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Title: Impact of a Discourse-Based Intervention on Stuttering Severity: Theta and Beta Brainwaves in Focus

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ABSTRACT

Objective: Stuttering has traditionally been treated through psychological or psychomotor therapeutic approaches; however, the condition has less been examined from a neuro-linguistic perspective as a potential explanatory solution. The purpose of the present study was to investigate the impact of Discourse-Based Lessons (Dis-BL) on stuttering severity and neural oscillatory activity, with a particular focus on beta and theta brainwaves.

Method: This study included 30 patients with stuttering problem, who were assigned to an experimental group and a control group. Stuttering severity was assessed twice in all participants using the Stuttering Severity Instrument--Fourth Edition (SSI-4). Also, Quantitative electroencephalography (QEEG) data were collected using a 19-channel system; due to poor signal quality, three participants were excluded from the QEEG analysis, resulting in a final sample of 14 participants in the experimental group and 13 in the control group for neural analyses. The experimental group received the Dis-BL intervention, while the control group received other usual treatments. Group differences were examined using parametric and non-parametric statistical procedures as appropriate.

Results: The findings indicated that the experimental group demonstrated a significant reduction in stuttering severity compared with the control group, with the Dis-BL group exhibiting fewer speech difficulties ($t(22.17) = 4.08$, $p < .05$). Effect size indices (Cohen's $d = 1.50$, Glass's $\Delta = 1.21$, and Hedges' $g = 1.50$) indicated a strong and practically meaningful treatment effect. Neurophysiological results also revealed significantly reduced beta-band activity in frontal, temporal, and sensorimotor regions in the experimental group, reflecting improved speech planning efficiency. Theta-band activity showed a consistent but non-significant reduction across cortical regions following the intervention which may be partly attributed to the reduced statistical power due to the modest sample size for QEEG analyses**.**

Conclusion: These findings suggest that discourse-based intervention can effectively reduce stuttering severity by enhancing anticipatory speech planning rather than directly targeting motor execution. The results underscored the importance of linguistic approaches in stuttering therapy and suggest that beta-band modulation may serve as a promising candidate neural correlate of therapeutic change, although further research with larger samples is needed to confirm this possibility.

Keywords: Beta Oscillation, Discourse, Planning, QEEG, Speech Fluency, Stuttering Severity, Theta Oscillation.

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Introduction,

Developmental stuttering is a neurological disorder characterized by persistent disruptions in fluency and is increasingly conceptualized as a psychomotor impairment involving atypical coordination between linguistic planning and speech motor execution (Max et al., 2004; Brown et al., 2005; Alm, 2004; Bloodstein & Ratner, 2008). Converging evidence from neuroimaging and electrophysiological data indicates that stuttering cannot be explained by speech disorder alone, but rather reflects atypical functional and structural organization within brain neural system (Chang et al., 2019a; Chang et al., 2019b; Chang et al., 2019c; Ingham et al., 2012; Guenther, 2016; Howell, 2011). Despite substantial advances in characterizing these neural abnormalities, how the role of linguistics may be systematically harnessed for intervention remains unclear.

Contemporary models of speech production emphasize the central role of language planning in fluent speech. According to Levelt's psycholinguistic framework (1989, 1999; Kormos, 2006), speech production is explained through several successive stages of conceptualization, formulation, and articulation. Disruptions at the formulation and articulation interface are believed to be detrimental to fluency. The reason might be due to the fact that inefficiencies at this stage may increase processing demands and destabilize subsequent motor execution (Levelt, 1989, 1999). Elsewhere, Segalowitz (2010, 2016) equals speech fluency as processing efficiency and distinguishes between macro-planning, which involves non-linguistic conceptual preparation, and micro-planning, which is language-specific. Deficits in micro-planning are hypothesized to impose demands on executive and motor control systems, thereby increasing the risk of fluency breakdown (Segalowitz, 2010, 2016).

On the other hand, neurophysiological studies highlight the role of specific neural oscillatory mechanisms that transform speech planning into motor execution. Beta-band oscillations (13–30 Hz) are critically involved in sensorimotor integration, maintenance of motor set, and predictive control of speech production (Engel & Fries, 2010; Arnal, 2012; Etchell et al., 2018). In individuals who stutter, atypical beta activity during speech, for instance, has been associated with increased reliance on "feedback-driven control" and decreased "speech automaticity" which is indicator of inefficient anticipatory motor control (Max et al., 2004; Chang et al., 2019a; Neef et al., 2015). In contrast, theta-band oscillations (4–8 Hz) are primarily associated with working memory, attention regulation, and early learning phases (Klimesch, 1999; Sauseng et al., 2010). Although theta activity contributes to linguistic processing, it is less directly involved in the rapid sensorimotor transformations required for fluent speech execution.

Literature is replete with a range of therapeutic approaches aiming at curing stuttering problems more effectively (Hamniuk & Tarkowski, 2016). Research reveals that early intervention, particularly in young children, may prevent developmental stuttering from becoming a chronic disorder. According to clinical guidelines, evaluations are recommended for the children whose stuttering problems persist for three to six months. This is the case, specially, when the symptoms occur alongside with struggle behavior or a family history record of stuttering or related communication disorders (Smith & Weber, 2017; Yaruss & Reardon, 2017).

Current treatment approaches are categorized as direct, indirect, or combined interventions (Hamniuk & Tarkowski, 2016). Furthermore, advances in genetics and neuroimaging have demonstrated that stuttering is associated with widespread structural and functional differences within speech-related neural networks (Yairi & Ambrose, 2013; Frigerio-Domingues & Drayna, 2017; Etchell et al., 2018; Chang et al., 2019b). Research on direct speech-intervention techniques and combined behavioral programs bounds alongside pharmacological studies which highlighted

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the role of dopaminergic systems and atypical neural activity in the persistent stuttering (Bothe et al., 2006; Maguire et al., 2019, 2020). Despite these substantial advances in treating stuttering, developing effective and durable clinical interventions remains insufficiently achieved.

The literature on stuttering clinical intervention reveals that, although numerous therapeutic strategies for stuttering have been developed, little attention has been given to the disorder from the perspective of linguistics, particularly with respect to the interaction between multiple linguistic layers and neurophysiological measures. This gap suggests that shifting the focus from speech output alone toward the speech underlying processes may provide new insights into more efficient interventions. Process-oriented approaches, supported by applied linguistic frameworks, have long been emphasized in language learning context (Van Lier, 2000) and may hold similar promise in clinical speech-language pathology too. To fill the present gap, the present study aims to investigate whether texts prepared following language discoursal features can change the brain Beta-band and Theta-band oscillation quantity. Specifically, this study addresses the following research questions: (1) Do Dis-BLs significantly reduce stuttering severity? (2) Do discourse based lessons (Dis-BL) significantly change Beta-band brain wave quantity in individuals who stutter? (3) Do Dis-BLs significantly change Theta-band brain wave quantity in individuals who stutter?

Materials and Methods,

Design

The present study employed a quasi-experimental pretest-posttest design with a control group.

Participants

The present study initially enrolled 30 patients with a primary diagnosis of developmental stuttering, with no reported neurological or psychiatric comorbidities. Participants were recruited through convenience sampling from Roshd Clinics and were then randomly assigned to either the experimental or control group using a simple randomization procedure (coin toss), conducted by an independent researcher who was not involved in the intervention or assessment phases. Each group contained 15 patients. The sample size was determined based on an a priori power analysis using G*Power 3.1.9.7 (Faul et al., 2007). For an independent-samples t-test with a large effect size (Cohen's $d = 0.80$), $\alpha = 0.05$, and power $(1-\beta) = 0.80$, the required sample size was calculated as 26 participants per group. However, due to practical constraints in recruiting children with developmental stuttering who met the strict inclusion criteria and were willing to undergo EEG recordings, the final sample was limited to 15 participants per group. This limitation is acknowledged and further addressed in the Discussion section.

Written informed consent was obtained from all participants or their legal guardians after a full explanation of the study procedures. All participants were administered the SSI-4, as well as quantitative EEG (QEEG), both before and after the testing sessions. The inclusion criteria consisted of being right-handed and having a diagnosed developmental stuttering. Exclusion criteria were other neurological disorders, psychological or psychiatric conditions, or the use of any psychotropic medications, as well as any other causes interfering with the quality of the EEG signal. Of these, after data collection, three were excluded from the final QEEG analysis due to invalidity of recorded signals because of poor quality: two from the control group and one from the experimental group. Thus, the final number remained for QEEG analysis included 13 control and 14 experimental participants; the number remained unchanged for SSI-4, though.

The patients in both groups were right-handed, between 6 and 16 years of age, and with reported stuttering onset from 2 to 6 years of age. Positive family histories of stuttering were noted for two

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participants, as described in Tables 1 and 2. None of the participants had any significant medical history or were currently prescribed psychotropic medication. Most participants showed typical learning patterns for their ages and typical educational and social performances overall. However, many of the participants had received speech therapy previously, with limited clinical improvement. Individual varied in psychological features including introversion, sensitivity, anxiety, low frustration tolerance, low self-esteem, perfectionism, impulsivity, and mild attention or academic difficulties, as detailed in Tables 1 and 2.

Table 1

Patients' Characteristics in Control Group

ID	Date of Birth	Gender	Sibling	Onset of Stutterin	Family History	Medical History	Medicati --	Handedn ess	Learning / Attentio n	Behavio ral Characte ristics
1	2017/12/14	M	Younger brother	3 y	-	-	-	Right	Good	-
2	2014/06/22	M	OCH*	~2.5 y	-	-	-	Right	Normal	-
3	2016/07/29	M	OCH	2 y	-	-	-	Right	Mild attention issues	Anxious, sensitive
4	2019/02/10	M	OCH	3 y	Father mild stuttering	-	-	Right	Normal	Impulsive, aggressive, high emotion
5	2014/01/01	M	OCH	2 y	-	-	-	Right	Adequate	Introverted, shy
6	2016/05/01	M	Older brother	3 y	-	-	-	Right	Normal	Low assertiveness, high dependency on mother
7	2015/12/06	M	Older brother	3.5 y	-	-	-	Right	Normal	Playful, impatient, low compliance
8	2011/10/21	M	OCH	3 y	-	Mild motor delay	-	Right	Mild learning difficultie s	High emotion, mild attention deficit
9	2013/05/12	M	OCH	3 y	-	-	-	Right	Normal	High emotion
10	2019/04/08	M	Older sister	2 y	-	-	-	Right	Appropria te	-
11	2019/05/24	M	OCH	2 y	-	-	-	Right	Normal	Previous speech therapy unsuccessful
12	2011/01/09	M	Younger brother	2 y	-	-	-	Right	Normal	Low emotion control, impulsive
13	2015/07/08	M	OCH	3 y	-	-	-	Right	Normal	-
14	2014/08/09	M	Older brother	3.5 y	-	-	-	Right	Low attention	Introverted, anxious
15	2012/12/21	M	Older brother	3 y	-	-	-	Right	Normal	-

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* OCH means only child in family.
** M means Male

Table 2
Patients' Characteristics in Control Group

ID	Date of Birth	Gender	Sibling	Onset of Stuttering	Family History	Medication	Handedness	Learning / Attention	Behavioral Characteristics
1	2007/08/04	M*	Older brother	5 y	-	-	Right	Good	Introverted, sensitive, independent, limited social interactions
2	2010/12/12	M	Older sister	6 y	-	-	Right	Some attention issues	Emotional, school behavior problems
3	2013/07/13	M	OCH*	3 y	-	-	Right	Normal	Previous therapy, relapsed, no issues
4	2008/06/15	M	OCH	3 y (temporary)	-	-	Right	Appropriate	Good social relations, sporty, some excitement
5	2014/03/15	M	OCH	3 y	-	-	Right	Appropriate	Social, reads books most of the time
6	2002/09/30	M	Two younger sisters	6 y	-	-	Right	Struggled with education	Introverted, anxious, previous therapy unsuccessful
7	2013/12/31	M	Older brother	3 y	-	-	Right	Weak	Low confidence, multiple unsuccessful therapies, no close friends
8	2015/11/17	M	OCH	2 y	-	-	Right	Appropriate	Good social and educational status, previous therapy unsuccessful
9	2015/03/20	M	OCH	3 y	-	-	Right	Appropriate	Good social and educational status, sporty, previous therapy unsuccessful
10	2013/06/19	M	OCH	4 y	-	-	Right	Normal	Not competitive, sensitive, good motor skills
11	2007/01/27	M	OCH	5 y	-	-	Right	Mild attention issues	Good social interactions

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ID	Date of Birth	Gender	Sibling	Onset of Stuttering	Family History	Medication	Handedness	Learning / Attention	Behavioral Characteristics
12	2013/12/14	M	OCH	3 y	-	-	Right	Good	Independent, idealistic, sensitive, attention-seeking behavior
13	2011/10/04	M	Two older brothers	4 y	-	-	Right	Normal	Good social interactions, multiple unsuccessful therapies
14	2016/05/29	M	OCH	3 y	-	-	Right	Normal	High emotion, social interactions good, previous therapy unsuccessful
15	2009/12/22	M	Younger sister	4 y	-	-	Right	Appropriate	Good social interactions, many close friends, good family relations, good educational status

*OCH means only child in family.
** M means Male

Measures

In the present study, two tests were employed for two purposes, namely ensuring homogeneity and measuring fluency development each of which will briefly be explained. The first measure was the School-Age version of the Stuttering Severity Instrument–Fourth Edition (SSI-4) which was used in order to ensure the homogeneity of the stuttering severity among patients in both groups. This instrument measures three main factors: frequency of stuttering events, duration of the longest moments of stuttering, and physical concomitants associated with stuttering. Frequency is measured based on the percentage of stuttered syllables, while duration is measured by calculating the average length of the three longest moments of stuttering. Similarly, the physical concomitants are measured across four distinct areas. The total score is obtained by adding up the scores from these three areas and then using the standardized conversion table to classify stuttering severity along an ordinal scale that ranges from “very mild” to “severe.” Also, the tool contains a measure called Naturalness of Speech, included on the scoring form, by which one may assess the degree of similarity of an individual’s speech to a natural speech pattern.

During the assessment process, the participants' speech samples for two tasks - reading a passage and picture description - were recorded for ten minutes. The audio samples were rated independently by three speech-language pathologists specializing in stuttering, all of whom were blind to the participants' group allocation (experimental vs. control) and to the time point (pre-test vs. post-test) of the recordings**.** The average score across the three raters was calculated as the participant's final score. A low score represented a low level of stuttering severity. The results indicated that the two groups were not significantly different in stuttering severity as confirmed by a non-significant Levene’s test and independent samples t-test ($F = 0.49$, p = n.s.; $t(28) = 0.097$, p = n.s.).

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The second instrument used in the present research was electroencephalogram (EEG). All recordings were conducted using a 19-channel EEG system (Model 201; Mitsar EEG Co., St. Petersburg, Russia) with electrodes positioned according to the international 10–20 system at the following sites: FP1, FP2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, O1, and O2. The occipital leads (O1, O2) were excluded from subsequent analyses due to their minimal role in speech-related neural networks (Etchell et al., 2018).

QEEG recordings were performed under resting-state conditions, with participants seated in a comfortable chair in a sound-attenuated, dimly lit room. Participants were instructed to remain relaxed, keep their eyes closed, and avoid movement during the 5-minute recording session. The QEEG signal was sampled at 500 Hz with an online band-pass filter of 0.5–70 Hz and a notch filter at 50 Hz to eliminate line noise. The reference electrode was placed on the linked ears (A1–A2), and the ground electrode was positioned at AFz.

Offline preprocessing was performed using NeuroGuide software (Version 3.3.8; Applied Neuroscience Inc., USA). Data were visually inspected for artefacts; epochs containing eye blinks, muscle activity, or movement artefacts exceeding ±100 μV were automatically rejected. Ocular artefacts were corrected using an independent component analysis (ICA) procedure. After artefact rejection, a minimum of 60 artifact-free epochs (each of 2-second duration) were retained for each participant to ensure reliable power estimation. Spectral analysis was performed using Fast Fourier Transform (FFT) with a Hamming window and 50% overlap. Absolute power (μV^2) was extracted for the theta (4–8 Hz) and beta (12–30 Hz) frequency bands.

The choice of frequency bands for analysis was driven by theory. The analysis was carried out for the theta frequency band (4-8 Hz) due to its core involvement in the integration of large-scale neural networks that give rise to the ability for language planning. Conversely, analysis was carried out for beta waves (12-30 Hz) due to their involvement with active cognitive control and sensorimotor processes critical to the execution of planning for speech motor sequences. The QEEG analysis was done on 19 cortical areas designated as follows: Frontal (FP1/FP2 and Fz/F2) and (F3/F4 and F7/F8); and Central (C3/C4/Cz); temporal (T3/T4 and T5/T6); and parietal (P3/P4) and occipital (O1/O2).

Changes in absolute power were examined before and after the intervention—both at the group level and for each individual—to better understand how the brain may reorganize its language pathways throughout treatment. The reliability of QEEG measures for Beta and Theta oscillation were satisfying, as are shown in Table 3.

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Table 3
Alpha Index across Groups, Wave, and Test Time

Group coex	test_time	Cronbach's Alpha	N of Items
Control_Theta	pretest	.986	19
	posttest	.987	19
Experimental_Theta	pretest	.957	19
	posttest	.988	19
Control Beta	pretest	.861	19
	posttest	.958	19
Experimental Beta	pretest	.906	19
	posttest	.946	19

Interventions

The Discourse-Based Lessons (Dis-BL) was constructed using a narrative genre in the present study. This genre was selected due to its grammatical and structural simplicity which makes it more suitable for younger stutter patients as recommended by Scott and Winsor (2000). A total of 30 stories were adapted from children's literature books such as "I and My Dad" and "Steps to Understanding—Elementary Level," of which five stories were used in this study. Each selected story was between 150 and 200 words and had sequenced pictures or illustrations.

Two versions of each story were developed named as original and scaffolded. In the modified version, any abstract sentence that was not represented in the illustrations following the text was deliberately deleted. This meant that only concrete, image-supported story parts were left. To scaffold information organization and memory, Factual Questions (FAC-SCAF) were designed to help patients follow the story using the images as infographic supports. Inferential Questions (INF-SCAFs) were later added to the original story to help speakers handle information that was implicit in the text but was not visually represented. This part allowed patients to consistently map stories to images, thereby supporting fluent story retelling through systematic visual scaffolding. The scaffolded version was practiced prior to the original version.

Results

Effects of Dis-BL on Stuttering Severity and Fluency

To answer the first question of the present study, data from 30 stutters (control = 15; experimental = 15) who completed the SSI-4 were analyzed using SPSS. These questions examined whether Dis-BL interventions significantly affected stuttering severity, speech fluency, and perceived speech difficulty. Stuttering severity was rated by three independent judges (as described in the Measures section)**,** yielding acceptable inter-rater reliability (r = .80). Normality assumptions were met for all variables. Also, as was mentioned earlier the results of the pretest revealed no significant differences between the experimental and control groups, confirming baseline equivalence.

The Independent-samples t-tests conducted on four SSI-4 dimensions: frequency, duration and concomitant physical behaviors, and speech naturalness demonstrated a significant group effect, with participants receiving the discourse-based DiS-BL intervention showing significantly lower stuttering severity than those in the control group. In other words, the patients in the experimental group exhibited fewer speech disruptions and greater fluency following the intervention. The results of the independent-samples t-test is presented in Table 3. As is shown in this Table, Levene's test for the posttest was significant (Levene $F = 5.150$, $p = 0.05$), therefore, to avoid statistical error, the degrees of freedom were corrected and reduced to 22.173. The t for equal variance not assumed indicated significant difference between two groups with the group receiving the DiS-BL intervention outperformed the control group; $t(22.173) = 4.08$, $p < 0.05$. Specifically, the experimental group ($M = 14$) demonstrated fewer speech difficulties than the control group ($M = 26.8$). Also, the effect size indices (Cohen's $d = 1.50$, Glass's $\Delta = 1.21$, and Hedges' $g = 1.50$) indicated that the observed effect was not only statistically significant but also practically and strongly meaningful.

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Table 4

Independent Samples t-Test

Variance Assumption	Levene F	Levene Sig.	T	df	Sig. (2-tailed)	Std. Error Difference	95% CI Lower	95% CI Upper	Cohen's d
Equal variances assumed	5.150	.031	-4.086	28	.000	3.11627	-19.11671	-6.34995	1.50
Equal variances not assumed			-4.086	22.173	.000	3.11627	-19.19315	-6.27351	1.50

The results indicated that Dis-BL enhanced fluency and reduced speech difficulty. These effects may be attributed either to the task repetition practiced in this intervention type or to predictable discourse structure through which the patients were trained. Both methods have supported in applied linguistics as efficient ways of improving speech fluency (Bygate, 2001; Lynch & Maclean, 2001; Gass et al., 1999).

Effects of Dis-BL on Beta Oscillation Activity

To answer the second research question of this study, the effect of Discourse-Based Lessons (Dis-BL) on beta wave patterns, the dataset was analyzed using both parametric (t-test) and non-parametric methods (Mann-Whitney U test) depending on the nature of the data distribution. To control for the type I error due to multiple comparisons across the cortical regions within the beta band, a False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995) was applied to all post-hoc comparisons (11 tests: 7 t-tests and 4 Mann-Whitney U tests). In this method, p-values are ranked from smallest to largest and each is adjusted using the formula $q = p \times (m / rank)$, where m is the total number of tests and rank is the position of each p-value in the ordered list. This procedure effectively controls the expected proportion of false positives among the significant results (Benjamini & Hochberg, 1995; Genovese et al., 2002).Only results with a q-value < 0.05 were considered statistically significant. Additionally, given the reduced sample size for the QEEG analyses (n = 14 in the experimental group and n = 13 in the control group), both parametric and non-parametric tests were employed to enhance the robustness of the findings (Button et al., 2013). Brain regions showing significant pre-test between group differences were excluded from final analysis to ensure that post-intervention outcomes could be confidently attributed to the treatment rather than pre-existing disparities. The analyses revealed significant effects across multiple cortical regions. As are shown in Tables 4 to 7, the results indicated that beta wave amplitudes were significantly higher in the control group than in the intervention group across several cortical locations. These differences were consistently observed in both statistical approaches. After FDR correction, all significant regions (F3, P3, F7, FP2, F4, C4, T4, FP1, C3, and T5) remained significant ($q < 0.05$), except for T3 which showed a trend that did not survive correction ($p = .058$, $q = .079$).

In the left prefrontal region (F3), which is associated with linguistic planning and cognitive control of speech, beta power was significantly higher in control group ($M = 14.93$, $SD = 6.72$) than in the experimental group ($M = 7.86$, $SD = 2.44$), $t(14.91) = 3.58$, $p = .003$, $q = .006$. Similarly, the adjacent F7 region, encompassing Broca's area and contributes to syntactic processing, showed elevated beta activity in control group ($M = 12.24$, $SD = 7.67$) compared with the experimental

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group (M = 5.26, SD = 1.48), t (12.83) = 3.23, p = .007, q = .012. The difference was significant too.

This pattern of divergence also extended to right-hemispheric regions. In the sensorimotor cortex (C4), patients in the control group demonstrated significantly higher beta power (M = 16.50, SD = 5.77) than those in the experimental group (M = 9.52, SD = 2.18), t (15.14) = 4.10, p = .001, q = .002. Non-parametric analyses further confirmed significantly reduced beta activity in the intervention group within left-hemispheric regions, including the frontopolar cortex (FP1, U = 36.00, p = .007, q = .012), the primary sensorimotor cortex (C3, U = 25.50, p < .05, q = .001), and the posterior temporal region (T5, U = 46.00, p < .05, q = .029). All of these regions remained significant after FDR correction (all q < 0.05). Effect sizes (Cohen's d) for these comparisons ranged from 1.12 to 1.60, indicating large effects across all regions (Cohen, 1988). The complete list of effect sizes is presented in Table 6. While these findings suggest that beta-band modulation may be associated with the therapeutic effects of Dis-BL, they should be interpreted cautiously given the correlational nature of the EEG data and the modest sample size. Future research with larger samples and active control conditions is needed to confirm beta-band activity as a reliable neural correlate of treatment response.

The reduction in beta power is indicative of decreased processing demands during speech planning and execution. The reduction in frontal region may reflect more efficient linguistic processing, whereas reduced activation in sensorimotor regions might represent optimized motor programming during speech production. These neurophysiological adaptations may indicate the potential effectiveness of Dis-BL treatments in modulating the neural networks underlying stuttering. Beta oscillations (approximately 15–30 Hz) is believed to play a critical role in preparatory speech mechanisms and may contribute to the onset of disfluencies in individuals who stutter. The results showed that the Dis-BL intervention significantly modulated beta activity in a broad set of cortical regions, including F3, P3, F7, FP2, F4, C4, T4, FP1, C3, T3, and T5. These findings are aligned with previous research showing abnormal beta synchronization in frontotemporal networks among people who stutter, which correlates with stuttering severity (Korzeczek, et al., 2022). Likewise, similar findings were observed in Chernychenko et al.'s study (2023), who demonstrated that effective interventions could reduce abnormal beta power in the left hemisphere—particularly within frontotemporal systems—resulting in improved speech fluency.

Table 5

Descriptive Statistics of Groups in Post-Test: Beta Waves in the different Brain regions

	groupcoex	N	Mean	Std. Deviation	Std. Error Mean
F3_LE_BETA	control	13	14.9323	6.72104	1.86408
	experimental	14	7.8557	2.43776	.65152
P3_LE_BETA	control	13	16.9200	6.37091	1.76697
	experimental	14	10.7507	4.63928	1.23990
F7_LE_BETA	control	13	12.2446	7.66591	2.12614
	experimental	14	5.2550	1.47678	.39469
FP2_LE_BETA	control	13	12.5669	4.84018	1.34242
	experimental	14	7.7564	2.37516	.63479
F4_LE_BETA	control	13	15.6531	6.34701	1.76034
	experimental	14	8.7814	2.40545	.64288
C4_LE_BETA	control	13	16.4962	5.76891	1.60001

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	experimental	14	9.5207	2.17797	.58209
T4_LE_BETA	control	13	14.4815	5.04285	1.39864
	experimental	14	8.9100	3.52503	.94210

Table 6

Independent Samples T-Test for Beta Waves across Different Brain Regions

		Levene's Test for Equality of Variances		t-test for Equality of Means							
									95% Confidence Interval of the Difference		Cohen's d
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper	
F3_LE_BETA	Equal variances assumed	16.440	.000	3.691	25	.001	7.07	1.91	3.12	11.02	1.40
	Equal variances not assumed			3.584	14.906	.003	7.07	1.97	2.86	11.28	1.40
P3_LE_BETA	Equal variances assumed	1.491	.234	2.892	25	.008	6.16	2.13	1.77	10.56	1.12
	Equal variances not assumed			2.858	21.839	.009	6.16	2.15	1.69	10.64	1.12
F7_LE_BETA	Equal variances assumed	12.612	.002	3.350	25	.003	6.98	2.08	2.69	11.28	1.26
	Equal variances not assumed			3.232	12.827	.007	6.98	2.16	2.31	11.66	1.26
FP2_LE_BETA	Equal variances assumed	6.821	.015	3.317	25	.003	4.81	1.45	1.82	7.79	1.28
	Equal variances not assumed			3.240	17.174	.005	4.81	1.48	1.67	7.94	1.28
F4_LE_BETA	Equal variances assumed	10.277	.004	3.774	25	.001	6.87	1.82	3.12	10.62	1.44
	Equal variances not assumed			3.667	15.165	.002	6.87	1.87	2.88	10.86	1.44
C4_LE_BETA	Equal variances assumed	11.444	.002	4.217	25	.000	6.97	1.65	3.56	10.38	1.40
	Equal variances not assumed			4.097	15.142	.001	6.97	1.70	3.34	10.60	1.40
T4_LE_BETA	Equal variances assumed	1.418	.245	3.348	25	.003	5.57	1.66	2.14	8.99	1.28
	Equal variances not assumed			3.304	21.310	.003	5.57	1.68	2.06	9.07	1.28

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Table 7

Descriptive Statistics of Groups in Post-Test: Beta Waves in the Left Hemisphere

groupcoex			FP1_LE_BETA	C3_LE_BETA	T3_LE_BETA	T5_LE_BETA
control	N	Valid	13	13	13	13
		Missing	0	0	0	0
	Median		10.5900	13.4300	8.3900	16.9100
experimental	N	Valid	14	14	14	14
		Missing	0	0	0	0
	Median		5.8000	7.2450	5.2650	6.4600

Table 8

Mann-Whitney U Test for Beta Waves Across Different Brain Regions

	FP1_LE_BETA	C3_LE_BETA	T3_LE_BETA	T5_LE_BETA
Mann-Whitney U	36.000	25.500	52.000	46.000
Wilcoxon W	141.000	130.500	157.000	151.000
Z	-2.669	-3.179	-1.893	-2.184
Asymp. Sig. (2-tailed)	.008	.001	.058	.029
Exact Sig. [2*(1-tailed Sig.)]	.007[b]	.001[b]	.061[b]	.029[b]
Exact Sig. (2-tailed)	.007	.001	.059	.028
Exact Sig. (1-tailed)	.003	.000	.030	.014
Point Probability	.001	.000	.002	.001

a. Grouping Variable: groupcoex

b. Not corrected for ties.

Effects of Dis-BL on Theta Oscillation Activity

To address the last question of the present research examining the effect of Discourse-Based Lessons (Dis-BL) on theta-wave activity, the data set were analyzed using a non-parametric (Mann–Whitney U test) statistical procedures due to the nature of data distribution across regions. To control for the Type error I, due to multiple comparisons across the cortical regions within the theta band, a False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995) was applied to all post-hoc comparisons (13 tests: 7 for the left hemisphere and 6 for the right hemisphere/midline regions) too. Only results with a q-value < 0.05 were considered statistically significant. Additionally, given the reduced sample size for the QEEG analyses (n = 14 in the experimental group and n = 13 in the control group), non-parametric tests were employed to enhance the robustness of the findings (Button et al., 2013).

As are presented in Tables 9 to 12, the results revealed a consistent pattern of reduced theta activity in the intervention group compared with the control group. In the left hemisphere, median theta values were lower across all examined regions (FP1, F3, C3, P3, F7, T3, and T5) following the intervention; however, after FDR correction, none of these differences reached statistical significance (all q > 0.05). Specifically, in the P3 region, the median theta value was lower in the experimental group (7.15) than in the control group (11.83); U = 54.5, Z = −1.77, p = 0.076. Similarly, in the F7 region, median theta activity in experimental group (5.03) was lower than that of control group (7.05), although the difference was trend not significant (U = 53.0, Z = −1.85, p = 0.065). Also, in the T5 region the value in the control group (5.61) was a bit higher than that of the experimental group (4.73); U = 53.0, Z = −1.84, p = 0.065. Specifically, in the P3 region, the

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median theta value was lower in the experimental group (7.15) than in the control group (11.83); U = 54.5, Z = −1.77, p = 0.076 (q = 0.114). Similarly, in the F7 region, median theta activity in experimental group (5.03) was lower than that of control group (7.05); U = 53.0, Z = −1.85, p = 0.065 (q = 0.102). Also, in the T5 region the value in the control group (5.61) was higher than that of the experimental group (4.73); U = 53.0, Z = −1.84, p = 0.065 (q = 0.102).

Reductions were also observed in other left-hemisphere regions, including FP1 (U = 59.0, p = 0.120, q = 0.156), F3 (U = 69.0, p = 0.286, q = 0.286), C3 (U = 62.0, p = 0.159, q = 0.191), and T3 (U = 57.0, p = 0.099, q = 0.129). Although these differences were not statistically significant, the direction of change was uniform across regions, indicating lower theta activity in the intervention group. In the right-hemisphere and midline regions, theta median values were consistently reduced in the experimental group across all examined regions. In the P4 region, the median theta value was 10.69 in the control group and 8.55 in the intervention group; U = 52.0, Z = −1.89, p = 0.058 (q = 0.099). A similar reduction was observed in the T4 region, where median values in the control group (7.77) was higher than that of the intervention group (6.01); U = 53.0, Z = −1.84, p = 0.065 (q = 0.102). Other regions also showed reductions in theta activity, although these changes were less pronounced. For instance, in the T6 region, median theta values decreased from 7.62 to 6.78 (U = 62.0, p = 0.159, q = 0.191). In midline regions, theta activity declined in Cz (U = 64.0, p = 0.190, q = 0.206) and Pz (U = 57.0, p = 0.099, q = 0.129), while minimal change was observed in Fz **(**U = 77.0, p = 0.497, q = 0.497). Overall, after FDR correction, none of the between-group differences reached statistical significance (all q > 0.05). Although the direction of change was consistently toward reduced theta activity in the experimental group, these findings should be interpreted as descriptive trends only, requiring replication in larger samples. The consistent pattern of reduction—particularly in posterior and temporal regions—may suggest a subtle modulation of neural activity related to cognitive and linguistic processing; however, this interpretation remains speculative given the lack of statistically robust differences.

Table 9

Descriptive Statistics in the Posttest: Theta waves of the Left Hemisphere

Groupcoex			FP1_LE_THETA	F3_LE_THETA	C3_LE_THETA	P3_LE_THETA	F7_LE_THETA	T3_LE_THETA	T5_LE_THETA
Control	N	Valid	13	13	13	13	13	13	13
		Missing	0	0	0	0	0	0	0
	Median		9.6300	9.3800	8.5400	11.8300	7.0500	3.7300	5.6100
Experimental	N	Valid	14	14	14	14	14	14	14
		Missing	0	0	0	0	0	0	0
	Median		6.7950	8.7650	7.2200	7.1450	5.0300	3.2100	4.7250

Table 10

Mann-Whitney U Test for Theta Waves in Different Regions of the Left Hemisphere

	FP1_LE_THETA	F3_LE_THETA	C3_LE_THETA	P3_LE_THETA	F7_LE_THETA	T3_LE_THETA	T5_LE_THETA
Mann-Whitney U	59.000	69.000	62.000	54.500	53.000	57.000	53.000
Wilcoxon W	164.000	174.000	167.000	159.500	158.000	162.000	158.000

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Z	-1.553	-1.068	-1.407	-1.771	-1.845	-1.650	-1.844
Asymp. Sig. (2-tailed)	.120	.286	.159	.076	.065	.099	.065
Exact Sig. [2*(1-tailed Sig.)]	.128[b]	.302[b]	.169[b]	.076[b]	.068[b]	.105[b]	.068[b]
Exact Sig. (2-tailed)	.128	.296	.169	.078	.066	.102	.068
Exact Sig. (1-tailed)	.064	.148	.085	.039	.033	.051	.034
Point Probability	.006	.005	.007	.002	.002	.003	.004

a. Grouping Variable: groupcoex

b. Not corrected for ties.

Table 11

Descriptive Statistics of in the Post-Test: Theta Waves across different Brain Regions

groupcoex			P4_LE_THETA	T4_LE_THETA	T6_LE_THETA	FZ_LE_THETA	CZ_LE_THETA	PZ_LE_THETA
control	N	Valid	13	13	13	13	13	13
		Missing	0	0	0	0	0	0
	Median		10.6900	7.7700	7.6200	9.7900	11.0600	13.2900
experimental	N	Valid	14	14	14	14	14	14
		Missing	0	0	0	0	0	0
	Median		8.5500	6.0150	6.7800	10.3350	10.3500	9.5700

Table12

Mann-Whitney U Test for Theta Waves in Different Brain Regions

	P4_LE_THETA	T4_LE_THETA	T6_LE_THETA	FZ_LE_THETA	CZ_LE_THETA	PZ_LE_THETA
Mann-Whitney U	52.000	53.000	62.000	77.000	64.000	57.000
Wilcoxon W	157.000	158.000	167.000	182.000	169.000	162.000
Z	-1.893	-1.844	-1.407	-.679	-1.310	-1.650
Asymp. Sig. (2-tailed)	.058	.065	.159	.497	.190	.099
Exact Sig. [2*(1-tailed Sig.)]	.061[b]	.068[b]	.169[b]	.519[b]	.202[b]	.105[b]
Exact Sig. (2-tailed)	.059	.068	.169	.519	.202	.105
Exact Sig. (1-tailed)	.030	.034	.085	.259	.101	.052
Point Probability	.002	.004	.007	.015	.008	.005

a. Grouping Variable: groupcoex

b. Not corrected for ties.

Theta-band oscillations (4–8 Hz) are widely recognized as reflecting higher-order cognitive processes, including working memory, attentional control, and the integration of linguistic and sensory information. In speech-related tasks, theta activity is therefore more closely associated with internal cognitive regulation than with the direct execution of speech motor commands. In the present study, several theta-related regions showed significant baseline differences between the experimental and control groups at pre-test and were consequently excluded from post-test analyses. Although this step was necessary to ensure analytical validity, it may have reduced sensitivity to post-intervention effects within the theta band. The results revealed a consistent but non-significant reduction in theta activity following the Discourse-Based Lessons (Dis-BL). Given the relatively slow and stable nature of theta oscillations, such changes may require longer intervention periods or tasks with greater demands on working memory and attentional control to reach statistical significance. Additionally, the relatively small sample size and the use of non-parametric analyses may have limited statistical power to detect subtle effects (Button et al., 2013). Future studies with larger samples and extended intervention durations may help to clarify the role of theta-band modulation following discourse-based interventions.

Discussion

Stuttering is widely conceptualized as a psychomotor speech disorder characterized by disrupted coordination within neural networks supporting speech planning and execution (Max et al., 2004; Alm, 2004). There are different Speech therapy techniques to treat stuttering problems, namely pausing and phrasing (American Speech-Language-Hearing Association [ASHA], n.d.), prolonged speech (Guitar, 2014), and speech shadowing (Sakai & Mori, 2015). Pausing and phrasing strategies aim to enhance speech fluency by systematically modifying the frequency and placement of pauses within connected speech (ASHA, n.d.), while prolonged speech reduces stuttering frequency by deliberately slowing speech rate and extending syllable duration, thereby facilitating more controlled speech production (Guitar, 2014). Speech shadowing, as anther technique, is a speech repetition task in which the patient repeat and listen to the ongoing speech at the same time without relying on any written text (Sakai & Mori, 2015). The methods all seem to work on speech planning process to help stutters produce speech fluently while none of them considers the planning ability as part of linguistic processes.

The present study conceptualized the intervention as a purely linguistic process, rooted in theories that assume language and cognition develop hierarchically (Bloom, 1956; Dale, 1969; Pienemann, 2003). Drawing upon principles governing rhetorical structures discovered by Kaplan (1966), the intervention was constructed using discoursal, structured, rule-governed patterns similar to those observed in Western scientific writing. Such linguistic structuring may empower individuals who stutter by enhancing their ability to anticipate upcoming discourse units prior to speech initiation, thereby reducing cognitive demand during planning. From a linguistic perspective, fluent speakers can extract order from inherently diverse linguistic input as depicted by Kaplan (1966), whereas individuals who stutter may struggle to impose such order without explicit scaffolding. By training participants who stutter to use predictable linguistic sequencing, the present approach may facilitate more efficient speech planning, supporting fluency through increased discourse-level predictability rather than direct motor or neurological manipulation.

As was observed, the Dis-BL improved Beta oscillation quantity indicating that speech planning has been ameliorated in the experimental group. Within applied linguistics and psycholinguistics, planning is consistently identified as a central determinant of cognitive fluency and the overall efficiency of the speech production system (Segalowitz, 2010, 2016; Tavakoli & Skehan, 2005).

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As was mentioned earlier, Levelt's model (1989, 1999) delineates speech production as a three-stage process—conceptualization, formulation, and articulation—where interruptions in planning and formulation can naturally lead to reduced fluency and increased stuttering (Howell, 2011). The results in Beta and Theta oscillations indicated that the Dis-BL intervention strengthened speech planning, by providing a structured and predictable rhetorical framework for the stutterers to produce speech more fluently. Segalowitz (2016) differentiates between macro-planning and micro-planning. Macro-planning involves the retrieval of non-linguistic conceptual knowledge and is not typically associated with fluent speech output (Levelt, 1989), whereas micro-planning is language-driven and prepares the preverbal message for smooth formulation and execution. The present findings suggest that Dis-BL primarily facilitated this micro-planning stage, thereby reducing processing demands during formulation and articulation.

From a neurophysiological perspective, this interpretation is strongly supported by the observed modulation of beta-band activity. Beta oscillations (13–30 Hz) are closely associated with sensorimotor maintenance, motor prediction, and preparatory states preceding voluntary movement and speech (Engel & Fries, 2010; Arnal, 2012). In individuals who stutter, atypical beta activity prior to speech onset has been linked to increased speech effort and stuttering severity, reflecting heightened reliance on conscious motor control (Neef et al., 2015). Following the Dis-BL intervention, a widespread and statistically significant reduction in beta power was observed in left frontal regions (F3, F7), bilateral sensorimotor cortices (C3, C4), and the midline frontal region (Fz). This pattern suggests improved neural efficiency during speech preparation, reduced cognitive–motor interference, and a shift toward predictive and automated speech control mechanisms (Chang et al., 2019a; Etchell et al., 2018). Notably, these beta-band findings remained significant even after applying False Discovery Rate (FDR) correction for multiple comparisons (all $q < 0.05$), which strengthens the robustness of the observed effects.

The Discourse-Based Lessons (Dis-BL) intervention was designed to specifically target speech planning mechanisms by imposing an explicit and predictable rhetorical structure on discourse production. Unlike conventional speech therapy approaches, which often emphasize articulatory accuracy or surface fluency techniques, Dis-BL systematically targets anticipatory planning at the discourse level by strengthening content organization, sequencing, and predictability prior to speech initiation. From a neurocognitive standpoint, such structured planning is expected to reduce processing demands during formulation and articulation, thereby facilitating more efficient coordination between linguistic and motor networks (Levelt, 1989; Segalowitz, 2010; Houde & Nagarajan, 2011). Notably, the observed beta wave modifications following intervention support the growing evidence that beta rhythm abnormalities reflect fundamental difficulties in auditory-motor coordination in people who stutter. The differential response across various cortical regions suggests that the Dis-BL approach may facilitate more efficient neural coordination within the speech motor network, potentially by enhancing timing precision and reducing excessive beta synchronization that typically precedes disfluent speech episodes.

In contrast, theta-band activity exhibited only limited and statistically non-significant reductions following the intervention. Although modest decreases were observed in select posterior and temporal regions, these effects did not reach significance after FDR correction (all $q > 0.05$). This dissociation between beta and theta modulation suggests that Dis-BL primarily influenced executive and motor planning networks rather than memory-oriented or attentional systems indexed by theta oscillations (Klimesch, 1999; Sauseng et al., 2010). Such a pattern is consistent with the theoretical focus of the intervention, which emphasizes goal-directed planning and discourse organization rather than working memory training per se. Several methodological factors

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may further account for the absence of statistically significant theta effects. Theta oscillations are relatively stable and may be less sensitive to short-term intervention-induced changes, particularly when interventions primarily target higher-level planning processes (Klimesch, 1999; Button et al., 2013). Additionally, the modest sample size and reliance on non-parametric statistical testing may have limited statistical power to detect subtle effects (Button et al., 2013).

Taken together, these findings provide preliminary converging behavioral and neurophysiological evidence that enhancing anticipatory speech planning may facilitate fluency improvements in individuals who stutter. By strengthening micro-planning processes and reducing cognitive load during speech preparation, Dis-BL appears to facilitate more efficient integration of linguistic and motor systems, as reflected in robust beta-band modulation. These results suggest that targeting discourse-level planning in stuttering intervention may be beneficial and that beta-band activity could serve as a promising candidate neural correlate of intervention-induced change. However, given the modest sample size, particularly for the QEEG analyses, and the exploratory nature of the neural measures, these findings should be interpreted with caution. Future research with larger, adequately powered samples and active control conditions is needed to confirm the reliability of these results and to establish beta-band modulation as a robust marker of therapeutic change (Alm, 2004; Arnal, 2012; Etchell et al., 2018; Neef et al., 2015).

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