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The Effect of Brain-Based Feedback on Cognitive Load and Affective Factors among EFL Learners: Anxiety, Enjoyment, and Motivation

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A B S T R A C T

Purpose: This study aimed to investigate the effects of brain-based feedback on perceived cognitive load and key affective factors, including foreign language anxiety, foreign language enjoyment, and second-language motivation, among intermediate EFL learners.
Methods and Materials: A quasi-experimental pretest–posttest design with a control group was employed. The participants were 60 intermediate EFL learners who were assigned to an experimental group receiving brain-based feedback and a control group receiving traditional corrective feedback. The intervention was implemented over eight weeks. Grounded in Cognitive Load Theory and Control-Value Theory, brain-based feedback was designed to align feedback delivery with learners' cognitive processing capacity and emotional responses. Data on perceived cognitive load, foreign language anxiety, enjoyment, and second-language motivation were collected before and after the intervention. Inferential statistical analyses were conducted to examine time, group, and time-by-group effects on the study variables.
Findings: A statistically significant time-by-group interaction was found for perceived cognitive load, $F(1, 58) = 40.40$, $p < .001$, $\eta p^2 = .41$, indicating a substantially greater reduction in cognitive load in the experimental group than in the control group. Significant time-by-group interaction effects were also obtained for the affective variables, with partial eta-squared values ranging from .24 to .49. These effects demonstrated that participants receiving brain-based feedback experienced significantly greater reductions in foreign language anxiety and significantly greater increases in foreign language enjoyment and second-language motivation compared with learners receiving traditional corrective feedback.
Conclusion: Brain-based feedback appears to be an effective instructional approach for simultaneously reducing learners' perceived cognitive demands and improving their affective experiences in EFL classrooms. Aligning feedback with learners' cognitive processing capacities and emotional needs may create more supportive learning conditions, reduce anxiety, and strengthen enjoyment and motivation. These findings highlight feedback as a targeted neuroscience-informed mechanism through which classroom practices can influence learners' internal cognitive and emotional conditions.
Keywords: *Brain-Based Feedback; Neuroscience-Informed Instruction; Cognitive Load; Foreign Language Anxiety; Foreign Language Enjoyment; Second-Language Motivation*

1. Introduction

Second language learning is increasingly understood as a multidimensional process in which linguistic development is inseparable from learners' cognitive resources, emotional experiences, and motivational states. Contemporary perspectives on second language acquisition (SLA) emphasize that successful learning depends not only on exposure to linguistic input or opportunities for practice but also on learners' ability to allocate attention, maintain information in working memory, regulate emotional responses, and sustain goal-directed effort over time (Brown & Lee, 2025). This broader understanding is especially important in English as a Foreign Language (EFL) settings, where learners frequently perform demanding tasks while simultaneously processing unfamiliar linguistic forms, monitoring their own production, interpreting interlocutors' messages, and responding to teacher intervention. As a result, classroom practices that appear pedagogically routine may influence not only linguistic performance but also the cognitive and emotional conditions under which learning takes place. Growing interest in educational neuroscience has reinforced this integrative perspective by emphasizing that learning emerges through interactions among attention, memory, emotion, motivation, and experience rather than through isolated cognitive mechanisms (Alkhassawneh & Al Sharif, 2025; Pradeep et al., 2024).

One instructional practice that may be particularly important at this cognitive–affective intersection is feedback. Feedback has traditionally occupied a central position in language teaching because learners require information about discrepancies between their current performance and desired linguistic forms. However, contemporary scholarship increasingly conceptualizes feedback not simply as information transmitted from a teacher to a learner but as a dynamic process requiring interpretation, engagement, and subsequent action by the learner (Winstone et al., 2022). Its effectiveness therefore depends not only on whether corrective information is accurate but also on how, when, and under what interpersonal conditions it is delivered. Feedback can direct attention, clarify errors, strengthen self-monitoring, and facilitate subsequent performance, yet it can also interrupt processing, increase uncertainty, threaten confidence, or encourage disengagement when learners cannot effectively process or emotionally accommodate it (Kutasi, 2023). This process-oriented perspective is particularly relevant to EFL classrooms, where feedback often occurs during cognitively demanding communicative activity and can therefore become part of the task demands experienced by learners.

Corrective feedback in language education can take multiple forms, including explicit correction, reformulation, recasts, prompts, clarification requests, and metalinguistic information. Research on oral corrective feedback has demonstrated that different feedback forms vary in their capacity to direct learners' attention to lexical and linguistic errors, and that the effectiveness of correction depends on contextual and learner-related characteristics rather than on the existence of correction alone (Tan et al., 2024). Classroom studies likewise indicate that error correction strategies must be selected carefully because corrective interventions can facilitate awareness and improvement while simultaneously influencing learners' willingness to participate (Dung, 2024). Teacher correction may also affect confidence as well as achievement, illustrating that a feedback episode has both instructional and affective consequences (Putri et al., 2024). These observations suggest that the pedagogical question is not simply whether learners should receive feedback, but how feedback can be structured so that corrective information remains cognitively manageable and emotionally constructive.

This issue can be examined through Cognitive Load Theory (CLT), which provides a useful framework for understanding how instructional conditions influence learners' limited processing resources. Language tasks can be cognitively demanding because learners must coordinate vocabulary, grammar, meaning, discourse, contextual information, and communicative intentions while maintaining relevant information in working memory. Research on second-language processing illustrates the critical role of working memory, particularly when learners must coordinate multiple sources of information during complex language production (Li et al., 2023). From a cognitive load perspective, learning conditions become problematic when instructional demands consume resources that could otherwise be allocated to relevant processing. Consequently, instructional design should limit avoidable cognitive demands while preserving effort directed toward meaningful learning (Surbakti et al., 2024). Evidence-based approaches to cognitive load management similarly emphasize segmentation, appropriate pacing, focused guidance, and reduction of unnecessary information as means of supporting learning efficiency (Parveen, 2025).

Feedback can itself constitute an important source of cognitive demand. When corrective information is lengthy, poorly timed, excessively frequent, or presented while learners are already engaged in demanding processing, it may require attention to shift between task completion and error interpretation. Such attentional switching can increase perceived mental effort even when the feedback is pedagogically accurate. Conversely, feedback that is appropriately timed, selective, and aligned with task demands may help learners direct their attention toward relevant information without unnecessarily disrupting ongoing processing. Research in digital game-based language learning provides empirical support for this relationship, showing that different forms of learner-, peer-, and collaboratively regulated feedback can differentially affect cognitive load (Feng & Yang, 2025). Cognitive load also interacts dynamically with learners' self-regulated learning processes, indicating that instructional support can alter how learners monitor, allocate, and adapt their cognitive resources over the course of a task (Wang & Lajoie, 2023). Feedback should therefore be viewed not merely as an informational addition to a language task but as part of the cognitive architecture of that task.

At the same time, recent scholarship has cautioned against interpreting learning exclusively through the management of working-memory demands. Educational learning involves emotional, motivational, metacognitive, and contextual processes that cannot be reduced to memory efficiency alone. Recent critiques and extensions of CLT argue that explanations of learning efficacy need to incorporate broader neuroscience-informed and adaptive perspectives (Gkintoni et al., 2025). Similarly, emerging theoretical work suggests that learning requires attention to emotion, motivation, agency, and contextual adaptation in addition to cognitive load management (Sortwell et al., 2026). For EFL learners, this broader perspective is particularly pertinent because cognitively demanding language use often occurs in socially evaluative circumstances in which learners may fear mistakes, anticipate judgment, experience enjoyment, or become more or less motivated depending on how classroom interaction unfolds.

Foreign language anxiety is one of the most consequential negative affective experiences in language learning. Anxiety can emerge when learners perceive linguistic demands as exceeding their competence or when communicative situations are interpreted as threatening to self-presentation. Elevated anxiety can reduce willingness to communicate, interfere with sustained engagement, and make learners reluctant to take the risks necessary for language development (Wang et al., 2022). The relationship between anxiety and communication is also intertwined with linguistic competence; even when learners possess relevant language knowledge, anxiety may weaken the extent to which competence translates into willingness to use the target language (Zhou et al., 2023). Feedback may be particularly important in this respect because correction makes performance discrepancies salient. If feedback is abrupt, evaluative, or interruptive, learners may interpret it as evidence of failure or inadequate competence, whereas appropriately framed feedback may present error as manageable information that supports further learning.

Positive affect deserves equal consideration. Foreign language enjoyment reflects learners' positive engagement with learning experiences and can support attention, participation, persistence, and willingness to explore language without excessive concern about errors. Research has shown that classroom experiences characterized by supportive interaction can amplify enjoyment and cultivate more positive attitudes toward language learning (Ramzan et al., 2023). Positive emotions can also influence cognitive learning processes by facilitating attention, flexible thinking, and sustained engagement (Ullah et al., 2024). Importantly, enjoyment and anxiety are not simply opposite ends of a single continuum; learners may encounter both during language learning, and instructional practices can alter the balance between them. Evidence concerning peer support further demonstrates that supportive classroom conditions can simultaneously reduce anxiety, increase enjoyment, strengthen achievement, and cultivate more adaptive learner beliefs (Namaziandost et al., 2024). Thus, the affective quality of feedback may be as consequential as the corrective content it conveys.

Motivation constitutes another central component of learners' engagement with feedback and language tasks. Motivation directs behavior toward valued goals and supports the persistence necessary for learning processes that require repeated effort and adjustment. Foundational perspectives on motivation and learning have long emphasized that behavior is organized in relation to goals and expectancies rather than being understood solely as a response to immediate reinforcement (Tolman, 2023). In language learning, feedback can reinforce or undermine such goal-directed engagement depending on whether it helps learners understand progress, develop a sense of competence, and view improvement as attainable. Feedback research increasingly emphasizes this motivational and emotional dimension, arguing that feedback should be examined in terms of learners' future engagement rather than

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only its immediate informational function (Fong & Schallert, 2023). Systematic evidence on second-language writing similarly indicates that learners' engagement with feedback includes affective, behavioral, and cognitive components, underscoring the importance of examining feedback as an experience with multiple interrelated consequences (Pearson, 2024).

Control-Value Theory provides a particularly useful explanation of how feedback may shape anxiety, enjoyment, and motivation. According to this framework, achievement emotions are strongly influenced by learners' appraisals of control over learning activities and the value assigned to those activities and outcomes (Pekrun, 2024). Feedback capable of increasing clarity, highlighting manageable next steps, and supporting learners' perceived competence may enhance their sense of control, whereas unpredictable or threatening correction may intensify uncertainty. Likewise, feedback that helps learners perceive progress and meaningful improvement may strengthen the value attached to classroom engagement. These emotional appraisals are relevant not only to learners' subjective experiences but also to cognitive functioning. A meta-analytic examination of affective cognition and learning performance indicates that cognitive and affective factors interact rather than operate independently, with learners' emotional states contributing to patterns of learning engagement and performance (Li, 2023). Consequently, the cognitive load imposed by feedback and the emotions elicited by feedback are likely to be mutually influential.

Educational neuroscience provides an increasingly prominent framework for understanding this interaction. Neuroeducation seeks to connect evidence concerning neural and cognitive functioning with educational practice while avoiding simplistic assumptions that any instructional method can be labeled "brain-based" merely because it appears engaging. Systematic examinations of brain-based learning theories indicate growing interest in translating principles concerning attention, memory, emotion, and neuroplasticity into more responsive teaching methods (Parayangattu & Goel, 2024). In educational technology, neuroscience perspectives have likewise been used to inform the design and implementation of strategies intended to accommodate cognitive processing and learner variability (Alkhassawneh & Al Sharif, 2025). Recent work involving artificial intelligence further illustrates how neuroscience principles may be combined with adaptive technologies to personalize instructional strategies and respond more flexibly to learners' cognitive needs (Shiwlani et al., 2024). These developments suggest a movement from generalized "brain-friendly" teaching toward more specific mechanisms through which instruction can be aligned with cognitive and affective processes.

Evidence from language education provides preliminary support for the potential of brain-based practices. Brain-based teaching has been associated with improved vocabulary retention and recall among Iranian EFL learners, suggesting that attention to cognitive processing principles can strengthen the durability of lexical learning (Amini et al., 2025). In writing instruction, brain-based learning strategies have also been investigated among lower-ability English learners, with findings indicating their potential usefulness for supporting writing performance (Wilson et al., 2024). Brain-based learning activities have additionally been integrated into online TESOL contexts, where attention to learning styles and varied instructional activities has demonstrated the adaptability of neuroscience-informed principles across instructional environments (Isaee et al., 2024). Beyond language education, technology-enhanced brain-based learning has produced promising but not uniformly significant outcomes, indicating that effects may depend on the specific instructional design and implementation context rather than on a broad brain-based label itself (Terblanche et al., 2026).

This variability highlights a central limitation in the existing literature. Brain-based learning is frequently investigated as a broad package comprising multiple instructional strategies. When attention cues, multimodal input, collaborative activities, pacing, emotional support, memory techniques, and technology are introduced together, it becomes difficult to determine which component is responsible for observed cognitive or affective changes. Educational neuroscience therefore benefits from research that isolates specific pedagogical mechanisms and specifies how those mechanisms are expected to operate. Feedback represents a particularly strong candidate because it is ubiquitous in EFL classrooms, can be manipulated through observable instructional decisions, and has both cognitive and emotional functions. A recent systematic review examining neuroscience, artificial intelligence, and feedback underscores growing interest in feedback systems that are adaptive to cognitive and learner characteristics, while also revealing the continuing need to understand how neuroscience-informed feedback principles operate in educational practice (Adiguzel et al., 2026).

A brain-based perspective on feedback does not require sophisticated neuroimaging equipment or automated

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technologies in the classroom. Rather, its pedagogical relevance can lie in translating established principles concerning limited processing capacity, attentional continuity, emotional safety, and learner readiness into concrete feedback decisions. In the present context, brain-based feedback can therefore be understood as feedback deliberately structured to avoid unnecessary interruption, provide cognitively manageable corrective information, and frame correction in a supportive manner. Such an approach is compatible with the broader evolution of feedback research from feedback as transmitted information toward feedback as an interactive learning process (Winstone et al., 2022). It is also consistent with emerging neuroscience-informed approaches that emphasize adaptive rather than uniform instruction (Pradeep et al., 2024). Importantly, this conceptualization permits brain-based feedback to be operationalized through observable characteristics such as timing, mode of correction, and affective framing instead of invoking neuroscience as a general pedagogical metaphor.

The timing of feedback may be particularly consequential. Immediate correction can be useful when rapid error resolution is necessary, yet interrupting a learner during a fluency-oriented task may divide attention between meaning construction and form correction. Delayed feedback can, under appropriate conditions, preserve communicative flow and allow learners to complete ongoing processing before allocating resources to error analysis. The mode of correction is similarly important: reformulation, concise prompts, and clarification cues may guide attention without requiring learners to process extensive evaluative information, whereas highly explicit correction may be more intrusive during demanding tasks. These decisions must be sensitive to task characteristics rather than treated as universally superior strategies, because effective cognitive load management depends on aligning instructional support with current processing demands (Parveen, 2025). Furthermore, contemporary work on cognitive load and neuroscience suggests that learning efficiency is shaped by dynamic interactions among cognitive capacity, context, and instructional adaptation rather than by a single fixed optimal amount of mental effort (Gkintoni et al., 2025; Sortwell et al., 2026).

Affective framing provides the third crucial dimension. Even concise and well-timed correction may generate negative consequences if it communicates judgment, threat, or impatience. Conversely, supportive language can preserve learners' sense of competence while making the informational function of correction clear. Feedback research emphasizes that motivational and emotional responses influence whether learners subsequently engage with feedback or avoid it (Fong & Schallert, 2023). Evidence that teacher correction can influence confidence reinforces the importance of considering interpersonal delivery alongside linguistic accuracy (Putri et al., 2024). In EFL classrooms, supportive affective framing may be particularly relevant because speaking and other communicative activities expose learners' incomplete linguistic knowledge publicly. Feedback that reduces perceived threat may therefore help protect attentional resources from anxiety while simultaneously supporting enjoyment and motivation.

Despite these theoretical connections, several gaps remain. First, research on corrective feedback has predominantly emphasized linguistic outcomes such as accuracy, uptake, or achievement, whereas cognitive load has received comparatively less attention as an outcome of feedback delivery (Tan et al., 2024). Second, studies of affective variables frequently examine anxiety, enjoyment, or motivation separately even though these factors interact with cognition and with one another. Third, the expanding literature on neuroscience-informed education often examines broad teaching models or technologically adaptive systems rather than isolating teacher feedback as a concrete mechanism (Adiguzel et al., 2026; Shiwlani et al., 2024). Finally, research examining feedback engagement suggests that learners' responses encompass cognitive, affective, and behavioral dimensions, yet empirical classroom studies that simultaneously evaluate cognitive load and multiple affective outcomes remain limited (Pearson, 2024). An integrated investigation can therefore provide a more process-oriented understanding of whether modifying feedback delivery changes not only what learners learn but also the mental effort and emotional experience accompanying learning.

Addressing this gap is important both theoretically and pedagogically. If feedback influences cognitive load, anxiety, enjoyment, and motivation simultaneously, then its effectiveness cannot be evaluated solely by determining whether errors are corrected. Rather, effective feedback must also be understood in terms of whether learners possess sufficient cognitive resources to process it and whether its delivery maintains emotional conditions conducive to engagement. Such an approach brings cognitive load perspectives into dialogue with Control-Value Theory and educational neuroscience, thereby conceptualizing feedback as an instructional mechanism situated at the intersection of cognition and affect. It also offers a practical route for

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neuroscience-informed pedagogy because teachers can modify feedback timing, correction mode, and affective framing without requiring specialized technologies or major alterations to the curriculum. In this sense, studying brain-based feedback can contribute to a more precise account of how neuroscience-informed principles may be translated into everyday EFL classroom practice while responding to concerns that successful learning requires more than memory management alone (Pekrun, 2024; Surbakti et al., 2024).

Accordingly, the present study aimed to examine the effect of brain-based feedback, compared with traditional corrective feedback, on EFL learners' perceived cognitive load, foreign language anxiety, foreign language enjoyment, and second-language motivation.

2. Methods and Materials

2.1. Research Design

The study employed a quantitative quasi-experimental design with a pretest–posttest control group format. This approach was suitable for examining instructional effects in a natural classroom context, where random assignment at the individual level was not feasible (Creswell & Creswell, 2017; Dörnyei, 2007; Mackey & Gass, 2021). Two intact classes were assigned to experimental and control conditions at the class level. To reduce potential selection bias, the classes were randomly allocated while maintaining their original structure. The experimental group received brain-based feedback, whereas the control group received traditional corrective feedback.

Both groups worked with the same instructional materials and tasks, and were taught by the same instructor under similar classroom conditions, ensuring that feedback type was the primary difference between groups. Data were collected at two points using pretest and posttest measures of cognitive load and affective variables (anxiety, enjoyment, and motivation). This made it possible for examining both within-group changes over time and between-group differences. Although causal claims should be interpreted cautiously due to the quasi-experimental design, the controlled conditions provide a reasonable basis for evaluating the effects of feedback strategies.

2.2. Participants

The participants were 60 adult intermediate EFL learners enrolled in a private language institute in Kerman, Iran. Participants ranged in age from 18 to 32 years and included both male and female learners. They were selected through convenience sampling based on their availability in intact classes, a common approach in classroom-based research where random selection is constrained by institutional conditions (Creswell & Creswell, 2017; Etikan et al., 2016). The learners were assigned to two groups of equal size (n = 30): an experimental group and a control group. All participants had prior experience in formal English language instruction and were attending communicative courses at the intermediate level at the time of the study. The two classes followed the same institutional syllabus and met under comparable instructional schedules, which helped reduce variability related to prior learning conditions.

To ensure group comparability in language proficiency, all participants completed the Oxford Placement Test (OPT) prior to the intervention. The results confirmed that learners were at the intermediate level corresponding to approximately B1 level based on CEFR alignment, and an independent-samples t-test indicated no statistically significant difference between the two groups at the pretest stage ($p > .05$). Establishing group equivalence through placement testing is a common procedure in SLA research (Dörnyei, 2007). The reliability of the placement test has been supported through large-scale piloting, and its validity has been established through alignment with the Common European Framework of Reference (CEFR) (Geranpayeh, 2003; Allan, 2004; Council of Europe, 2001). Based on these considerations, the two groups were considered sufficiently homogeneous for the purposes of the study. All participants provided informed consent prior to participation.

Table 1 presents the demographic characteristics of the participants. As shown, the two groups were comparable in terms of age, gender distribution, educational background, and prior English learning experience.

Table 1

Demographic Characteristics of Participants

Variable	Experimental Group (N = 30)	Control Group (N = 30)	Total (N = 60)
Gender			

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Male	14 (46.7%)	13 (43.3%)	27 (45.0%)
Female	16 (53.3%)	17 (56.7%)	33 (55.0%)
Age (years)			
Range	19–32	18–31	18–32
Mean (SD)	24.8 (3.6)	25.1 (3.9)	24.9 (3.7)
Educational Background			
High School Diploma	9 (30.0%)	10 (33.3%)	19 (31.7%)
Bachelor's Degree	17 (56.7%)	16 (53.3%)	33 (55.0%)
Master's Degree	4 (13.3%)	4 (13.3%)	8 (13.3%)
English Learning Experience			
Years of Study (Mean ± SD)	5.2 (1.4)	5.4 (1.6)	5.3 (1.5)
Placement Test (OQPT)			
Mean Score (SD)	42.6 (4.8)	43.1 (5.1)	42.9 (4.9)

2.3. Instruments

2.3.1. Oxford Placement Test

To determine participants' language proficiency at the outset of the study, OPT was administered. The test comprises three sections of vocabulary, grammatical structures, and reading comprehension consisting of 40 vocabulary items, 40 grammar items, and 20 reading comprehension items. This test has been widely used in language research, with its reliability supported through large-scale piloting and its validity established through alignment with the Common European Framework of Reference (CEFR) (Geranpayeh, 2003; Allan, 2004; Council of Europe, 2001). The internal consistency of the test was estimated using Cronbach's alpha, yielding a coefficient of α = .84, indicating acceptable reliability. To further support content validity, the test was reviewed by two experienced EFL instructors familiar with standardized language assessment.

2.3.2. Cognitive Load Measure

Learners' cognitive load was measured using the Paas Mental Effort Rating Scale (1992), a single-item 9-point Likert-type scale ranging from 1 (very, very low mental effort) to 9 (very, very high mental effort). Participants rated the amount of mental effort they invested during task performance. This measure has been widely used in cognitive load research and is considered sensitive to variations in instructional conditions (Leppink et al., 2013; Paas, 1992; Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Although a single-item scale does not capture the full multidimensional nature of cognitive load, it is well suited to classroom-based studies where repeated and immediate measurement is required.

2.3.3. Foreign Language Anxiety Scale

Learners' anxiety was measured using the Short-Form Foreign Language Classroom Anxiety Scale (S-FLCAS), an 8-item instrument adapted from Horwitz et al. (1986). Responses were collected on a Likert scale, with higher scores indicating greater levels of anxiety. The short-form version has shown strong psychometric properties in recent research (Botes et al., 2022). In the present study, the scale demonstrated satisfactory internal consistency (Cronbach's α = .84).

2.3.4. Foreign Language Enjoyment Scale

Learners' enjoyment was measured using a short-form version of the Foreign Language Enjoyment Scale developed by Botes et al. (2021), based on the original scale by Dewaele and MacIntyre (2014). The instrument consists of nine items designed to capture learners' positive emotional experience during classroom interaction. Responses were recorded on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating greater enjoyment. Previous research has reported satisfactory reliability and construct validity for this short-form version, with strong internal consistency across its subcomponents, including teacher appreciation, personal enjoyment, and social enjoyment (Botes et al., 2021). In the present study, the scale demonstrated good internal consistency (Cronbach's α = .87).

2.3.5. L2 Motivational Self System Questionnaire

Learners' motivation was captured through a questionnaire based on the L2 Motivational Self System (Dörnyei, 2009), with items adapted from Taguchi, Magid, and Papi (2009). The instrument was developed and validated across three contexts (Japan, China, and Iran) and

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has been widely used in L2 motivation research. Its construct validity was established through structural equation modeling, and previous studies have reported acceptable internal consistency for its core components in the Iranian context. Items from the Iranian version were used, with minor adjustments to ensure contextual relevance. The questionnaire consisted of two sections: the first measured Ideal L2 Self and Ought-to L2 Self (items 1–13), and the second assessed L2 Learning Experience (items 14–19). Responses were recorded on a 6-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree), with higher scores indicating stronger motivational orientation. Scores were calculated by averaging the item responses. The questionnaire showed acceptable internal consistency in this study (Cronbach's α = .79).

The internal consistency of the questionnaire instruments was assessed using Cronbach's alpha. The results are summarized in Table 2.

Table 2

Reliability of the Study Instruments

Instrument	Items	Cronbach's α
OPT	100	.84
Cognitive Load	1	—
Anxiety (S-FLCAS)	8	.84
Enjoyment (FLE)	9	.87
Motivation (L2MSS)	19	.79

2.4. Procedure

Data collection was carried out over an eight-week period in a natural classroom setting. Prior to the study, permission was obtained from the language institute, and participants were informed about the purpose of the research. Participation was voluntary, and confidentiality was maintained throughout the process. As no formal institutional review board was available, ethical procedures followed the institute's approval process alongside established guidelines for educational research (British Educational Research Association, 2018). At the initial stage, all participants completed OPT to confirm their proficiency level and ensure group comparability. Based on the results, all learners were identified as intermediate-level, and two intact classes were assigned to the experimental and control groups.

Pretest data were then collected. Participants in both groups completed measures of cognitive load and affective variables, including anxiety, enjoyment, and motivation. Cognitive load was assessed immediately after task performance using the mental effort rating scale, allowing learners to report their perceived level of mental effort. These measures served as baseline data for subsequent comparisons. The instructional intervention was implemented over eight consecutive weeks, with two 90-minute sessions per week (16 sessions in total). Both groups followed the same instructional content and completed comparable communicative tasks. Feedback was provided orally during classroom interaction in both groups. The difference between conditions was therefore limited to how feedback was delivered, particularly in terms of timing, wording, and interactional style.

In both groups, learners received continuous teacher feedback as part of normal classroom interaction. However, the nature of this feedback differed systematically between conditions. In the experimental group, brain-based feedback was implemented, defined in this study as feedback practices intended to reduce unnecessary cognitive load, avoid disruptive timing, and maintain a supportive interactional tone. In practice, the teacher avoided interrupting learners during fluency-oriented tasks unless communication broke down. Feedback was typically delayed until the end of the activity and delivered through reformulation, brief guiding prompts, or clarification cues. This approach aimed to preserve task flow while still directing attention to selected language issues. In contrast, the control group received traditional corrective feedback, characterized by more immediate intervention during task performance. Errors were addressed through explicit correction, direct indication of incorrect forms, or immediate reformulation. Unlike the experimental condition, feedback was not systematically delayed and did not follow a supportive or load-sensitive interactional pattern.

To maintain consistency in the experimental condition, the feedback procedures were guided by a structured protocol specifying timing and delivery principles. The instructor was briefed prior to the intervention and reviewed

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the feedback checklist after each session to ensure consistent implementation. Throughout the intervention, learners engaged in regular communicative activities. Cognitive load ratings were collected after selected tasks to capture learners' perceived mental effort, and these ratings were averaged to provide a more stable estimate across the instructional period. At the end of the intervention, posttest data were collected using the same instruments administered at the pretest stage. All participants completed the cognitive load and affective measures under comparable conditions. The data were then coded and entered into SPSS for analysis.

2.5. Data Analysis

The data were analyzed using SPSS Statistics (Version 26). Prior to the main analyses, the dataset was screened for accuracy, missing values, and outliers. Descriptive statistics, including means and standard deviations, were calculated to provide an initial overview of the data. To determine the suitability of parametric analyses, key statistical assumptions were examined. Normality was assessed using Shapiro–Wilk tests alongside visual inspection of histograms and Q–Q plots, and homogeneity of variances was evaluated using Levene's test. As the within-subject factor (time) included only two levels (pretest and posttest), the assumption of sphericity was not applicable. These procedures follow standard practice in parametric statistical analysis (Field, 2018; Tabachnick & Fidell, 2019).

To address the research questions, mixed-design analyses of variance (mixed ANOVA) were conducted for each dependent variable, including cognitive load and the affective measures (anxiety, enjoyment, and motivation). In this analysis, time (pretest vs. posttest) served as the within-subject factor, and group (experimental vs. control) as the between-subject factor. The interaction between time and group was of primary interest, as it reflects the effect of the intervention. Where significant interaction effects were identified, follow-up pairwise comparisons with Bonferroni adjustment were performed to examine the direction of differences. Statistical significance was set at $p < .05$. Effect sizes were reported using partial eta squared (η^2) and interpreted according to conventional benchmarks, where .01 indicates a small effect, .06 a medium effect, and .14 a large effect (Cohen, 1988). It should be noted that the internal consistency of the questionnaire instruments was evaluated using Cronbach's alpha coefficients based on the data obtained from the present sample.

3. Findings and Results

Table 3 summarizes the descriptive statistics. A comparison of pretest and posttest means showed changes in perceived cognitive load and affective variables across the study period.

Table 3

Descriptive Statistics for Cognitive Load and Affective Variables by Time

Variable	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Cognitive Load	5.84	0.91	5.01	1.39
Anxiety	3.64	0.40	3.22	0.57
Enjoyment	3.09	0.42	3.62	0.42
Motivation	3.35	0.40	3.74	0.64

Prior to the main analyses, the data were examined for the assumptions required for mixed-design ANOVA. As shown in Table 4, the Shapiro–Wilk results, together with visual inspection of Q–Q plots, indicated that the distributions were generally acceptable. One posttest anxiety value in the control group showed a deviation from normality; however, given the balanced group sizes and the absence of extreme outliers, the data were considered suitable for parametric analysis. Levene's tests indicated that the assumption of homogeneity of variance was met across variables ($p > .05$), and Box's M tests supported equality of covariance matrices ($p > .05$). Since the within-subject factor included only two levels, the assumption of sphericity was not applicable. Overall, the data met the necessary conditions for mixed-design ANOVA.

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Table 4

Summary of Assumption Tests for All Variables

Variable	Group	Shapiro–Wilk (Pre)	Shapiro–Wilk (Post)	Levene's Test (Pre/Post)	Box's M (p)	Interpretation
Cognitive Load	Control	.665	.355	.635 / .435	.866	Assumptions met
	Experimental	.938	.144			
Anxiety	Control	.251	.005	.317 / .701	.949	Minor deviation
	Experimental	.259	.664			
Enjoyment	Control	.683	.776	.235 / .297	.281	Assumptions met
	Experimental	1.000	.813			
Motivation	Control	.446	.431	.749 / .254	.869	Assumptions met
	Experimental	.469	.864			

To address the first research question, a mixed-design ANOVA was conducted with time (pretest vs. posttest) as the within-subject factor and group (control vs. experimental) as the between-subject factor. As shown in Table 5, the two groups had similar perceived cognitive load scores at the pretest stage (Control: $M = 5.81$, $SD = 0.90$; Experimental: $M = 5.87$, $SD = 0.94$). At the posttest stage, the control group reported a slightly higher mean score ($M = 6.02$, $SD = 0.99$), whereas the experimental group reported a lower mean score ($M = 3.99$, $SD = 0.92$).

Table 5

Descriptive Statistics for Cognitive Load by Group and Time

Group	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Control	5.81	0.90	6.02	0.99
Experimental	5.87	0.94	3.99	0.92

The ANOVA results are shown in Table 6. The analysis indicated a significant main effect of time, $F(1, 58) = 26.00$, $p < .001$, partial $\eta^2 = .31$, and a significant main effect of group, $F(1, 58) = 30.88$, $p < .001$, partial $\eta^2 = .35$. More importantly, the time × group interaction was significant, $F(1, 58) = 40.40$, $p < .001$, partial $\eta^2 = .41$. This interaction indicates that changes in perceived cognitive load over time differed between the experimental and control groups.

Table 6

Mixed ANOVA Results for Cognitive Load

Source	F	df	p	Partial η^2
Time	26.00	1, 58	< .001	.31
Group	30.88	1, 58	< .001	.35
Time × Group	40.40	1, 58	< .001	.41

As shown in Figure 1, perceived cognitive load decreased in the experimental group from pretest to posttest, while the control group showed a slight increase.

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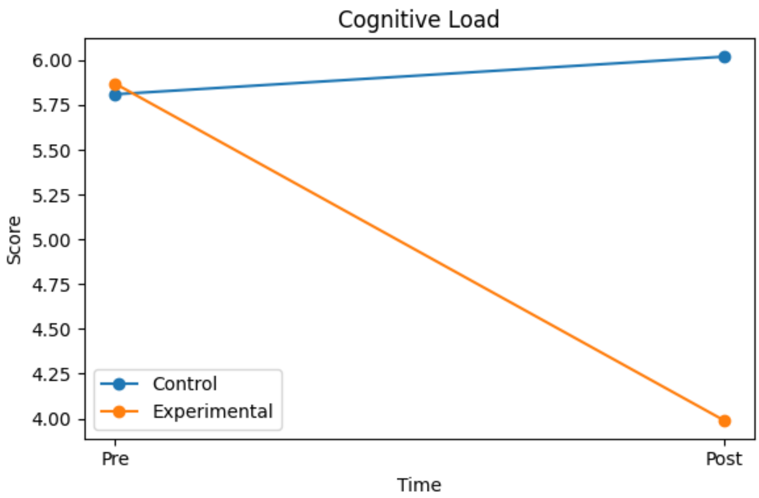
Figure 1

Changes in Cognitive Load from Pretest to Posttest by Group



Effects of Brain-Based Feedback on Affective Factors (RQ2)

Regarding the second research question, three separate mixed-design ANOVAs were conducted for anxiety, enjoyment, and motivation. Descriptive statistics are presented in Table 7. At the pretest stage, the two groups showed relatively similar mean scores across the affective variables. At the posttest stage, anxiety decreased in the experimental group (M = 2.82, SD = 0.42) but slightly increased in the control group (M = 3.62, SD = 0.40). Enjoyment increased in both groups, although the increase was larger in the experimental group (M = 3.92, SD = 0.27) than in the control group (M = 3.31, SD = 0.31). Motivation also increased in the experimental group (M = 4.20, SD = 0.41), whereas the control group showed a slight decrease (M = 3.28, SD = 0.48).

Table 7

Descriptive Statistics for Affective Variables by Group and Time

Variable	Group	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Anxiety	Control	3.56	0.41	3.62	0.40
Anxiety	Experimental	3.71	0.38	2.82	0.42
Enjoyment	Control	3.04	0.46	3.31	0.31
Enjoyment	Experimental	3.14	0.37	3.92	0.27
Motivation	Control	3.39	0.40	3.28	0.48
Motivation	Experimental	3.31	0.40	4.20	0.41

The mixed-design ANOVA results are presented in Table 8. For anxiety, the analysis revealed a significant main effect of time, $F(1, 58) = 32.04$, $p < .001$, partial $\eta^2 = .36$, and a significant main effect of group, $F(1, 58) = 19.82$, $p < .001$, partial $\eta^2 = .26$. The time × group interaction was also significant, $F(1, 58) = 41.69$, $p < .001$, partial $\eta^2 = .42$, indicating that anxiety changed differently across the two groups. For enjoyment, there was a significant main effect of time, $F(1, 58) = 76.65$, $p < .001$, partial $\eta^2 = .57$, and a significant main effect of group, $F(1, 58) = 24.28$, $p < .001$, partial $\eta^2 = .30$. The interaction effect was significant, $F(1, 58) = 17.88$, $p < .001$, partial $\eta^2 = .24$, and showed that changes in enjoyment differed between the experimental and control groups. For motivation, the results indicated a significant main effect of time, $F(1, 58) = 33.59$, $p < .001$, partial $\eta^2 = .37$, and a significant main effect of group, $F(1, 58) = 24.50$, $p < .001$, partial $\eta^2 = .30$. The time × group interaction was significant, $F(1, 58) = 56.37$, $p < .001$, partial $\eta^2 = .49$. This shows that motivational change was different across the two conditions.

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Table 8

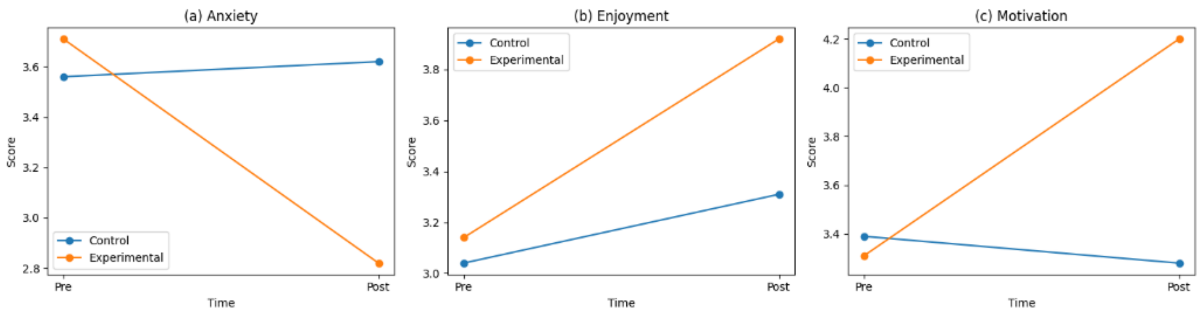
Mixed ANOVA Results for Affective Variables

Variable	Source	F	df	p	Partial η²
Anxiety	Time	32.04	1, 58	< .001	.36
	Group	19.82	1, 58	< .001	.26
	Time × Group	41.69	1, 58	< .001	.42
Enjoyment	Time	76.65	1, 58	< .001	.57
	Group	24.28	1, 58	< .001	.30
	Time × Group	17.88	1, 58	< .001	.24
Motivation	Time	33.59	1, 58	< .001	.37
	Group	24.50	1, 58	< .001	.30
	Time × Group	56.37	1, 58	< .001	.49

As illustrated in Figure 2, anxiety decreased more clearly in the experimental group, while enjoyment and motivation increased more noticeably in the same group compared with the control group.

Figure 2

Changes in (a) Anxiety, (b) Enjoyment, and (c) Motivation from Pretest to Posttest by Group



4. Discussion and Conclusion

The present study examined the effects of brain-based feedback on EFL learners' perceived cognitive load and three affective factors: foreign language anxiety, foreign language enjoyment, and second-language motivation. Overall, the findings demonstrated that brain-based feedback produced substantial advantages over traditional corrective feedback across both cognitive and affective domains. Regarding cognitive load, the significant time × group interaction, $F(1, 58) = 40.40$, $p < .001$, $\eta p^2 = .41$, indicated that changes in perceived mental effort differed markedly between the two conditions. Learners who received brain-based feedback experienced a considerable reduction in cognitive load, whereas those exposed to traditional corrective feedback showed a slight increase. Significant interaction effects were also found for anxiety, $F(1, 58) = 41.69$, $p < .001$, $\eta p^2 = .42$; enjoyment, $F(1, 58) = 17.88$, $p < .001$, $\eta p^2 = .24$; and motivation, $F(1, 58) = 56.37$, $p < .001$, $\eta p^2 = .49$. Thus, brain-based feedback was associated with reduced anxiety and greater increases in enjoyment and motivation compared with traditional feedback. Collectively, these findings suggest that modifying the timing, form, and affective framing of feedback can alter not only how much cognitive effort learners perceive during language learning but also how they emotionally experience classroom participation.

The substantial reduction in perceived cognitive load among learners receiving brain-based feedback can first be explained in terms of cognitive load management. Language learners are routinely required to coordinate lexical retrieval, grammatical encoding, comprehension, communicative intention, and monitoring within limited working-memory capacity. When feedback is delivered immediately during demanding communicative activity, learners may be required to interrupt meaning-focused processing, redirect attention toward an error, interpret corrective information, and subsequently return to the original communicative task. Such repeated shifts can create additional processing demands. In the brain-based condition used in this study, feedback was generally delayed during fluency-oriented activity and was provided through concise reformulations, clarification cues, and guiding prompts. These characteristics likely reduced unnecessary interruptions and allowed learners to preserve attentional continuity. This interpretation accords with evidence showing that instructional design should minimize avoidable cognitive demands and organize information in ways that support efficient processing (Parveen, 2025; Surbakti et al., 2024). It is also compatible with the broader argument that cognitive load should be understood dynamically in relation to the instructional environment rather than as a fixed characteristic of learners or tasks (Wang & Lajoie, 2023).

The present finding also corresponds closely with Feng and Yang's research demonstrating that the structure and regulation of feedback can significantly influence cognitive load during language learning (Feng & Yang, 2025). Different feedback arrangements require learners to allocate cognitive resources differently, meaning that feedback itself becomes part of the cognitive architecture of the learning task. The current results extend this position by showing that cognitively sensitive teacher-provided feedback can reduce perceived load even without complex technological systems. Similarly, evidence-based approaches to cognitive load management emphasize pacing, segmentation, selective presentation, and the avoidance of information that competes unnecessarily for working-memory resources (Parveen, 2025). Delaying correction until a cognitively appropriate moment may have functioned as a form of instructional pacing in the current study, permitting learners to complete one processing sequence before engaging with corrective information.

The findings are also consistent with educational neuroscience perspectives that advocate designing instruction in accordance with interactions among attention, memory, and cognitive processing capacity (Alkhassawneh & Al Sharif, 2025; Pradeep et al., 2024). Neuroscience-informed instruction does not imply that learning should be made cognitively effortless; rather, instructional demands should be arranged so that cognitive resources are directed toward learning-relevant processes instead of being consumed by avoidable interference. Recent research has similarly questioned explanations of learning that focus solely on the quantity of working-memory demands and has emphasized the importance of adaptive, context-sensitive instructional support (Gkintoni et al., 2025; Sortwell et al., 2026). From this perspective, the reduced cognitive load observed in the experimental group may reflect better alignment between the moment at which corrective information was presented and the learners' readiness to process it. Brain-based feedback may therefore have improved cognitive efficiency by regulating when additional linguistic information entered the learners' processing system.

The present results further align with studies showing positive outcomes of brain-based instruction in language education. Amini and colleagues found that brain-based teaching facilitated vocabulary retention and recall among Iranian EFL learners (Amini et al., 2025), while Wilson and colleagues reported beneficial effects of brain-based learning strategies on English writing performance (Wilson et al., 2024). Brain-based activities have also been successfully incorporated into online TESOL instruction, demonstrating the potential adaptability of neuroscience-informed principles across learning environments (Isaee et al., 2024). Although these studies focused primarily on achievement-related outcomes rather than cognitive load, their findings are compatible with the present result because more effectively organized processing may facilitate both immediate task management and longer-term learning. At the same time, the current findings add greater specificity to this literature by isolating feedback rather than treating brain-based instruction as a package of multiple teaching practices.

Nevertheless, the findings should not be interpreted as indicating that all brain-based practices necessarily produce superior learning conditions. Terblanche and colleagues reported improvements associated with technology-enhanced brain-based learning that were not uniformly statistically significant (Terblanche et al., 2026). Such variation highlights the importance of intervention characteristics, learner population, instructional context, and implementation fidelity. The current study suggests that one reason brain-based approaches may differ across investigations is that the effectiveness of broad instructional packages depends on the particular mechanisms embedded within them. The relatively large interaction effect for cognitive load in the present study may therefore be attributable to the direct manipulation of feedback characteristics that were closely connected to processing demands. This interpretation is consistent with recent systematic work emphasizing the need to understand how neuroscience and adaptive technologies can inform feedback more specifically rather than applying neuroscience principles only at a general instructional level (Adiguzel et al., 2026; Shiwlani et al., 2024).

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The second major finding concerned foreign language anxiety. Learners receiving brain-based feedback experienced a pronounced decrease in anxiety, whereas anxiety remained comparatively unfavorable in the traditional-feedback condition. The significant interaction effect with a large effect size suggests that the manner in which corrective information is communicated can meaningfully influence learners' emotional experience. This result can be interpreted through Control-Value Theory, which proposes that achievement emotions arise partly from learners' perceptions of control over activities and outcomes and the value they attribute to those activities (Pekrun, 2024). Supportive, predictable, and manageable feedback may increase perceived control by making errors appear correctable and by clarifying how improvement can occur. Conversely, frequent or abrupt correction may increase uncertainty and strengthen perceptions that classroom performance is evaluative or threatening.

This explanation is particularly relevant in foreign language learning because anxiety can consume attentional resources and inhibit communication. Previous research has demonstrated that foreign language anxiety is negatively implicated in learners' willingness to communicate (Wang et al., 2022). Zhou and colleagues similarly showed that anxiety can moderate the relationship between second-language competence and willingness to communicate, indicating that linguistic ability alone does not guarantee active language use when learners experience substantial apprehension (Zhou et al., 2023). The supportive framing used in the experimental condition may therefore have reduced the perceived interpersonal threat associated with correction. When errors were handled as normal and manageable aspects of learning rather than as immediate failures requiring interruption, learners may have felt more secure in taking communicative risks. Research on teacher correction likewise demonstrates that the way correction is delivered can affect learners' confidence as well as academic performance (Putri et al., 2024), while work on classroom error-correction techniques emphasizes that corrective practices should promote learning without discouraging participation (Dung, 2024).

The significant improvement in foreign language enjoyment provides complementary evidence that brain-based feedback changed the emotional quality of the classroom experience rather than merely decreasing a negative emotion. Enjoyment increased more strongly among learners in the experimental group, indicating that supportive feedback may have helped learners experience communicative activity as more positive and manageable. This finding corresponds with research showing that positive classroom experiences can increase enjoyment and foster constructive attitudes toward English learning (Ramzan et al., 2023). Positive emotions have also been associated with enhanced cognitive engagement, attention, and flexibility during learning (Ullah et al., 2024). Consequently, greater enjoyment may have encouraged learners to engage more openly with classroom tasks and interpret corrective information as part of progress rather than as a threat to competence.

The improvement in enjoyment is also consistent with findings regarding supportive interpersonal processes in language learning. Namaziandost and colleagues showed that peer support can reduce anxiety while simultaneously increasing enjoyment, achievement, and adaptive beliefs (Namaziandost et al., 2024). Although the present intervention concerned teacher feedback rather than peer support, both findings underscore the broader role of psychologically supportive classroom interaction. Brain-based feedback may have created a similar sense of instructional support by preserving communicative flow, avoiding unnecessarily evaluative interruption, and presenting correction through constructive cues. This interpretation also accords with the motivational and emotional perspective on feedback proposed by Fong and Schallert, who argue that the effects of feedback should be understood in terms of how learners emotionally and motivationally engage with future learning rather than solely in terms of immediate correction (Fong & Schallert, 2023).

Motivation demonstrated the strongest interaction effect among the affective variables, with $\eta p^2 = .49$. Learners receiving brain-based feedback became substantially more motivated, whereas the control condition showed a comparatively unfavorable pattern. This finding suggests that feedback aligned with learners' cognitive and emotional needs may strengthen their willingness to continue investing effort in language learning. Motivation is fundamentally goal-directed and depends on learners' expectations that effort can produce meaningful progress (Tolman, 2023). Supportive feedback may have strengthened this expectation by providing learners with manageable information about improvement without making corrective episodes excessively disruptive. When students understand what requires improvement while simultaneously preserving a sense of competence, they may perceive greater progress toward desired language-learning goals.

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The motivational finding can also be understood through contemporary conceptualizations of feedback as a process rather than a one-way transmission of corrective information. Winstone and colleagues argue that effective feedback depends on what learners do with feedback and how it becomes incorporated into subsequent learning processes (Winstone et al., 2022). Pearson similarly demonstrated that engagement with second-language writing feedback contains interconnected affective, behavioral, and cognitive dimensions (Pearson, 2024). The current findings support this multidimensional perspective: feedback that was easier to process cognitively was also associated with stronger motivation and more favorable emotional responses. Kutasi's synthesis of educational feedback further emphasizes that feedback effectiveness depends on learner interpretation and engagement, not merely on the objective quality of information presented (Kutasi, 2023). Thus, brain-based feedback may have strengthened motivation because learners were more able and willing to engage with the information they received.

An important aspect of the findings is the simultaneous occurrence of lower cognitive load, lower anxiety, greater enjoyment, and stronger motivation. These outcomes should not necessarily be regarded as independent effects. Cognition and affect interact dynamically during learning, and changes in emotional states may alter the cognitive resources available for task processing. Meta-analytic evidence indicates meaningful interactions between affective cognition and learning performance (Li, 2023). Anxiety may occupy attentional and working-memory resources through worry and self-monitoring, whereas positive emotions may support more flexible engagement. Working memory is particularly important in second-language production, where learners must maintain and coordinate several elements concurrently (Li et al., 2023). Reducing emotionally driven interference may therefore have contributed indirectly to the reduction in perceived cognitive load observed in the experimental group.

Conversely, reduced cognitive load may itself have supported the affective improvements. When learners experience tasks as cognitively manageable, they may feel greater control and competence, which can reduce anxiety and promote enjoyment and motivation. This reciprocal interpretation is consistent with Control-Value Theory (Pekrun, 2024) and with recent arguments that learning cannot be adequately explained by memory management without considering emotion, motivation, and broader adaptive processes (Sortwell et al., 2026). Brain-based feedback may consequently operate through a reciprocal mechanism: cognitively sensitive feedback decreases avoidable processing demands, while supportive affective framing reduces threat and increases perceived control; these changes then reinforce engagement, enjoyment, and motivation, which in turn may further support efficient cognitive processing.

Taken together, the results make an important contribution to the emerging literature on neuroscience-informed feedback. Artificial intelligence and neuroeducation research increasingly emphasizes personalized and adaptive feedback capable of responding to learners' cognitive characteristics (Adiguzel et al., 2026; Shiwlani et al., 2024). The current study indicates that meaningful adaptation can also occur through ordinary teacher practices. Adjustments in feedback timing, corrective mode, and emotional framing were associated with large changes in cognitive load, anxiety, and motivation and a substantial change in enjoyment. Thus, the practical significance of neuroscience-informed teaching may lie not only in advanced technologies but also in translating principles of attention, limited processing capacity, emotional regulation, and learner readiness into everyday instructional decisions. This finding is consistent with the broader objective of neuroeducation to establish productive connections between knowledge of learning processes and realistic teaching practices (Parayangattu & Goel, 2024; Pradeep et al., 2024). Overall, the findings support conceptualizing feedback as a cognitive–affective instructional mechanism whose effectiveness depends on how well its delivery is aligned with learners' processing demands and emotional conditions.

Several limitations should be considered when interpreting the findings. First, the study involved only 60 intermediate EFL learners from a single private language institute, which limits the extent to which the results can be generalized to learners with different proficiency levels, ages, educational backgrounds, or cultural and institutional contexts. Second, the quasi-experimental design relied on intact classes rather than individual random assignment; consequently, although the groups were comparable before the intervention and instructional conditions were carefully controlled, unmeasured group characteristics may have contributed to the observed differences. Third, cognitive load and affective outcomes were primarily assessed through learners' self-reports. Such measures provide valuable information about perceived mental effort and subjective emotional experience but may be influenced by response

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tendencies and do not directly measure underlying cognitive or physiological processes. Fourth, the intervention lasted eight weeks, and no delayed follow-up assessment was included, making it impossible to determine whether the observed changes in cognitive load, anxiety, enjoyment, and motivation would be maintained over longer periods. Finally, brain-based feedback consisted of several interconnected characteristics, including delayed timing, reformulation and prompting, and supportive affective framing. Although these features constituted the intended intervention, the design does not permit determination of the independent contribution of each component.

Future studies should replicate the investigation with larger and more diverse samples across different EFL and ESL contexts and should include beginner, advanced, adolescent, and university-level learners to determine whether the effectiveness of brain-based feedback varies according to learner characteristics. Randomized controlled designs would strengthen causal inference where institutional conditions permit individual assignment. Longitudinal studies with follow-up assessments several months after instruction would also clarify whether cognitive and affective improvements are sustained. Future research should complement self-report measures with behavioral indicators, task-performance measures, eye-tracking, response-time data, or appropriate physiological indices to obtain a more comprehensive picture of cognitive and emotional processes. Component-based experimental designs could separately manipulate feedback timing, correction type, and affective framing to establish which features account for the strongest effects and whether combinations of components produce additive or interactive benefits. Further studies could also investigate potential moderators such as working-memory capacity, baseline anxiety, language proficiency, personality, feedback preferences, and motivational orientation. Finally, comparative research could examine teacher-delivered brain-based feedback alongside adaptive digital and artificial-intelligence-supported feedback to determine whether similar cognitive–affective benefits can be achieved through different delivery systems.

EFL teachers can use the findings to reconsider feedback as more than an immediate response to learner error. During cognitively demanding or fluency-oriented tasks, teachers should avoid interrupting learners for every noncritical error and instead select feedback moments that allow students to preserve communicative flow. Corrective information should be concise, focused, and proportionate to learners' immediate processing capacity, with reformulations, clarification cues, and brief prompts used when appropriate rather than lengthy explanations during task performance. Feedback should also be framed in language that communicates support, progress, and the normality of error in language development rather than judgment or failure. Teachers may benefit from observing individual differences, because some learners may require more explicit guidance whereas others respond better to delayed or minimally intrusive correction. Language institutes can incorporate these principles into teacher-development programs by training instructors to coordinate feedback timing, content, and interpersonal tone. Simple feedback checklists or reflective teaching logs can further help teachers monitor whether their corrective practices reduce unnecessary interruption while maintaining adequate attention to linguistic development. In this way, brain-based feedback can be implemented as an accessible classroom practice without requiring specialized technology or major changes to the existing language curriculum.

Authors' Contributions

All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the study and participated in the research with informed consent.

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