). However, the PWS did exhibit significantly reduced cerebellar activation at the one year post-treatment follow up scan. The authors concluded that at the immediate post-treatment scans, the participants had not yet automatized their new more fluent manner of speaking meaning that high levels of attention and monitoring were still necessary for fluent speech to be produced. However, the authors claimed that at the 1 year post-treatment follow up, the participants had a chance to "practice" their newer more fluent speech patterns and no longer required as much attention and monitoring, thus becoming more automatic. It should be noted that there is no evidence which indicates that the participants had been "practicing" their speech habits. However, these findings do suggest that the cerebellum does indeed play a significant role in the automatisation of speech movements. Perhaps more importantly, these results suggest that the functional role of the cerebellum in the production of fluent speech is amenable to treatment. These findings have been supported by the work of Neumann *et al.* who observed hyperactivity of the cerebellum immediately after treatment followed by reduced activations in the cerebellum as a function of time. Neumann *et al*. also found that a general lateralization of activity occurred toward the left hemisphere after the remediation of stuttering [7].

Finally, it is important to note that fluent speech has not been demonstrated to be both necessary and sufficient to normalize the neuronal activation levels of the cerebellum. Fox *et al.* observed high levels of bilateral cerebellar activation in PWS during both stuttered speech and fluent choral speech [6]. Choral speech, or the perception that one is speaking in unison with another individual or group of individuals, has long been known to enhance the fluency of individuals who stutter [25]. The findings of Fox *et al.* and the findings of Neumann *et al.* combine to support the conclusion that temporarily enhanced fluency does not correspond with cerebellar activity normalization, whereas more stabilized fluent speech patterns do correspond with cerebellar activity normalization. This finding is clinically important. One particular weakness of many stuttering treatments is the lack of documented reports of long-term effectiveness [26]. In fact, it has been reported that the relapse rate of stuttering is at least as high as 70% [27-29]. Superficial and temporary gains in fluency do not lead to the neurological changes that accompany more stable fluent speech patterns. Therefore, stuttering treatments would be well served to utilize techniques that have been shown to change neurological activity. If they do not, it is likely that they will yield the temporary and superficial positive outcomes that plague so many stuttering treatment protocols as indicated by the previously mentioned extremely high relapse rates.

Given that PWS exhibit both neuroanatomical and neurophysiological differences compared to fluent speakers, it is intuitive that the remediation of stuttering should focus upon tasks and behaviors that have been shown to affect the anatomy and physiology of these neurological regions. However, the traditional method of treatment for young children who stutter (CWS), e.g., 5 years of age or younger, often consists of indirect treatment techniques, whereby the parents are taught methods to facilitate fluency in the child's own environment [30]. These methods may consist of increasing pause time during conversation, a reduction in parental speaking rate, and/or attempting to reduce the cognitive load required of the CWS. Direct therapy, e.g., direct work on dysfluent speech, may not be used with CWS in an effort to prevent increased awareness of stuttering and the potential subsequent development of compensatory strategies, or secondary behaviors which may increase the severity of the disorder. These secondary behaviors typically occur in the head and neck area of the PWS and contribute to the impression of tense, struggled speech. Common secondary behaviors include head jerks, lip tremors, nostril flaring, eye-blinks and facial contortions [30].

In contrast to this premise, the Lidcombe Program of Early Stuttering Intervention, which includes direct therapy as well as indirect methods, has been shown to be an effective remedial program for CWS [31-34]. The Lidcombe program is an evidence-based practice which is designed to treat stuttering in children who are pre-school aged. In this age group, stuttering can be highly variable and one must consider the high rates of spontaneous recovery during the clinical process of stuttering assessment and intervention. Spontaneous recovery rates differ based upon the methodology by which the data is obtained, but a moderate estimate of the proportion of young children who experience spontaneous recovery is approximately 70-80% [35]. The Lidcombe program focuses on the parental provision of verbal contingencies (rewards and punishment) for their child's speech. Initially, the distinction between fluent (smooth) and dysfluent (bumpy) speech is focused on with both the parent and the child. Soon into the program, it is expected that the parent will assume the role of primary therapy provider. Initially, only fluent speech is praised and dysfluent speech is ignored. As fluency improves, negative verbal reinforcement is provided for dysfluent words such as "that word was a little bumpy." After a period of acknowledging disfluencies, the parent begins to request the child to self-correct their dysfluent speech and praise is offered for corrected speech. As is the case with most stuttering treatments, the activities eventually progress to different contexts, incorporating other settings and individuals into treatment activities.

Jones *et al.* conducted a randomized control trial on the efficacy of the Lidcombe program [32]. Study participants consisted of 54 CWS between the ages of 3 and 6 years. The CWS were required to obtain a frequency proportion of stuttered syllables of at least 2%. The CWS were also excluded if they had received speech services in the past twelve months. Twenty-nine participants were randomly selected for the Lidcombe program and 25 were selected to the control group which received no therapy. Speech samples were collected before randomization and at three month intervals for nine months. At the end of nine months, the Lidcombe group demonstrated a significant reduction in stuttering frequency compared to the control group. Furthermore, this group obtained clinically significant reductions in stuttering proportions that were even greater than those predicted by spontaneous recovery (p. 660).

A second line of treatment that has become increasingly popular in both schools and clinics utilizes both exercise and movement based stimulation in an attempt to reorganize cognitive processing. An example of these types of techniques, also known as educational kinesiology tasks, is known as Brain Gym®. Brain Gym® consists of a series of movements that are designed to facilitate whole brain learning by re-patterning the brain [36]. Although the evidence for this "re-patterning" is lacking [37] there is evidence that the engagement of the cerebellum through movement tasks can have a positive effect on academic performance, specifically reading. There are many common neurological links between stuttering and reading disorders such as dyslexia. Neuroimaging studies have demonstrated increased activation in the right hemisphere homolog of Broca's area in both PWS [8] and in people with dyslexia [38-43]. Neuroimaging studies have also demonstrated decreased activation in Wernicke's area in PWS [9, 10] and in people with dyslexia [40], as well as disruptions in cerebellar activity in both PWS [6, 7, 12-14] and people with dyslexia [44-54].

Reading disorders such as dyslexia are often characterized by a lack of automaticity in decoding or word recognition. Automaticity in decoding is the hallmark feature of fluent reading. As previously mentioned, the cerebellum is specialized for automatic preprogrammed timing of muscle contractions for optimizing motor performance. It is known to be involved in the coordination of smooth movements, maintenance of balance and posture, visually guided movements, and motor learning [21, 53, 55, 56]. As previously mentioned, the cerebellum is vital in the automatisation of over-learned tasks such as driving a car, typing, or reading. The cerebellar deficit theory [51] hypothesizes that it is the difficulties in the automatisation of skills that leads to the myriad of deficits often observed in individuals with dyslexia [44, 45, 54], such as learning the grapheme-phoneme connection [57]. Therefore, the research suggests that both stuttering and reading share a common link in cerebellar dysfunction.

Based on this hypothesis, Dore and Rutherford created a program designed to assess and improve cerebellar function [58]. This type of intervention was originally completed at centers that were called dyslexia, dyspraxia, and attention-deficit treatment centers (DDAT) but they have since been renamed Dore Achievement Centres (DAC) [59]. The DAC operate on three main premises. The first premise is that the cerebellar deficit theory is true and dyslexic individuals do indeed exhibit cerebellar dysfunction. The second premise states that the cerebellum has elastic properties and it can be retrained, at least in childhood [58]. The third premise is that training on one sort of cerebellar task should generalize to other unrelated tasks which require activation of the cerebellum, such as reading. Therefore, DAC type interventions do not specifically target reading exercises, but instead target exercises they believe will retrain functions of the cerebellum. Reynolds *et al*. stated that the treatment tasks consist of using a balance board; throwing and catching bean bags (including tossing the bean bags from hand to hand with careful tracking by eye); practicing dual tasking; and other stretching and coordination tasks [59]. The overall goal of this treatment as stated by Dore and Rutherford is to stimulate simultaneously the central nervous system mechanisms found to be immature in learning disabled children on electro-neurophysiological assessment exercises [58]. This program has been found to yield beneficial results in a reading disordered population [59] as well as in a follow up study completed 18 months later [60].

Reynolds and Nicolson investigated the effects of DAC treatment in 35 school children (average age: 9.4 years) who were considered at risk for dyslexia based upon a screening test [60]. The participants were divided into two groups with one group receiving DAC treatments while the other group received no additional treatment other than what was already being provided at school. The DAC treatment occurred after school hours in the child's home daily. After six months of this treatment, a dyslexia screening test and a battery of cerebellar tasks were re-administered to the participants. The authors found that the participants improved on both the cerebellar and reading tasks after the treatment phase. Specifically the cerebellar improvements were seen in posturography, eye tracking, and bead threading. In regards to reading, it was found that the participants showed improvements in semantic fluency, nonsense word reading, phonological skill, and working memory. There were no significant improvements in spelling or writing. The follow up testing revealed similar results with the participants continuing to exhibit improvements in motor skills, phonology, speech/language fluency, and working memory [60]. It should be noted that there is no general consensus regarding the efficacy of such programs and no independent efficacy data has been published at the time of this review.

Although reading disorders and fluency disorders have been revealed to share common neural underpinnings, no study exists which has examined whether similar treatment techniques would benefit individuals with either disorder. Research has shown that educational kinesiology exercises can have a positive effect on the reading and learning abilities of children with language learning delays. However, no study has been conducted to investigate the effects of an educational kinesiology approach to the treatment of stuttering. If the preponderance of data that has shown the cerebellum does play a significant role in the automatisation of tasks is true and if the preponderance of data which shows that PWS exhibit defective activation in the cerebellum which can be normalized with remediation is true, then tasks that tax the cerebellum could theoretically improve the fluency capabilities of CWS. The purpose of the current study was to investigate if the introduction of educational kinesiology tasks into the treatment of childhood stuttering would have an effect on the fluency of a young child.

METHODS

The participant for this case study was a 3-year, 5-month old male who had been referred to an outpatient speech and hearing clinic for a fluency evaluation. The initial evaluation and all subsequent speech treatment was administered by a licensed and certified speech-language pathologist. At the initial evaluation, both formal and informal testing was completed. The *Stuttering Severity Instrument -4* (SSI-4) [61] was administered in order to obtain a standardized measure of stuttering severity. Results revealed a frequency score of 16, a duration score of 10, and a physical concomitant score of 9. These three scores combined to yield a percentile rank of 96-99 and a severity rating of very severe.

In addition, the *Goldman-Fristoe Test of Articulation -2* (GFTA-2) [62] was administered in order to obtain information about the participant's articulation abilities by sampling both spontaneous and imitative sound productions. The participant obtained a standard score of 112 with a percentile rank of 68 and an age equivalent of 4 years; 3 months indicating that the participant's articulation abilities were within normal limits.

Finally, the *Preschool Language Scales -5* (PLS-5) [63] were administered in order to provide a comprehensive developmental language assessment. The participant obtained a receptive language standard score of 108 with a percentile rank of 70 and an age equivalent of 3 years; 7 months which indicates that his receptive language abilities were within normal limits. The participant also obtained an expressive standard score of 112 with a percentile rank of 79 and an age equivalent of 3 years; 10 months which indicates that his expressive language abilities were within normal limits.

Informal testing consisted of obtaining a 100 word speech sample. The participant exhibited stuttering-like disfluencies (SLD) on 16% of the spoken syllables which classified the participant as a CWS according to Ambrose and Yairi [64]. Furthermore, the speech sample revealed the participant's SLDs consisted of whole and part-word repetitions and silent blocks. All whole word repetitions occurred during the production of monosyllabic words. No multi-syllabic words were repeated. Other disfluencies (OD) consisted of phrase repetitions and revisions along with interjections (see Table **1** for a breakdown of disfluency type). Ambrose and Yairi recommend examining the ratio of SLDs to ODs when potentially diagnosing preschool children with fluency disorders. The participant's ratio between ALDs and ODs was 63%. Therefore, 37% of the disfluencies were characterized as ODs. These results are consistent with the normative data reported by Ambrose and Yairi. These authors found that CWS produced 66% SLDs compared to 34% ODs. If the current participant would have produced one less OD, then he would have exhibited an identical pattern to the norms provided by Ambrose and Yairi. Further analysis of the spontaneous speech sample revealed that repetitions were generally one repetition in length, although two utterances contained 3-4 unit repetitions. Disfluencies were perceived as fast and irregular. The participant demonstrated awareness of his disfluencies and produced secondary behaviors as well. Secondary behaviors included, but were not limited to, interjections, phrase revisions, and body movements.

Informal observation revealed that the participant demonstrated an advanced vocabulary and frequently communicated at open-ended, conversational levels. Pragmatic deficits were present including reduced conversational turn-taking abilities, difficulties with topic maintenance, inattention to tasks, and a decreased ability to engage with same-aged peers. Behavioral characteristics included heightened sensitivity, reduced emotional regulation, and excessive verbal expression.

Formal speech therapy services were recommended at a frequency of two times per week, for 30 minute sessions. A modified version of the Lidcombe program was utilized [31]. The program was followed with the basis of the program serving to provide structure and guidelines for treatment. During the initial phase of therapy, structured situations were used to praise fluency on a 5:1 ratio, acknowledge stutters, and/or request repairs. Indirect strategies consisted of using a reduced rate of speech, increased pause time, and a reduction of questioning [1].

Occupational therapy (OT) services were initiated 4 ½ months later, secondary to deficits noted as reduced stationary control, reduced object manipulation, and not crossing midline. Stationary control refers to a child's ability to control the body while not in motion and can be worked on while sitting or standing. Object manipulation refers to a child's ability to throw, kick, and catch. Crossing midline refers to a child's ability to cross the midline of the body. An example of a task that requires crossing midline is drawing from the left side of the page to the right side without transferring the writing utensil to the other hand when crossing the center of the page. Potential causes of these deficits include reduced interhemispheric communication and coordination.

OT services were provided once per week, for 50-minute sessions by a licensed and certified occupational therapist. The treatment protocol included Brain Gym® exercises, consisting of drawing figure eights and performing cross crawls, which were designed to increase interhemispheric communication. Drawing a figure eight is the act of drawing an eight in a continuous manner without lifting the writing utensil. Cross crawls involve the left arm crossing midline to touch the right leg and the right arm crossing midline to touch the left leg. These exercises were regularly incorporated into the participant's occupational therapy.

RESULTS

Treatment results obtained from the initial 4 months revealed a minimal decrease in stuttering-like disfluencies. At three months post-evaluation, the participant exhibited SLDs on 15% of spoken syllables. At three and a half months post-evaluation, the participant exhibited SLDs on 21% of spoken syllables. At four months post-evaluation, the participant exhibited SLDs on 12% of spoken syllables. Three and four unit repetitions were present at the initial evaluation. Following four months of treatment, only one and two unit repetitions were present.

As previously mentioned, OT services were initiated 4 ½ months after the initiation of speech treatment. The participant's fluency was once again assessed at 5 ½ months post-evaluation which was one month following the implementation of occupational therapy services and Brain Gym® exercises. The participant exhibited disfluencies on only 6% of the syllables he produced. At 6 ½ months post-evaluation, the child exhibited disfluencies on only 5% of the syllables he produced. The participant was discharged from speech treatment at this point. At the time of discharge, 3 months after the initiation of OT services, the participant's disfluencies were slow and regular, consisting of only one repetition per unit. According to the normative data provided by Ambrose and Yairi, children who do not stutter produce disfluencies on approximately 5.65% of spoken syllables [64].

The previously mentioned stuttering proportions were subjected to statistical analysis. Stuttering proportions were transformed to arcsine units prior to being subjected to inferential statistical analysis [65]. A repeated measures ANOVA was administered to investigate mean differences in transformed stuttering proportions as a function of treatment (Lidcombe and Lidcombe/Brain Gym®). A significant main effect was found for treatment, $F(1, 4) = 13.559$; $p = 0.032$. On average, the participant exhibited a higher proportion of stuttered syllables while receiving only speech treatment (16 stuttered syllables/100 syllables) than when receiving the combined speech and movement treatments (5.5 stuttered syllables/100 syllables).

DISCUSSION

The purpose of the current study was to examine the combined effects of educational kinesiology and standard stuttering treatment on the fluency levels of a 3-year, 5-month old male. Initial evaluation results indicated that the participant exhibited a severe fluency disorder consistent with stuttering. The results indicated that standard treatment in isolation was minimally successful in reducing the severity and frequency of disfluencies. However, when educational kinesiology tasks were introduced by an occupational therapist, the child's stuttering severity level decreased to the point where the child was no longer considered a CWS. It should be noted that spontaneous recovery is common in this age [64]. Therefore, natural processes of development cannot be ruled out as potential contributors to the combined treatment's success. However, the participant improved rapidly once the educational kinesiology program was implemented. "Spontaneous" recovery is not synonymous with "instantaneous" recovery. Instead, spontaneous recovery is believed to occur over time [30] although the literature provides few descriptions of how stuttering frequency specifically changes during the period which spontaneous recovery occurs. Therefore, the current authors cannot claim unequivocally that these findings of improvement do not coincide with natural recovery from the disorder. However, the timing of the onset of the improvement co-occurred with the onset of the Brain Gym® activities and did so following a 4 ½ month period in which a standard fluency treatment was provided with little success. The coinciding timing along with the sheer magnitude of the decrease in stuttering behaviors provides support regarding the beneficial effects of the cerebellar tasks.

Furthermore, four months of the modified version of the Lidcombe program did not prove to be sufficient to reduce the stuttering behaviors of the participant to a level considered to be within normal limits. This could be directly related to the modification of the program since the speech-language pathologist and not the primary caregiver assumed the primary role of treatment provider. Parental participation is considered key to the implementation of the Lidcombe program [31], and this study did not implement that aspect of the Lidcombe program. It is also possible that the child's hyperactive behavior, poor attention, and deficient pragmatic skills contributed to this intervention's lack of success. However, the scope of this study was not to determine why this protocol did not prove to be successful; rather, this study focused on the results of the combined interventions. When

Table 1. Type and frequency of disfluencies noted in a 100 word language sample during the initial evaluation.

Type	Pause	Interjection	Phrase Repetition	Part Word Repetition	Phrase Revision	Whole Word Repetition
Number of Occurrences	5	7	4	8	2	9

the modified Lidcombe program and the educational kinesiology programs were being implemented simultaneously, tremendous gains in fluency were observed.

It remains unknown why the combination between the standard fluency enhancing treatment and the educational kinesiology treatments yielded benefits in verbal fluency. The current authors hypothesize that this finding was the result of more efficient neural activation being caused by the combination of the two treatments. The Lidcombe program is highly based upon operant conditioning and requires the provider to praise fluent speech regularly. However, the participant exhibited so little fluent speech that few instances qualified for a reward in the form of verbal praise. The child's hyperactivity and robust expressive language output often resulted in SLDs being produced before the clinician could offer praise. The Lidcombe program, nor any other protocol that the current authors are aware of, does not recommend praising or rewarding disfluencies. It also does not recommend overly using negative reinforcement (punishment). Instead, the program recommends negative reinforcement only be delivered after a pre-established number of praised fluent utterances. Following this protocol was difficult for this participant, which likely contributed to the limited success of the program. However, when the Brain Gym® exercises were initiated, the participant's fluency vastly improved.

It is hypothesized that the Brain Gym® exercises led to a better utilization of the participant's neurological resources. Numerous neuroimaging studies have demonstrated dysfunction in the cerebellar regions of PWS [6, 7, 12, 13, 14, 16]. As previously mentioned, the cerebellum plays a vital role in the development and maintenance of automatic fluent speech. Automatisation of the speech mechanism leads to effortless, forward moving speech. It is hypothesized that PWS do not obtain this level of automatisation as stuttering has often been characterized as a dyscoordination disorder with both sensorimotor and cognitive linguistic processes being affected [8, 13]. It is possible that stimulating the cerebellum *via* the educational kinesiology tasks resulted in an improved ability for the participant to coordinate the respiratory, phonatory, and articulatory systems required for speech. These results are similar to those that have been found in studies using cerebellar tasks to improve reading function in dyslexic individuals [59, 60].

One final possible explanation for the observed increase in fluency focuses on the cerebellum's role in working memory. Working memory is a term used to describe the ability to simultaneously maintain and process goal relevant information. More specifically, it is the ability to mentally store information in an active and readily accessible state, while concurrently and selectively processing new information, making possible skills such as planning, reasoning, problem solving, reading, and abstraction [66, 67]. It also has been defined as a processing resource of limited capacity that is involved in the preservation of information while the subsequent processing of congruent or non-congruent information occurs [68, 69]. Individuals who are performing tasks that rely on working memory must be capable of remembering some task elements while ignoring or inhibiting other elements that may not be task relevant [69].

The cerebellum has been shown to be active during verbal working memory tasks [70, 71] and damage to the cerebellum has been shown to result in working memory deficits [72]. Formalized stuttering treatment consists of many tasks that require verbal working memory abilities. First, the client must be able to listen and follow directions. The client must be capable of selecting the more salient elements of the language used by the therapist to give the directions and then be able to remember those elements so that they can adapt and react to the instructions. Secondly, if the client is capable of comprehending and remembering the directions, the client must then be capable of planning the motoric response. In this scenario the motoric response would be the articulation of speech sounds. This planning relies on the working memory system. Furthermore, oftentimes the tasks in stuttering treatment are imitative in nature, and therefore require additional working memory resources as the client processes both the clinician's verbal cuing and their own motoric plan. It is possible that the potential enhancement of cerebellar activity due to the movement tasks improved function of working memory in the participant, allowing him to better understand and follow directions and plan more appropriate speech system maneuvers. Hence, a working memory system that is not operating efficiently could create a serious barrier to therapeutic progress. In contrast, a more efficient working memory system could remove this barrier and allow the treatment to succeed.

Although the results indicate that the combined stuttering and movement treatments yielded significant reductions in SLDs, the current study was conducted with inherent limitations. First of all, the case study design of this study could limit the generalizability of these results to other children who stutter. As previously stated, this child exhibited attentional and pragmatic deficits and it is unclear as to whether the combined treatments acted upon those behavioral characteristics which could allow for the improvement in fluency as a by-product. A second limitation of the current study is a lack of obtaining a reliable measure of working memory. It would be of interest to have investigated if working memory abilities had improved throughout the course of treatment. Finally, it cannot be determined without the use of neuroimaging the extent of activation/deactivation that occurred within the cerebellum and/or other brain areas.

These results indicate that the involvement of movement based activities can be a viable aspect in the delivery method of fluency treatment. Future studies should include tasks which more explicitly focus on engaging the cerebellum. In addition, a future group study should be devised in order to gauge the generalizability of these results to CWS as a group. Finally, measures of working memory should be obtained in conjunction with a group study to examine the effects of educational kinesiology on the function of working memory.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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