

Article

Exploring Hemispheric Lateralization and Second Language Class Performance in 10 y.o. Students

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Abstract: This study investigated the relationship between functional hemispheric asymmetry at various brain levels and the performance of fourth-grade students in English as a second language classroom activities. Specifically, the study explored the impact of leftward and rightward asymmetry patterns on total classroom scores, considering lessons with a two-week interval and pre-lesson and post-lesson measurements. The sample comprised 27 right-handed students from an English-intensive school program. To assess functional hemispheric asymmetry before and after two English classes, computer laterometry based on a ‘two-source’ lead–lag dichotic paradigm was employed. Results revealed that leftward asymmetry in lability (brainstem-related) and excitability (primary auditory cortex-related) predicted higher total scores in classroom activities. The interaction between leftward lability and excitability asymmetries was a significant predictor of improved performance. These findings suggest that multiple regions of the left hemisphere are involved in supporting various linguistic tasks and emphasize the dynamic nature of functional hemispheric asymmetry. No significant relationship was observed between rightward asymmetry and classroom scores. However, future research may explore specific language tasks and sex-related differences in lateralization. The study underscores the importance of considering individual cognitive profiles in language learning and teaching, potentially improving language acquisition outcomes.

Keywords: functional hemispheric asymmetry; language processing; classroom activities; lateralization; English language acquisition



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1. Introduction

It has long been known that different zones of the left hemisphere make distinct contributions. However, their role in various types of language activity, including second language acquisition, is still not completely understood. For example, the left perisylvian language network (including the left posterior superior temporal gyrus, regions of the left anterior temporal lobe, inferior temporal gyrus, left inferior frontal cortex, and left insular cortex) underpins many linguistic functions [1], and activation in this area is similar in two languages for early bilinguals [2]. Left functional lateralization even occurs at the level of the primary auditory cortex [3]. Late bilinguals performed better on word processing tasks in their native and foreign languages when they exhibited left hemisphere dominance in the dichotic listening test [4]. Children with a more pronounced left-asymmetric pattern of brain activation (predicted by the precision of speech temporal coding in the auditory brainstem) perform better than children with weaker asymmetry in tasks involving phonological speech processing, including reading and spelling [5]. Regarding school-aged children, there have been reports suggesting that the extent and location of left hemisphere dominance vary depending on the specific linguistic tasks [6].

Speech production consistently required left hemisphere activation as proficiency in a foreign language increased among adults. However, the dominance of the hemispheres could shift rightward during reading and speech comprehension [7]. Indeed, the idea that

right hemisphere activity is essential for certain aspects of language processing is emphasized in numerous studies. In a review [8], it was pointed out that the right hemisphere may encompass two primary brain systems to avoid interference with language tasks: the emotional system and the system responsible for orienting visual–spatial attention. Regions of the right hemisphere contribute to various crucial aspects of language processing, including prosody [6,9], pragmatic aspects of verbal communication in both native and foreign languages [10], and even reading [11]. It has been shown that in early childhood, the right hemisphere counterparts of the left lower frontal and upper temporal language regions are functionally engaged in sentence processing. However, as individuals progress through childhood and adolescence, the right hemisphere’s involvement in sentence processing diminishes, and by adulthood, it is largely diminished [12]. The reduced role of the right hemisphere is even observed as proficiency in a foreign sign language increases [13].

The complex organization of the speech process in both native and foreign languages is well described by theories. For example, it is posited that language acquisition is a learned skill governed by a ‘functional language system (FLS)’, which coordinates physical activity distributed across various regions of the intricate human brain [14]. According to the concept of ‘comprehensive or noetic frameworks’ for language localization, speech emerges from the collective processing occurring throughout the entire brain [15].

Considering that the activation of left hemisphere regions is primarily necessary for most linguistic functions and that different brain regions/levels are predominantly involved in various tasks, this study aimed to investigate the relationship between functional hemispheric asymmetry at different brain levels and the success of foreign language class activities.

Research on structural and functional hemispheric asymmetry is rarely conducted in the context of real classroom activities. Most often, such studies are conducted in laboratory settings or controlled experiments involving specific stimuli in school environments. In a previous study, the author demonstrated that among the most proficient third-grade students in the English class, a more pronounced left hemispheric functional lability asymmetry was observed [16], but that study did not consider the interaction of different types of asymmetry and their influence on classroom performance. That study aimed to assess the relationship between functional brain asymmetry at different brain levels separately and the success of real English language class activities.

Since functional hemispheric asymmetry depends on the context and the state of the participant (such as emotional arousal [17] or mental fatigue [18]), it was important to examine whether classroom performance is equally related to asymmetry in different lessons. It was also essential to clarify whether changes in the profile of functional asymmetry before and after the lesson are associated with the total score for classroom activities. The aim of this study was to investigate the effects of functional hemispheric asymmetry at various brain levels, considering different lessons in the context of a foreign language (English), as well as the measurement stage (before and after the lesson).

The study examined two hypotheses:

1. High performance in English classroom activities is associated with leftward functional hemispheric dominance at different brain levels.
2. The relationship between functional hemispheric dominance and performance in English classroom activities may be influenced by a specific lesson or the timing of measurements (before or after a class).

We validated these hypotheses using computer-based laterometry technology [19], which relies on dichotic listening with the lead–lag paradigm. This approach facilitated the investigation of the correlation between performance in English classroom activities and functional hemispheric lability, excitability, and stability asymmetries.

2. Materials and Methods

2.1. Study Sample

The experiment involved 30 neurologically healthy right-handed Russian students (11 boys and 19 girls) of the 4th grade studying at a school that specializes in the English language, with an age of 10.4 ± 0.5 years. However, data from three girls were omitted from the analysis because they did not exhibit lability or excitability asymmetry at certain measurement stages. Consequently, the ultimate sample size comprised 27 students, consisting of 11 boys and 16 girls. Each participant exhibited strong academic performance in all school subjects.

2.2. Functional Hemispheric Asymmetry Assessment

Functional hemispheric asymmetry assessment was performed using computer-based laterometry, the fundamental principles of which were described in Demareva et al. [19]. In this ongoing study, a virtual acoustic environment was established using a sequence of dichotic impulses at a 3 Hz frequency, progressively altering the lead–lag delay duration by 23 μ s.

The research began with a training phase in which participants familiarized themselves with the stimuli. During the experimental phase, participants were instructed to provide joystick responses when (1) the sound transitioned from the center to one ear, (2) the sound achieved pronounced lateralization towards one ear, and (3) an auditory image featuring two distinct sounds in each ear emerged (one dominant and loud, the other an echoing sound, softer but discernible). The stimuli were initially presented with a lead on the left side and then on the right.

The evaluation of functional hemispheric activity was conducted by examining key laterometry parameters, including Δt_{\min} L and R (μ s), which measured the delay in sound shifting from the center to the left or right ear. Δt_{\max} L and R (μ s) measured the delay when the sound reached extreme lateralization to the left or right. Additionally, Δt_{rash} L and R (μ s) assessed the delay when two distinct sounds were perceived dominantly in the left or right ear.

These laterometry parameters serve as indicators: lower Δt_{\min} suggests increased opposite hemisphere lability to the sound lead direction, showing lower activation thresholds in the brainstem; lower Δt_{\max} signifies heightened excitability in the opposite hemisphere to the sound lead, reflecting lower activation thresholds in the primary auditory cortex; and lower Δt_{rash} indicates reduced stability in the opposite hemisphere to the sound lead, pointing to shorter durations of neuronal activity in the frontal, parietal, and occipital brain regions [19,20].

By comparing these parameters (Δt_{\min} , Δt_{\max} , and Δt_{rash}) for sound leading to the left (L) and right (R), we can gauge functional hemispheric asymmetry concerning lability, excitability, and stability. This assessment of asymmetry is represented by coefficients (1–3), providing insights into the functional differences between the hemispheres:

$$A_{\text{min}} = (\Delta t_{\min} R - \Delta t_{\min} L) / (\Delta t_{\min} R + \Delta t_{\min} L) \quad (1)$$

$$A_{\text{max}} = (\Delta t_{\max} R - \Delta t_{\max} L) / (\Delta t_{\max} R + \Delta t_{\max} L) \quad (2)$$

$$A_{\text{rash}} = (\Delta t_{\text{rash}} L - \Delta t_{\text{rash}} R) / (\Delta t_{\text{rash}} L + \Delta t_{\text{rash}} R) \quad (3)$$

Positive values for A_{min} , A_{max} , and A_{rash} stand for right hemispheric functional asymmetry for lability, excitability, and stability, respectively, and negative values stand for left hemispheric asymmetry.

2.3. Classroom Activities Assessment

To evaluate the students' English classroom activities, a special protocol was used to assess the success of student interaction as well as the use of old and new language material during the class.

The assessment of classroom activities involved the consideration of the following criteria (see Table 1).

Table 1. Scoring for the classroom activities criteria.

N ^o	Criteria	Scores Range (Min–Max)
Cr ₁	Interaction with students	1–3
Cr ₂	Interaction with the teacher	1–3
Cr ₃	Interaction within a group	1–3
Cr ₄	Accuracy in using new lexical material	1–5
Cr ₅	Fluency in using new lexical material	1–5
Cr ₆	Utilization of new grammar structures	1–5
Cr ₇	Incorporation of new vocabulary	1–5
Cr ₈	Accuracy in using previously learned lexical material	1–5
Cr ₉	Fluency in using previously learned lexical material	1–5
Cr ₁₀	Utilization of previously learned grammar structures	1–5
Cr ₁₁	Incorporation of previously learned vocabulary	1–5

Therefore, criteria 1 to 3 were rated using a 3-point scale, while criteria 4 to 11 were assessed on a 5-point scale. Specific options for each score were not provided. The teacher received the instruction: ‘Please evaluate the following criteria within the given score ranges’.

The total weighted score was calculated using Formula (4):

$$total\ score = \frac{Cr_1 + Cr_2 + Cr_3}{9} + \frac{Cr_4 + Cr_5 + Cr_6 + Cr_7 + Cr_8 + Cr_9 + Cr_{10} + Cr_{11}}{40} \quad (4)$$

Thus, the total score could take values from 0 to 1, where 1 meant receiving the maximum score for all criteria.

2.4. Study Design

Two measurements were obtained 2 weeks apart (lesson 1 and lesson 2). The design of each measurement was as follows.

Initially, the participants underwent computer-based laterometry assessments. Subsequently, they participated in a 45-minute English class. Within the class, the teacher scored the students’ activities levels across 11 criteria. Following the end of the class, the students underwent a second round of computer-based laterometry assessments. Figure 1 illustrates the study design.

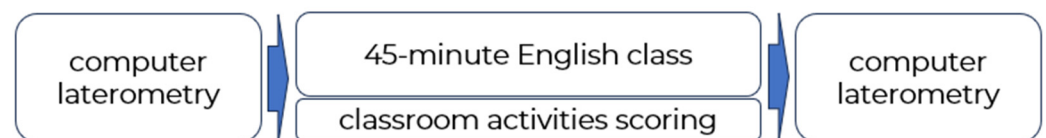


Figure 1. Study design scheme.

Thus, we obtained functional hemispheric asymmetry scores before and after each of the two lessons, as well as total scores for classroom activities in each of the two lessons.

The research plan and process were endorsed by the Ethics Committee of Lobachevsky State University, and all participants or their legal guardians furnished written informed consent in accordance with the Declaration of Helsinki guidelines.

2.5. Statistical Analyses

Modeling with a linear mixed model with an analysis of variance was implied to investigate the relationship between asymmetry (left or right, for hemispheric lability, excitability, and stability) and total score for classroom activity (0–1) across two lessons (1 and 2) and two stages of measurement (before and after a class).

We incorporated the subject as a random factor, recognizing the multilevel characteristics of the measurements and addressing variance stemming from both between-subject and within-subject sources [21]. Asmin, Asmax, Asrash, lesson, and stage were considered as fixed effects. The reference levels for all the fixed effects were automatically chosen according to alphabetical order (see Table 2).

Table 2. Reference levels for fixed effects.

Effect	Levels	Reference Level
Asmin	left, right	left
Asmax	left, right	left
Asrash	left, right	left
lesson	1, 2	1
stage	1 (before), 2 (after)	1 (before)

The models were run in RStudio (v. 2022.07.2 Build 576) using lme4 package (v. 1.1-31) [22]. The entire model considered all the variations of fixed effects compositions and included 34 parameters: ‘total score \sim intercept + Asmin * Asmax * Asrash * stage * lesson + (1 | subject)’. Then a backward procedure was adopted to obtain the final model with significant parameters. Using the default alpha parameter for fixed effects of 0.05 resulted in retaining only the effects of Asmin and Asrash in the model. Since we aimed to investigate the effects of the lesson and stage (at least at a trend level), we manually set the alpha parameter for fixed effects to 0.07. The final model with 14 parameters was the following: ‘total score \sim intercept + Asmin + Asmax + Asrash + stage + lesson + (1 | subject) + Asmin:Asmax + Asrash:stage + Asmin:lesson + Asrash:lesson + stage:lesson + Asrash:stage:lesson’. An ANOVA of type III with Satterthwaite’s method was carried out [23]. A *t*-test with Šidák correction was applied to explore the significant differences in total score across different levels of fixed effects with the R package emmeans (v. 1.8.3) [24]. The Wilcoxon matched pairs test (*W*) was used to compare the total scores across two lessons.

3. Results

3.1. Classroom Activity Total Score Distribution

The classroom activity total scores distribution within lessons 1 and 2 is presented in Figure 2.

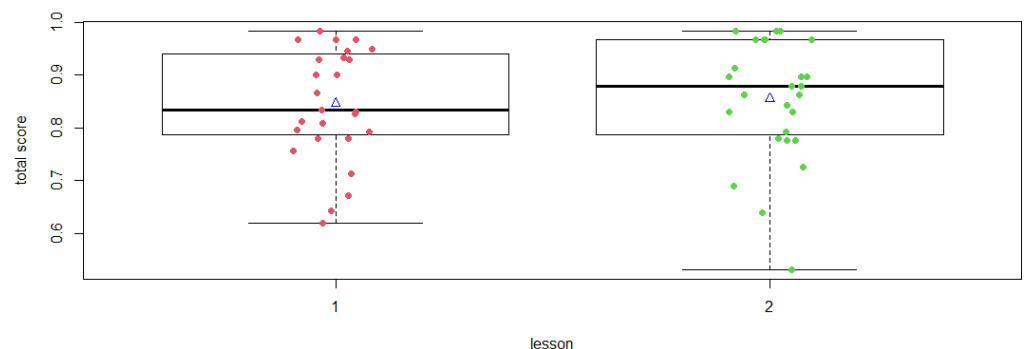


Figure 2. Box plot illustrating the distribution of total scores across lessons 1 (red dots) and 2 (green dots). The median is indicated by bold horizontal lines, and means are represented by triangles.

The mean total score for lesson 1 was 0.85 ± 0.11 and for lesson 2 0.86 ± 0.11 . Therefore, the total scores for lessons 1 and 2 did not differ ($W = 336.5$; $p = 0.6335$).

3.2. Effect of Asymmetry, Lesson, and Stage on the Total Score for English Class

The final model is presented in Table S2 (Supplementary Material). This model appeared to be quite reasonable for the total score (AIC = -183.5 ; conditional $R^2 = 0.519$).

Asmin (right) showed a noteworthy but not quite statistically significant ($p = 0.097$) negative association with the total score ($B = -0.06$, 95% confidence interval [CI] $[-0.12-0.01]$). This suggests that students with Asmin (right) tended to achieve slightly lower total scores in classroom activities. Similarly, Asmax (right) displayed a nearly significant ($p = 0.050$) negative impact on the total score ($B = -0.05$, 95% confidence interval [CI] $[-0.11-0.00]$). The interaction between Asrash (right), stage (2 (after)), and lesson (2) also approached statistical significance ($p = 0.057$) as a negative predictor of the total score ($B = -0.13$, 95% confidence interval [CI] $[-0.27-0.00]$).

However, the interaction between Asmin (right) and Asmax (right) emerged as a significant predictor of the total score ($B = 0.13$, 95% confidence interval [CI] $[0.05-0.20]$). Additionally, the interaction between Asmin (right) and lesson (2) had a significant positive influence on the total score ($B = 0.07$, 95% confidence interval [CI] $[-0.14-0.00]$). It is worth noting that analyzing lessons separately did not yield significant contributions to explaining the total score.

Detailed results for the fixed effects can be found in Table 3, which summarizes the ANOVA findings.

Table 3. ANOVA results for fixed effects.

Effect	Sum of Squares	Mean Square	df	F	<i>p</i>
Asmin	0.01	0.01	1	2.41	0.123
Asmax	0.00	0.00	1	0.29	0.589
Asrash	0.00	0.00	1	0.05	0.828
stage	0.00	0.00	1	0.33	0.568
lesson	0.00	0.00	1	0.22	0.641
Asmin:Asmax	0.07	0.07	1	11.99	0.001
Asrash:stage	0.00	0.00	1	0.26	0.613
Asmin:lesson	0.02	0.02	1	4.31	0.041
Asrash:lesson	0.00	0.00	1	0.00	0.960
stage:lesson	0.00	0.00	1	0.66	0.419
Asrash:stage:lesson	0.02	0.02	1	3.72	0.057

To better understand the effects, we conducted post-hoc analysis (see Figures 3 and 4 for significant pairwise differences).

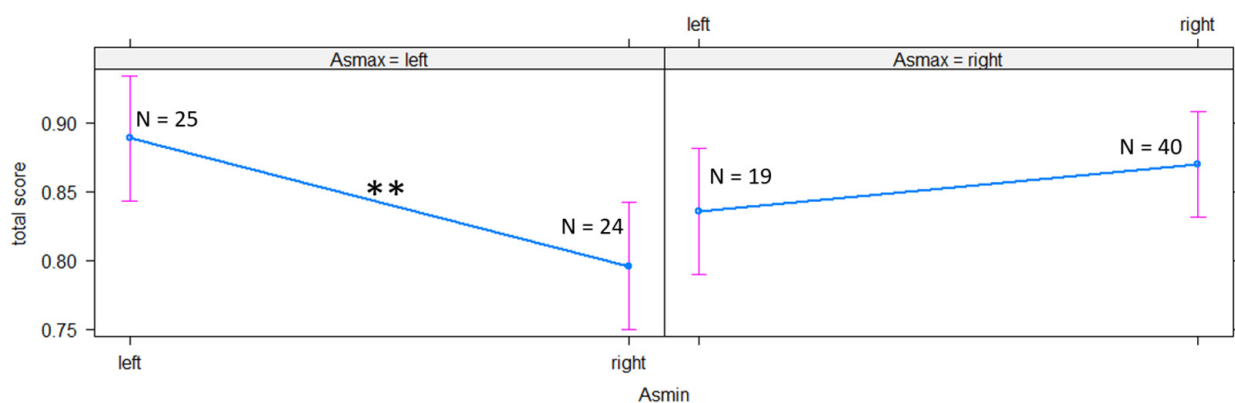


Figure 3. Post-hoc analysis of the effect Asmin*Asmax (**— $p < 0.01$). Error bars indicate 95% confidence intervals.

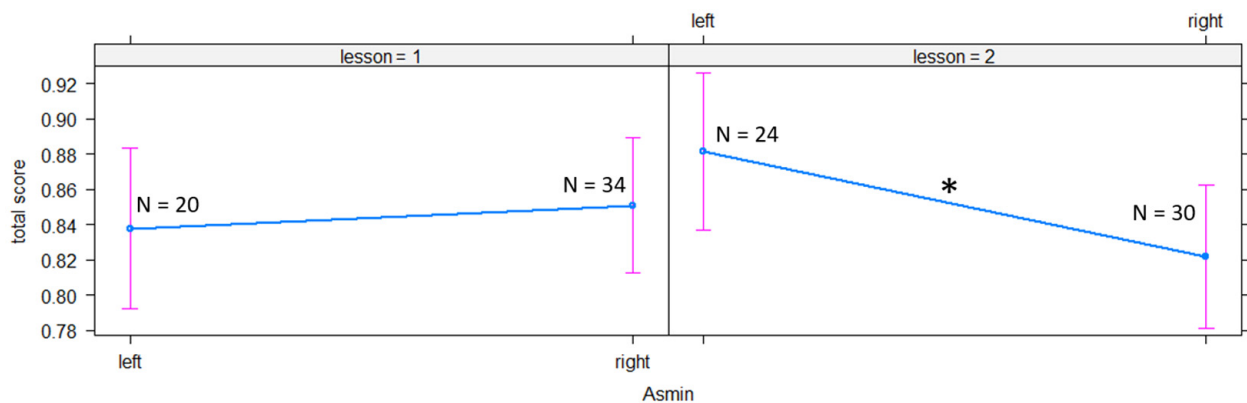


Figure 4. Post-hoc analysis of the effect Asmin*lesson (*— $p < 0.05$). Error bars indicate 95% confidence intervals.

Asmin and Asmax interaction had a significant association with the total score ($F = 11.99$; $p = 0.001$). Post-hoc analysis revealed that Asmin (left) alongside with Asmax (left) resulted in better total score than Asmin (left) alongside with Asmax (right) ($t = 3.04$; $p = 0.003$).

The interaction between Asmin and lesson had a significant association with the total score ($F = 4.31$; $p = 0.041$). Further examination through post-hoc analysis demonstrated that when Asmin (left) was combined with lesson (2), it led to a higher total score compared to when Asmin (right) was paired with lesson (2) ($t = 2.36$; $p = 0.020$).

On the other hand, the interaction involving Asrash, stage, and lesson had a tendency towards significance in relation to the total score ($F = 3.72$; $p = 0.057$). However, post-hoc analysis did not reveal any statistically significant differences between pairwise comparisons.

4. Discussion

The study aimed to investigate the relationship between classroom activities performance and functional hemispheric asymmetry at various brain levels, considering different lessons (with a two-week interval) and asymmetry before and after the lesson. The study sample consisted of fourth-grade students studying English as a second language. For the first time, we explored whether and to what extent the total score for classroom activities performance in a second language could be affected by lability, excitability, and stability asymmetries measured before and after two real lessons in children aged 10.4 ± 0.5 years.

The results obtained from the regression model helped elucidate the impact of hemispheric asymmetry at different brain levels, as measured before and after the lessons, on classroom performance. When examined separately, leftward asymmetries in lability (Asmin) and excitability (Asmax) demonstrated a tendency to contribute to the total score for English class. However, their interaction had a significant effect. Consequently, the combined left hemispheric functional asymmetry in lability and excitability predicted higher total scores for classroom activities.

As lability asymmetry reflects functional activity at the level of brainstem [19,20], the abovementioned result aligns with the fact that leftward cortex asymmetry mediated by the brainstem leads to better performance in tasks related to phonological speech processing, including reading and spelling [5]. Meanwhile, excitability asymmetry reflects functional activity at the level of the primary auditory cortex [19,20] and asymmetry there reliably indicates functional lateralization [3]. This area is closely linked to the perisylvian language network [1]. Therefore, leftward excitability asymmetry being associated with improved scores in second language classes is not surprising.

Classroom activities encompass various tasks, and the collaborative effect of lability and excitability asymmetries supports findings from other studies, indicating that the extent and locations of left hemisphere dominance vary depending on specific linguistic tasks [6]. Furthermore, these results emphasize that the functional activity of the entire

brain is necessary to support linguistic functioning [14,15]. It is worth noting that during the lessons, a substantial amount of time was devoted to speaking activities, aligning with the finding that speech production requires left hemisphere activity [7].

Notably, leftward asymmetry in lability showed a significant effect on the total score only when interacting with the lesson effect. This underscores the dynamic nature of functional hemispheric asymmetry and suggests that leftward asymmetry at just one brain level may not suffice for optimal performance in second language classes. This observation further supports the notion that different regions of the left hemisphere are required for various linguistic tasks [6].

In this study, no connection was found between rightward asymmetry at any brain level and total classroom scores. Other studies have highlighted the significance of rightward asymmetry in various linguistic aspects, such as reading and speech comprehension [7], prosody [6,9], pragmatics [10], and reading [11]. However, it is important to consider that only the total score was analyzed in this article, and individual protocol components were not considered. Future research may explore different language tasks and aspects of activity during lessons to determine whether a relationship exists between prosody [6,9], pragmatics [10], emotional [8] aspects of verbal communication, reading [11], and rightward functional hemispheric asymmetry. Also, sex differences may be considered in future research, as other studies have reported about the possible sex effect on lateralization [25].

In summary, regarding leftward asymmetry and its association with linguistic outcomes, the results of this study align with previous research where leftward asymmetry, as measured by dichotic listening, led to enhanced word processing [4] and better scores in second language classes and proficiency tests [16].

It is essential to acknowledge certain limitations of our study. Firstly, the overall number of study participants was relatively small ($n = 30$), with the exclusion of three participants from the analysis. To ensure robust and reliable findings, future research should consider increasing the sample size. Secondly, the multitude of examined effects could have influenced the outcomes. Additionally, the results apply solely to healthy children and cannot be extrapolated to other populations. Furthermore, the study exclusively involved right-handed children, and future research could explore the identified effects while considering various behavioral asymmetries.

5. Conclusions

In summary, the results of the study corroborated the assumption that high performance in English classroom activities should be supported by leftward functional hemispheric dominance at different brain levels (at least, brainstem and auditory cortex). The study underscored that the connection between functional hemispheric dominance in lability and performance in English classroom activities can be potentially mediated by a specific lesson's content.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/sym15122147/s1>, Table S1: Results of the first linear mixed-effects model for asymmetry, stage, and lesson parameters; Table S2: Results of the final linear mixed-effects model for asymmetry, stage, and lesson parameters.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

Conflicts of Interest: The author declares no conflict of interest.

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