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Preliminary Report on the Efficacy of the Dichotic Offset Training Program in Auditory Integration Processing Disorder: A single-subject study

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- INT-type APD represent inefficient communication between cerebral hemispheres
- The primary treatment for the INT-type APD is the DOT Program
- INT-type APD treatment with DOT can be conducted via telerehabilitation

Abstract

Background and aims: Auditory integration deficit is one of the subcategories and the most complex form of Auditory Processing Disorder (APD). This is due to its association with specific brain regions such as the corpus callosum and angular gyrus, which are key areas for multisensory integration. This study introduced the first Persian development of the dichotic offset training program. It presents preliminary findings on its efficacy when delivered in-person versus on-line.

Methods: In this single-subject study, two children, aged 13 years, diagnosed with auditory integration deficit, participated The main intervention consisted of 8-14 sessions of Persian-Dichotic Offset Training (DOT), followed by post-treatment follow-up assessments utilizing two methods of treatment delivery: in-person and on-line. Data collected via Persian Buffalo Model Questionnaire-Revised (PBMQ-R), Randomized Dichotic Digits Test (P-RDDT), Persian-Dichotic Offset Test (P-DOM), and Persian-Staggered Spondee Word (SSW) and analyzed employing a single-subject statistical formula.

Results: The results suggest that the treatment effectively reduced integration problems in both in-person and on-line methods, as indicated by competitive left ear stimulus, Type A pattern, and qualitative error IX, the left ear performance, and the questionnaire scores. Both delivery methods proved effective, but online administration showed slightly superior outcomes.

Conclusion: The P-DOT Program, especially in its on-line method, appears to be a promising intervention for children with APD (integration subcategory). By enhancing binaural hearing skills, this approach may considerably improve the brain regions responsible for dichotic processing. These preliminary single-subject findings, pending confirmation through larger-scale studies, particularly Randomized Controlled Trial(RCT) studies, may inform evidence-based clinical protocols for audiologists.

Keywords: Auditory processing disorder, dichotic offset training, Buffalo model auditory training, integration, telerehabilitation

Introduction

Central auditory processing (APD) refers to the use of auditory information via the central auditory nervous system (CANS) and the neurobiological activities that underpin that processing, which could be represented via auditory potential electrophysiologically [1]. It is responsible for behaviours such as sound localization and lateralization, auditory discrimination, auditory pattern recognition, the temporal aspect of audition (Masking, resolution, integration, and ordering), auditory function with competing acoustic signals, and auditory performance in degraded acoustic signals. On the other hand, any disruption in the behaviors mentioned will lead to APD despite normal peripheral hearing [1]. First conceptualized by Katz (1992) as "what we do with what we hear," APD reflects failures in the CANS's ability to analyze and interpret acoustic signals [2, 3]. The disorder demonstrates across the lifespan, with prevalence estimates ranging from 2-7% in pediatric populations (with a 2:1 male-to-female ratio) to 23-76% in older adults, suggesting significant clinical implications for communication challenges and quality of life [4, 5]. These challenges frequently co-occur with academic struggles, particularly in reading and writing, as well as psychosocial consequences, including weakened self-esteem and social withdrawal [2].

The heterogeneous presentation of APD has led to the development of classification systems, with the Buffalo Model emerging as a particularly useful framework for clinical assessment and intervention planning [6]. The Buffalo Model organizes APD into four distinct subcategories based on neuroanatomical and functional contemplations: Decoding deficits (involving impaired phonemic analysis primarily associated with left hemisphere dysfunction), Tolerance-Fading Memory deficits (reflecting auditory attention and working memory impairments), Integration deficits (stemming from interhemispheric transfer dysfunction), and Organization deficits (involving temporal sequencing abnormalities) [6]. Of these, Integration (INT) deficits represent a particularly debilitating subtype characterized by inefficient communication between cerebral hemispheres mediated by the corpus callosum. Patients with INT deficits typically present with profound reading difficulties (dyslexia), delayed processing speeds, and significant challenges in binaural listening tasks [7].

Dichotic listening involves the simultaneous presentation of different stimuli to each ear. There are two main theories on binaural hearing mechanisms: the organic model and the top-down prediction model [8]. Neuroanatomically, dichotic listening performance, which is a key diagnostic marker for INT deficits, reflects the specialized organization of the auditory system. Kimura suggested a model of ear advantage, which demonstrates that while each ear projects bilaterally to auditory cortices, the contralateral pathways (right ear to left hemisphere and vice versa) demonstrate stronger and faster transmission than the ipsilateral pathways [9]. This anatomical arrangement, combined with left hemisphere dominance for language processing in most individuals, creates the well-documented Right Ear Advantage (REA) phenomenon. In INT deficits, impaired interhemispheric transfer via the corpus callosum disrupts this normal pattern of auditory processing, leading to characteristic deficits on dichotic listening measures such as the SSW test and DOM [3, 4]. The primary treatment for the INT deficit is the DOT Program.

There are three main dichotic listening training methods: Dichotic Interaural Intensity Difference (DIID), Dichotic Interaural Time Difference (DITD), and DOT. They target auditory processing deficits like the INT deficit. DIID uses intensity variation between ears to strengthen weaker pathways [10, 11], while DITD enhances interhemispheric transfer through minor temporal delays [12]. DOT, on the other hand, creates controlled asynchrony in stimulus onset, engaging callosal functions vital for binaural integration. While all methods show improvements, the offset paradigm provides a more systematic training experience, allowing the auditory cortex to resolve competing signals more effectively. This specificity in timing mechanisms makes DOT particularly effective for interhemispheric integration deficits. Using simple phonemes in DOT, instead of the more complex linguistic units (such as digits, consonant-vowels, and words) found in DIID and DITD [11], makes DOT less affected by linguistic comprehension and overall cognitive load.

The DOT represents a targeted intervention approach specifically designed to address INT deficits through systematic manipulation of interaural timing differences [13, 14]. It is developed by Katz et al. , the protocol employs eight progressively challenging temporal offsets (ranging from 500 ms to 0ms simultaneous presentation) across 160 training items [15]. The graduated difficulty structure, moving from easy (large offsets) to difficult (no offset), promotes neural plasticity in interhemispheric pathways. Crucially, DOT utilizes non-linguistic stimuli (spondee words composed of alphabetic letters) to minimize language confounds while maintaining necessary cognitive demands for auditory memory and sequencing [1, 13]. Initial efficacy studies demonstrated remarkable improvements, with post-training reductions of ≥50% in dichotic listening errors [15] though these findings await replication in diverse linguistic and other cultural contexts other than English, including Persian-speaking populations.

Furthermore, it is suggested that DOT could effectively replace DIID training when it is unsuitable or its candidacy conditions are unmet [16]; however, it is explored that the Interaural Time Difference (ITD) training could potentially alleviate dichotic deficits. In other words, manipulating the timing of sounds presented to each ear might improve listening skills in children experiencing dichotic issues [17]. Both methods, DIID and DITD, remain unclear in their effectiveness for recovering the INT deficit.

The current study extends this line of investigation by evaluating DOT efficacy through two delivery modalities: traditional in-person administration method and a novel telerehabilitation, in the current study known as on-line, adaptation method. This comparative approach addresses critical gaps in APD rehabilitation research while responding to the growing need for accessible auditory training options, particularly in underserved communities. Telehealth delivery offers potential advantages in terms of cost-effectiveness, convenience, and scalability, though its equivalence to face-to-face administration remains empirically yet needs to be determined for DOT protocols. By systematically comparing outcomes across delivery formats, this study aims to both validate the efficacy of DOT for INT-type APD and establish preliminary evidence for telehealth delivery models in auditory rehabilitation.

Methods

Phase 1: Development of Persian-dichotic offset training

The Persian adaptation of the DOT program involved a systematic multi-stage development process. Persian phonemes were recorded in an acoustically-treated studio using a Neumann transformerless (TLM) microphone with a pop filter and Adobe Audition CC software. Each phoneme was precisely calibrated to a 1-second duration; the disyllabic /ɑ/ was excluded for consistency with the original monosyllabic structure. Recordings featured a male speaker with flat spectral characteristics, underwent loudness normalization, and were saved as 24-bit/48kHz WAV files. Primary face validity was established through expert evaluation (audiologists, speech-language pathologists, linguists) using criteria validated for the DOM test.

Perceptual Synchronization (0 ms Offset) was determined by digitally aligning Left Competing (LC) and Right Competing (RC) channel onsets in Audition CC, followed by empirical validation: 160 items were evaluated by audiologists and normal-hearing individuals to identify points of maximal perceptual overlap, confirmed via a 5-point expert rating scale (1=poor, 5=excellent synchrony). Seven temporal offsets (50–500 ms) were then generated relative to the 0-ms point, applied by delaying RC relative to LC. Unlike the DOM test, P-DOT used a fixed presentation order (largest to smallest offset), with odd/even items assigned to right/left ears, respectively.

A standardized instruction protocol (task explanation, recall procedure, examples) and two practice items were prepended to the 160-item main file (20 items/offset).

Secondary face validity was assessed by 16 experts evaluating the complete program. Clinical validation involved administering P-DOT at 60 dB SL to 5 norm-hearing and 5 APD individuals, with feedback collected via questionnaires. The final version was reviewed by the original DOT developer (Prof. Jack Katz).

Phase 2: Efficacy Investigation of Persian-dichotic offset training

In this single-subject study, the participants were two children (13 years), as it is plausible to use two cases in the single-subject study [18], with CAPD confirmed by: Normal peripheral hearing (PTA ≤25 dB HL, 500–8000 Hz) and middle ear function (Type A tympanogram), normal non-verbal IQ (Wechsler), monolingual Persian proficiency, no neurological disorders, significant deficits (≥2 subcategories) on P-BMQ-R[19]) and test battery including: P-SSW, P-DOM [20], randomized dichotic digits test Randomized Dichotic Digits Test (RDDT [21]. Then, an ABA single-subject design was implemented. It encompassed baseline (A1), during which it assessed P-SSW, P-DOM, RDDT, and P-BMQ-R, P-DOT Integration Therapy (B), which involved 8–14 sessions (2x/week; in-person/online) progressing from 500 ms to 0 ms offset criterion. Each treatment session lasted approximately 1.5 hours, with a 10-minute break between assessments. Post-session tests are identical to A1. Finally, the monitoring stage (A2) was accomplished: Repeat of A1 after a 4-week rest. Data collection typically occurred after each rehabilitation session to track improvements and changes in a single-subject study on a session-by-session basis. The presentation of items should continue until the number of errors the child makes exceeds 6. Then the session is stopped, and in the next session, the previous session is reviewed, and a new session begins. During therapy sessions, the child receives only encouragement without corrective feedback. However, the infant's facial expressions are monitored and analyzed to aid in interpreting responses.

The audiologist performed all in-person evaluations and rehabilitation sessions directly with the child, while parents observed without participating. For on-line treatment sessions, parents were permitted to assist only, when necessary, specifically by entering responses into the web application if the child experienced difficulties with writing or slow typing. All in-person assessments and rehabilitation sessions were conducted in a controlled clinical environment with optimized acoustic conditions. The on-line components of the study were administered in a quiet home setting that met predetermined noise-level criteria. The rehabilitation program employs a progressive framework with eight offset times (ranging from 500 ms to 0 ms), where successful completion is determined by the child's ability to progress through all difficulty levels rather than by a fixed number of sessions. If the child does not achieve the target 0 ms offset time within the initial eight sessions, the rehabilitation continues adaptively until this clinical endpoint is reached.

Stimulus presentation and instructions

In the Dichotic Offset rehabilitation program, participants receive prerecorded instructions at the start of the rehabilitation file. They are instructed: "You will hear letters in one or both ears. After a beep, repeat all letters heard, even if unsure (e.g., if ‘Jim / ta / shin / qaf’ is presented, respond: ‘Jim / ta / shin / qaf’)." Training items are provided before the main tasks to familiarize participants with the procedure.

Stimulus order and randomization

The program follows a structured sequence, presenting offsets from easiest to hardest (500, 400, 300, 200, 150, 100, 50, and 0 ms). Each of the eight offsets consists of 20 items (160 total), with 80 items starting in the right ear and 80 in the left. Odd-numbered items are presented to the right ear, while even-numbered items go to the left, in accordance with the original DOT protocol.

Data analysis:

Two statistical analyses were considered: expert/patient feedback analysis through qualitative statistics and evaluation of the P-DOT efficacy, which involved single-subject statistics, including slope direction change, two SD band method, C-statistic for phase trends, and percentage of all non-overlapping data (PAND)

Web-application design: The online rehabilitation platform, built with structured query language (SQL) and hyper text markup language (HTML), offers personalized auditory processing rehabilitation while reducing interference factors like fatigue. Audiologists must register and pay a membership fee to access the system, where they enter patient data to formulate tailored rehabilitation plans based on assessments. The platform has three main sections: assessment, rehabilitation, and questionnaire. Assessments (P-SSW, P-PST, P-DOM, RDDT, and speech in noise) deliver stimuli through calibrated Sennheiser HD280 PRO headphones, allowing patients to pause or replay items once. They have 15 seconds to respond, either verbally or with parental assistance, and their answers are recorded as audio files; optional video recordings can capture qualitative errors. The P-DOT rehabilitation follows a similar format, while the P-BMQ-R questionnaire requires online response selection. All results—including response recordings, accuracy metrics, and questionnaire data—are stored in the specialist's panel for analysis. Audiologists interpret these findings and provide customized rehabilitation plans to patients via the platform and SMS, ensuring ongoing monitoring and adjustments.

Results:

Development and validation of the Persian-dichotic offset training

The initial face validity of the P-DOT program was assessed for recording quality, clarity, patient instruction delivery, and acoustic properties. Perceptual simultaneity overlap was applied, with the perceptual center point (zero offset) determined using Adobe Audition CC by aligning the energy profiles of competing RC and LC stimuli. To achieve this, 160 items with digitally created zero offsets were prepared, and audiologists and individuals with normal hearing identified the point of maximum perceptual overlap. Speech therapists and linguists rated the perceptual simultaneity of LC and RC using a 5-point scale (1: poor synchronization; 5: excellent synchronization). Consensus confirmed zero offset as optimal. Subsequent temporal offsets (50–500 ms) were applied relative to this baseline.

In secondary face validity, 8 audiologists, 4 speech therapists, and 4 linguists evaluated the final DOT version for acoustic quality, articulation, and intelligibility. All offsets achieved 100% approval. The program was then administered via a two-channel audiometer at 60 dB SL(13) to 5 normative and 5 CAPD children (ages 7–12). questionnaire. The 160 items were presented to the right and left ears, starting with a 500 ms offset, followed by offsets of 50, 100, 150, 200, 300, 400, and 0 ms. Normal-hearing children (aged 7–12) scored 100% satisfaction with recording quality and content comprehension, while children with CAPD scored 100% and 97%, respectively.

The final revised file was sent to Jack Katz, the original DOT developer, to ensure the best possible Persian version. The final files were saved in WAV format as 24-bit stereo with a 48,000 Hz sampling rate using Adobe Audition CC.

Demographic and clinical profiles

Demographic characteristics of patients with CAPD are presented in Table 1.

Table 1 indicates that CAPD involvement occurs in the integration subcategory, based on results from the Persian phonemic synthesis (P-PST), P-SSW, and P-DOM tests.

Single-subject Statistical Analysis

Based on previous studies (2), indices sensitive to assessing and monitoring the integration subcategory in SSW and DOM include competitive LC stimulus, Type A pattern, and qualitative error IX. In the RDDT, only the left ear performance is relevant. Thus, this study focuses on these indices.

Staggered spondee word **test results**

Figure 1 illustrates the ascending-descending trend of LC, Type A Pattern, and Quality IX errors in the SSW test for both in-person and on-line cases, comparing performance before and after rehabilitation. The lines represent the best-fit to baseline performance, extended through the treatment phase.

Visual analysis of the in-person case showed baseline ascending-descending points at 25% (LC), 75% (Type A), and 50% (qualitative error IX) for the number of error reductions. Post-treatment, these reductions in errors increased to 72.7%, 81.8%, and 90.9%, respectively. For the on-line case, baseline values were 50% across all indices, rising to 84%, 84.6%, and 76.9% post-treatment. These error reductions indicate treatment effectiveness.

As demonstrated in Figure 2, at least two consecutive points during treatment fell below this range, confirming treatment significance.

Table 2 presents C-statistic values for comparing case performance at baseline, during treatment, and post-treatment.

Both cases showed non-significant baseline performance that became significant post-treatment.

Total PAND analysis for the SSW test revealed treatment effectiveness. For the LC stimulus, PAND values in the pre-treatment, treatment, and post-treatment baselines were 78%, 100%, and 89% for the in-person case, and 71%, 100%, and 100% for the on-line case, respectively. Type A pattern PAND values were 84%, 100%, and 89% for the in-person case, and 71%, 100%, and 100% for the on-line case, respectively. For quality error IX, PAND values were 89%, 100%, and 73% for the in-person case, and 66%, 100%, and 80% for the online case, respectively, confirming robust treatment effectiveness.

Persian-Dichotic Offset Test Results

Similar analyses were conducted for the DOM test (Figures 3 and 4). Table 3 presents C-statistic values for DOM, confirming treatment significance.

Figure 3 illustrates the ascending-descending trend of LC, Type A Pattern, and Quality IX errors in the DOM test for both in-person and on-line cases, comparing performance before and after rehabilitation.

In the in-person sample, visual analysis of LC indicators, type A pattern, and qualitative error IX revealed that 50% of ascending-descending line points were at baseline. Post-treatment, 90.9%, 81.8%, and 90.9% of points were below the line, respectively. In on-line case, baseline figures were 75%, 62.5%, and 37.5%, respectively, with post-treatment figures at 100%, 100%, and 76.9%. Error rates decreased across all indicators, in both in-person and on-line settings, suggesting effective treatment.

Visual analysis of the in-person case showed baseline ascending-descending points at 25% (LC), 75% (Type A), and 50% (qualitative error IX) for the number of error reductions. Post-treatment, these reduction in errors increased to 72.7%, 81.8%, and 90.9%, respectively. For the on-line case, baseline values were 50% across all indices, rising to 84%, 84.6%, and 76.9% post-treatment. These error reductions indicate treatment effectiveness.

All samples showed at least two consecutive data points below two standard deviations during the treatment phase, indicating a significant treatment effect on DOM performance (Figure 4).

The table shows that the treatment significantly improved performance compared to the insignificant baseline.

The percentage of PAND in the DOM test indicated treatment effectiveness. For the LC stimulus, PAND values for pre-treatment baseline, treatment, and post-treatment baseline were 84%, 100%, and 94% (in-person) and 85%, 100%, and 90% (online). For the type A pattern, the values were 84%, 100%, and 84% (in-person) and 85%, 100%, and 90% (online). For qualitative error IX, the values were 68%, 100%, and 89% (in-person) and 76%, 100%, and 80% (online).

Randomized dichotic digits test results

Figure 5 shows the change in error rate for left-ear RDDT responses before and after rehabilitation, depicted via ascending-descending line for the left ear, presented separately for in-person and on-line scenarios.

Table 4 presents C-statistic values for RDDT, confirming treatment significance.

In-person case showed ascending-descending line points improved from 75% at baseline to 90.9% above the line post-treatment. On-line case improved from 50% to 100%. Error reduction indicates effective treatment.

Similar to SSW and DOM, both cases showed significant treatment effects in the RDDT test, as evidenced by at least two consecutive data points exceeding two standard deviations during the treatment phase (Figure 6).

The table shows that the treatment led to a significant change from baseline.

The PAND in the RDDT test indicated treatment effectiveness. In the in-person case, PAND was 84% (baseline before treatment), 100% (baseline before and after treatment), and 94% (treatment and baseline after). In the on-line case, PAND was 76%, 100%, and 95%, respectively.

Persian buffalo model questionnaire-revised results

Similar analyses were conducted for the P-BMQ-R via ascending-descending line graph (Figure 7), the two-standard-deviation range (Figure 8), and Table 5 for presenting C statistic values.

Visual analysis revealed that during baseline, 0% (in-person) and 62.5% (online) of ascending-descending line points were within the baseline phase. Post-treatment, these percentages shifted to 72.7% (in-person) and 92.3% (online) of points falling below the ascending-descending line. These results suggest that the treatment effectively reduced integration problems in both in-person and online settings, as indicated by the questionnaire scores showing a gradual decrease across sessions.

In both cases, the P-BMQ-R performance met the treatment significance condition, as at least two consecutive points during treatment fell below the two-standard-deviation range.

As shown in Table 5, samples exhibited non-significant performance at baseline, but changes became significant after treatment.

In analyzing treatment effectiveness using the P-BMQ-R, the in-person case showed PAND percentages of 78% at baseline before treatment, 100% during treatment, and 78% at subsequent baseline. The online case showed corresponding percentages of 71%, 100%, and 85%, respectively, indicating decisive effectiveness.

All measures (SSW, DOM, RDDT, P-BMQ-R) demonstrated statistically significant treatment effects ($p<0.001$) with consistently high PAND scores (68–100%), validating the efficacy of Persian DOT for improving auditory integration in APD.

Discussion:

This single-subject study aimed to evaluate the efficacy of the P-DOT program in improving central auditory processing abilities within the INT category of APD. The results from two case studies, one in-person and the other on-line, demonstrate promising outcomes that support the potential of P-DOT as an effective intervention for individuals with INT category of APD, particularly those experiencing interhemispheric communication deficits linked to corpus callosum and angular gyrus dysfunction, a core pathology in integration type APD. Below, we contextualize these findings, discuss their implications, and address study limitations.

Effectiveness of the Persian-dichotic offset training program in improving auditory integration

Considering multiple assessments, including the SSW, the DOM, the RDDT, and the P-BMQ-R, both cases exhibited substantial improvements post-intervention. The significant reduction in errors, as evidenced by the visual analyses, C-statistic values, and PAND percentages, indicates that the DOT successfully improved, hence enhanced binaural integration and interhemispheric transfer abilities. These findings are consistent with previous research emphasizing the role of temporal offsets in fostering auditory synchronization and integration [2, 13]. Neuroplastic changes that occur within the central auditory nervous system are likely responsible for supporting the observed improvements in auditory processing capabilities. The P-DOT program plays a significant role in enhancing interaural timing differences, which are essential for accurately locating sounds in a three-dimensional space. By focusing on these timing differences, the program strengthens the neural connections found within key areas of the brain, specifically in the corpus callosum and the angular gyrus. These regions are critically important for effective binaural processing, allowing individuals to better perceive and interpret auditory information from both ears simultaneously [22]. The progressive reduction in errors (e.g., LC stimuli, Type A patterns, and qualitative error IX) indicates enhanced suppression of competing signals and improved temporal sequencing of auditory information, directly addressing the INT deficits that underpin academic struggles like dyslexia and slow processing. The brain's neuroplasticity enables it to remap neural pathways through targeted training, improving auditory processing efficiency. Reducing errors during training is vital as it strengthens accurate auditory processing strategies and fosters better neural representations [23].

The significant reduction in errors observed on the SSW, DOM, and RDDT tests provides strong evidence for the efficacy of the P-DOT protocol in remediating integration deficits. This finding directly supports and extends the pioneering work of Katz et al. (1984), who first established the benefits of DOT in English-speaking populations. Our successful replication of these results in a different linguistic and cultural context strengthens the generalizability of the DOT method and underscores its foundation in training fundamental auditory neural pathways rather than language-specific cues. Furthermore, Weihing et al. (2014) reported the superiority of DIID for speech-in-noise outcomes, our study demonstrated DOT's particular potency for core binaural integration metrics, such as the competitive left ear score [11]. This suggests that the choice of intervention may be goaloriented: DOT appears uniquely suited for targeting the interhemispheric transfer deficits characteristic of INT, which aligns with its proposed mechanism of action via the corpus callosum.

The findings of this study demonstrate that the P-DOT program significantly enhances not only basic dichotic listening skills but also higher-order auditory processing functions related to speech comprehension and auditory scene analysis [24]. These results align with previous research indicating that targeted auditory training can lead to improvements in speech perception and auditory processing in individuals with CAPD [25]. The marked reduction in qualitative error IX in both tests further highlights the program's effectiveness in enhancing auditory perceptual accuracy, a critical factor for academic and communicative success [24]. This is particularly relevant given the established link between auditory processing deficits and challenges in educational and social settings [26]. The improvement in perceptual accuracy indicates that the P-DOT program enhances the neural networks involved in auditory discrimination and attention, leading to better cognitive processing of auditory information [27].

The results of this study demonstrate the significant efficacy of the P-DOT program in remediating integration deficits (INT) in both traditional in-person and novel on-line delivery modalities. Our results directly support and extend the foundational work of Katz et al. (1984), who developed the DOT protocol and reported post-training reductions of ≥50% in dichotic listening errors [13]. The observed progressive reduction in errors across sessions in our study, particularly in the competitive left ear scores on the SSW and DOM tests, provides robust cross-linguistic validation of their original findings, confirming that the neuroplastic principles underpinning DOT are effective beyond English-speaking populations.

A key point of discussion arises from the comparison with other dichotic training methods. As noted in the introduction, while DIID and DITD show benefits [10, 12, 16, 17], their reliance on complex linguistic stimuli like digits and words (11) introduces confounding variables like language load and cognitive capacity. The superior and consistent outcomes achieved with P-DOT in this study can be attributed to its unique design, which utilizes simple phonemes. This aligns with the theoretical advantage proposed by Katz et al. (1984), allowing the training to specifically target the interhemispheric transfer dysfunction of INT deficits via the corpus callosum without being obscured by higher-order linguistic processing demands [13]. This specificity makes P-DOT a more precise tool for the intended neurophysiological target.

Comparison of in-person and on-line training methods

One notable aspect of this study is the comparison between in-person and on-line modalities of delivering the P-DOT intervention. Both cases demonstrated statistically significant improvements, with the on-line case showing slightly more pronounced gains in some measures. This aligns with the growing evidence supporting the efficacy of telehealth in auditory rehabilitation [28], particularly when innovative digital tools and precise calibration techniques are employed. The online modality offers increased accessibility and flexibility, key factors in expanding treatment reach, particularly for populations with limited access to specialized services or underserved populations who are in regions where accessing audiology clinics in person is challenging.

The comparison between in-person and on-line delivery modes of the P-DOT program yields noteworthy insights. While both methods demonstrated efficacy, the online delivery showed comparable, and in some cases, superior outcomes, particularly in tasks involving LC stimuli and Type A patterns. This finding is consistent with emerging evidence supporting the effectiveness of tele-rehabilitation approaches in audiology [29]. The success of on-line treatment delivery method is particularly promising, as it expands access to therapeutic interventions, especially for individuals in distant locations or underserved areas. However, further research is needed to explore whether these results generalize across diverse populations and varying degrees of APD severity.

While the small sample size limits definitive conclusions, these preliminary findings suggest that on-line auditory training via P-DOT can be as effective, if not more so, than traditional in-person methods. Future studies with larger samples are warranted to validate these observations and optimize protocols for tele-rehabilitation.

The observed improvements in interhemispheric communication, as evidenced by the program's impact on corpus callosum and angular gyrus dysfunction, highlight the P-DOT program's potential to address core pathologies associated with INT-type APD. This is supported by neuroimaging studies that have identified these brain regions as critical for auditory integration and speech processing. The program's ability to enhance these functions suggests its utility as a targeted intervention for individuals with specific neuroanatomical deficits contributing to APD [22]. The dichotic offset technique appears to facilitate interhemispheric transfer and neural synchronization, improving the cognitive and perceptual integration of auditory stimuli.

Clinically, the successful adaptation and validation of the P-DOT program fills an important gap in diagnostic and rehabilitative resources for Persian-speaking children with APD. It offers a promising tool for audiologists and speech-language pathologists to tailor interventions more effectively and to incorporate telerehabilitation solutions into routine practice. The results highlight the critical need for early identification and intervention for APD, as neuroplasticity is typically more pronounced in childhood. By utilizing neuroplasticity principles, clinicians can create targeted interventions to enhance auditory processing skills and improve academic and social outcomes for children with APD [30].

Limitations and future directions

While the study shows promise, its small sample size and lack of controls limit the generalizability of its findings. Future larger-scale studies are needed to confirm efficacy, include more diverse and co-morbid populations, and investigate long-term functional outcomes and underlying neural mechanisms.

Conclusion:

This preliminary investigation provides promising evidence supporting the efficacy of the P-DOT program in ameliorating INT deficits in children with APD. The comparable success of on-line and in-person delivery methods of training underscores the potential of telerehabilitation in the auditory rehabilitation field. These findings pave the way for broader implementation and rigorous validation of digital dichotic training protocols, which could significantly enhance accessibility and outcomes in the management of APDs. By mitigating interhemispheric deficits, DOT enhances binaural processing, which may translate to improved academic and social functioning. This study provides a foundation for evidence-based, accessible APD rehabilitation in Persian-speaking communities and highlights telerehabilitation as a transformative tool for clinical audiology practice. However, the findings are preliminary and require confirmation in larger samples.

Ethical Considerations

Data availability statement: The data that support the findings of this study are available on request from the corresponding author.

Compliance with ethical guidelines: The approval of the Ethics Committee of Tehran University of Medical Sciences (TUMS) with the code of ethics IR.TUMS.FNM.REC.1401.163 was obtained.

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Table 1: Demographic characteristics of the participants with central auditory processing disorder

Patient Code	Name	Gender	Education	Ear Dominance	Lesion Site	Involved Subcategories	Assessment Mode
Case 1	A. A.	Female	6th grade	Right	Left Temporal Lobe (Posterior-Middle)/Corpus Callosum & Angular Gyrus	Integration	In-Person
Case 2	M.H.M.	Male	6th grade	Right	Left Temporal Lobe (Posterior-Middle)/Corpus Callosum & Angular Gyrus	Integration	On-line

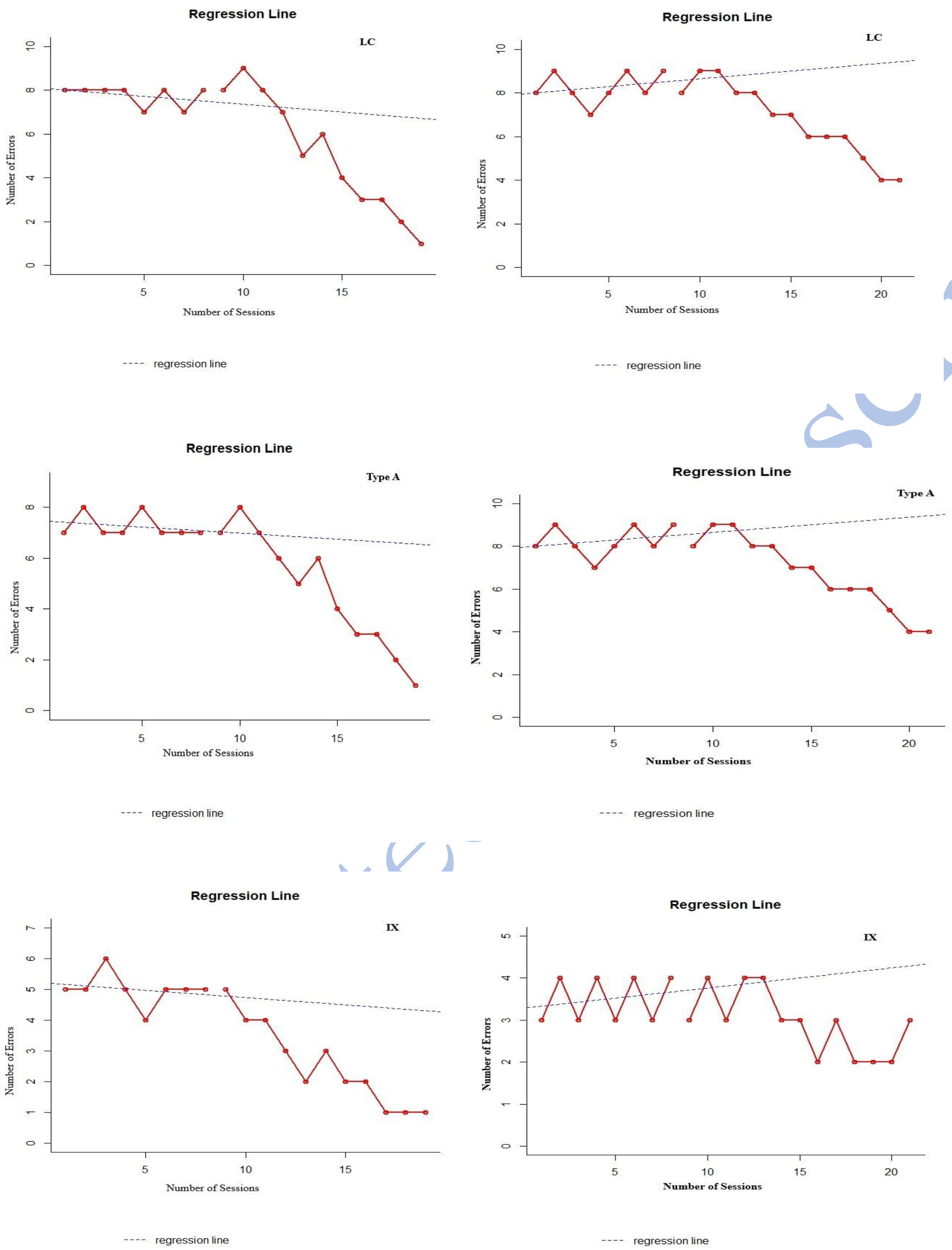

Figure 1: Ascending-descending performance line of LC, Type A, and qualitative error IX in staggered spondee word. Left side: In-Person case; right side: on-line case.

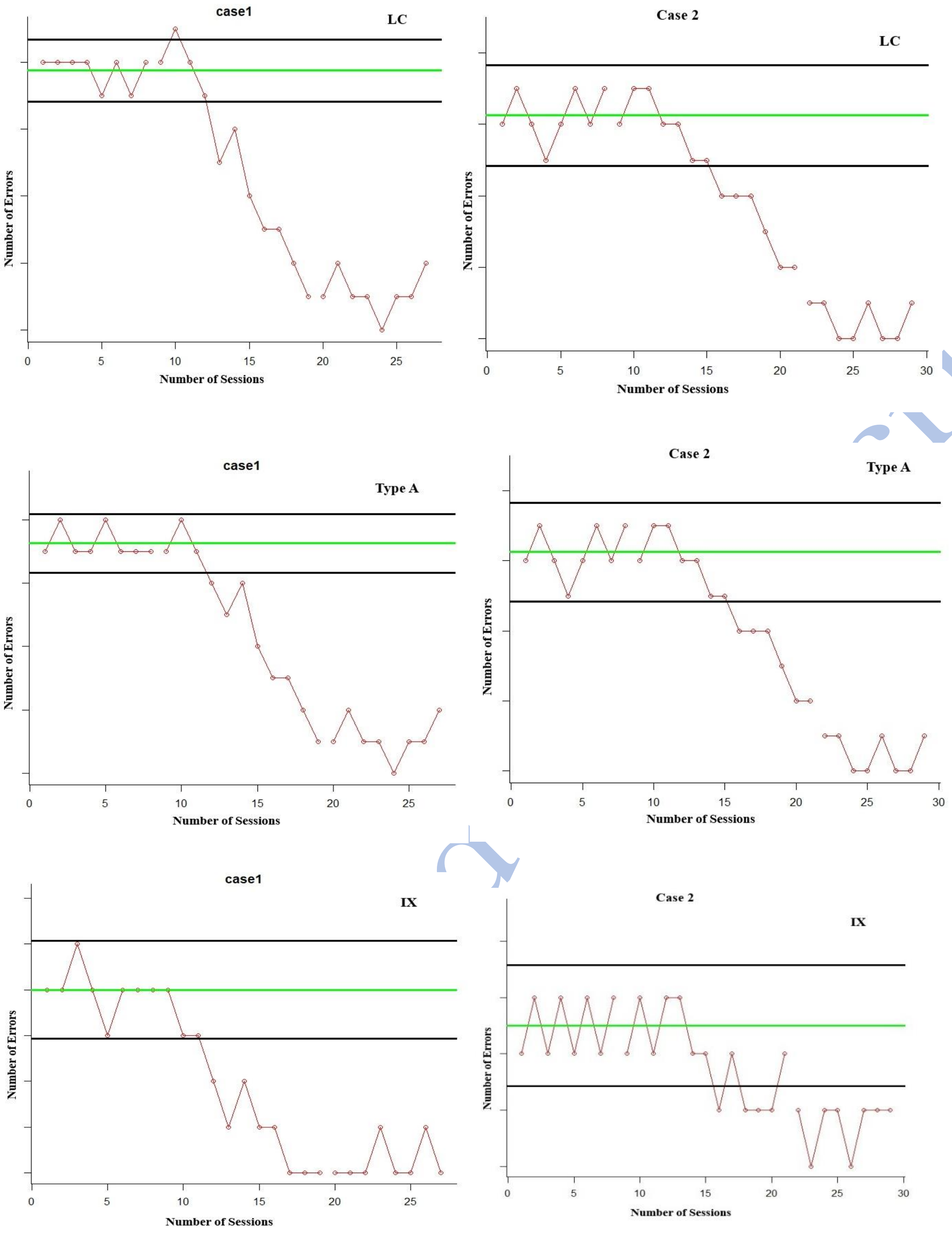

Figure 2: Two standard deviation performance of LC, Type A pattern, and qualitative error IX in staggered spondee word Test. Left side: In-person case; Right side: On-line case.

Table 2: C Statistic values for LC, Type A, and qualitative error IX variables in staggered spondee word test

		In-Person			**Online**		
Phase	**Statistic**	**LC**	**Type A**	**IX**	**LC**	**Type A**	**IX**
Baseline (Pre-treatment)	C	-0.33	-0.33	0	0	0	-0.75
	p-value	0.4	0.40	1	1	1	0.05
Treatment	C	0.91	0.90	0.89	0.86	0.86	0.24
	p-value	0.0001	0.0001	0.0002	0.0001	0.0001	0.28
Baseline (post-treatment)	C	0.93	0.92	0.82	0.95	0.95	0.57
	p-value	0.0001	0.0001	0.0006	0.00002	0.000002	0.01

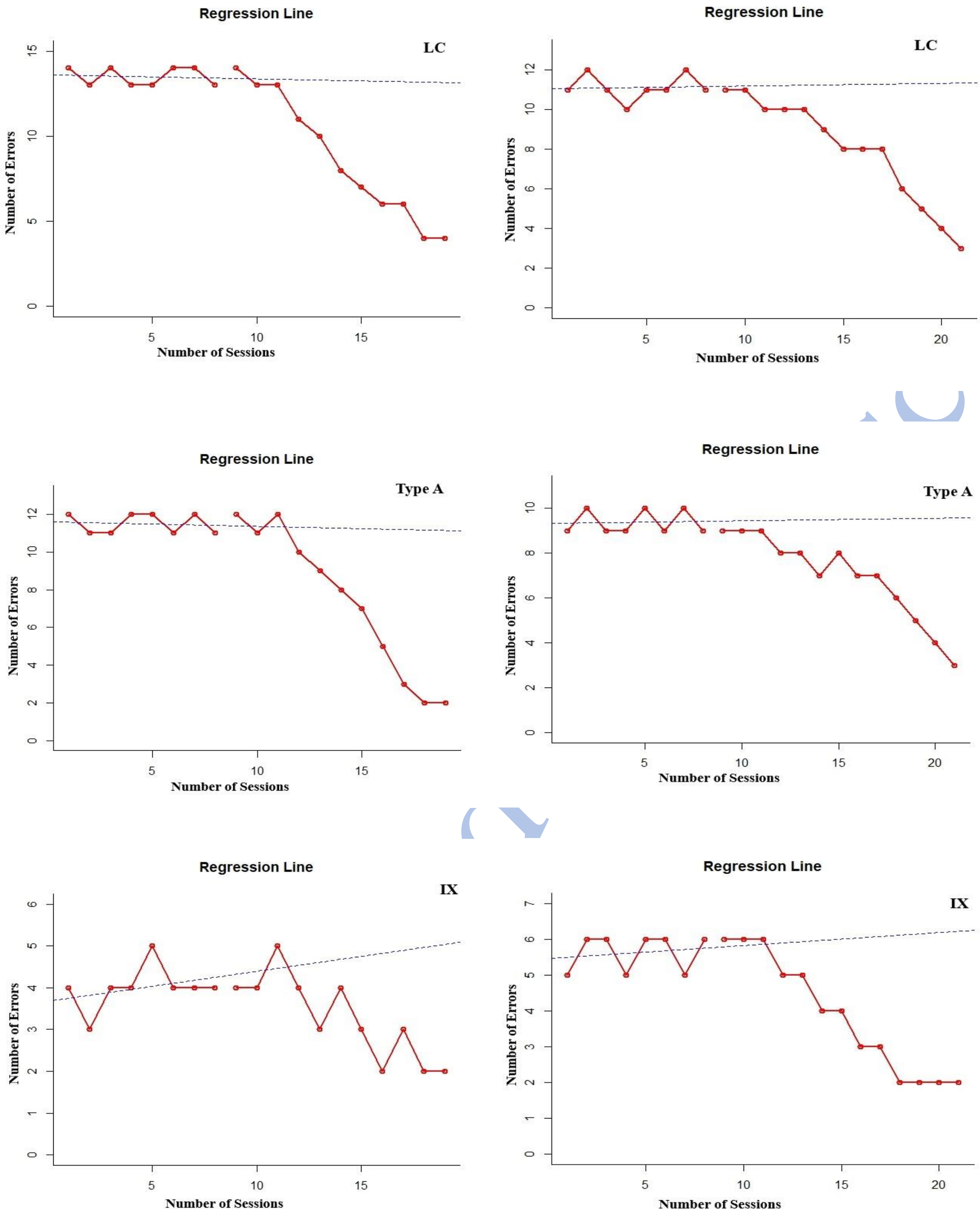

Figure 3: Ascending-descending performance line of LC I, Type A pattern, and quality IX errors in Persian-dichotic offset test. Left: In-Person Case; right: on-line case.

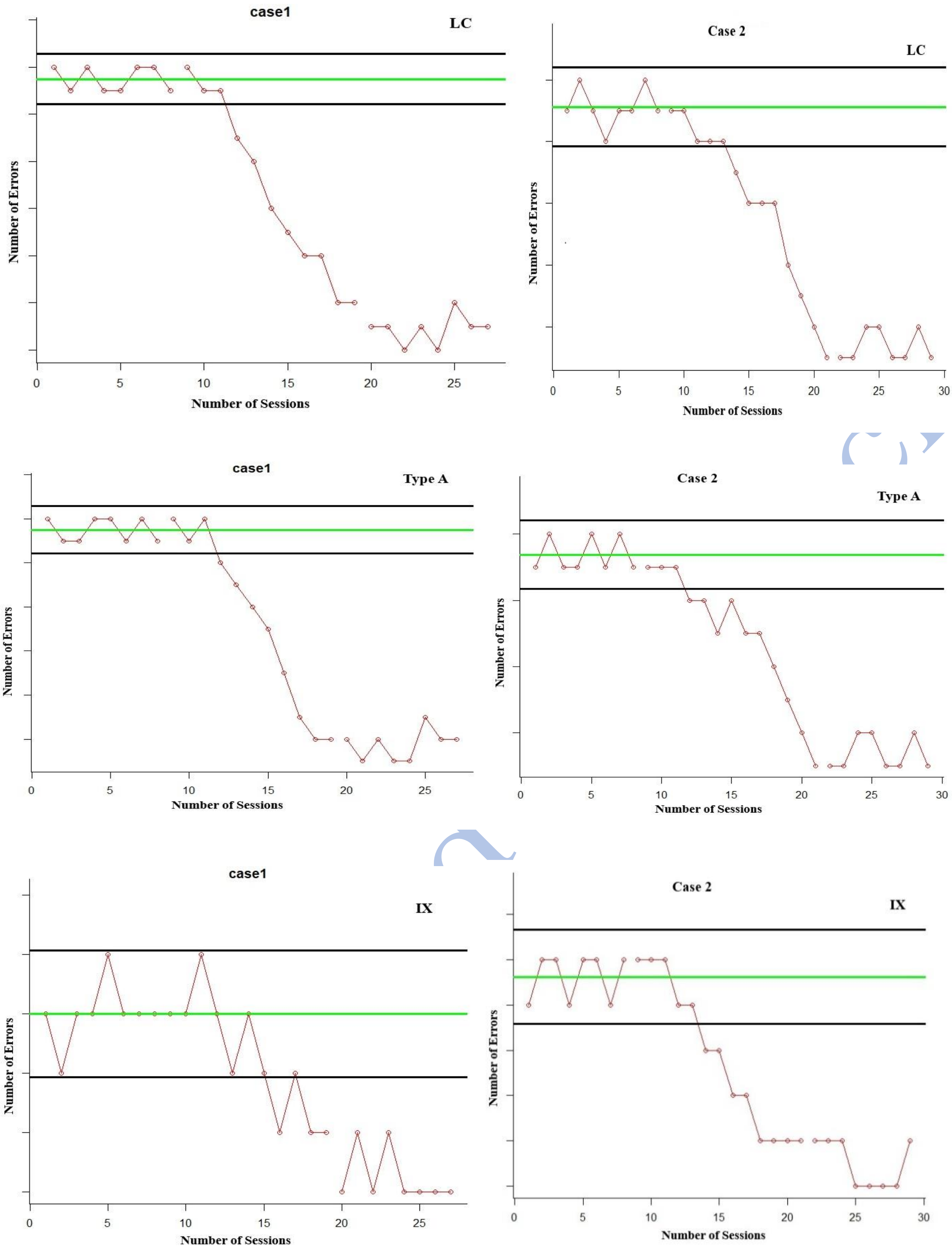

Figure 4: Two standard deviation performance of LC, Type A pattern, and qualitative error IX in the Persian-dichotic offset test. Left side: In-person case; right side: on-line case.

Table3: C Statistic values for LC, Type A, and qualitative error IX variables in Persian-dichotic offset test

		In-person			On-line		
Phase	**Statistic**	**LC**	**Type A**	**IX**	**LC**	**Type A**	**IX**
Baseline (Pre-treatment)	C	-0.25	-0.25	0	-0.04	-0.6	-0.33
	p-value	0.53	0.53	1	0.91	0.13	0.40
Treatment	C	0.95	0.94	0.58	0.94	0.90	0.90
	p-value	<0.00	<0.00	0.01	<0.00	<0.00	<0.00
Baseline (post-treatment)	C	0.95	0.95	0.78	0.96	0.94	0.95
	p-value	<0.00	<0.00	0.001	<0.00	<0.00	<0.00

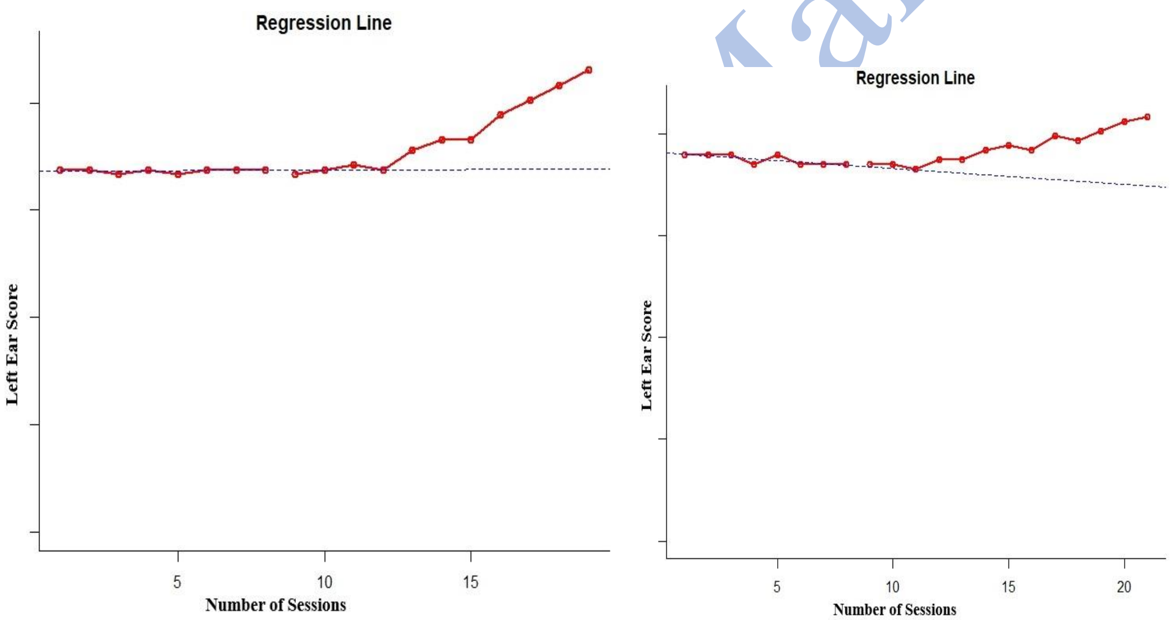

Figure 5: Ascending-descending performance line of the left ear stimulus in randomized dichotic digits test. Left side: In-person case; right side: on-line case.

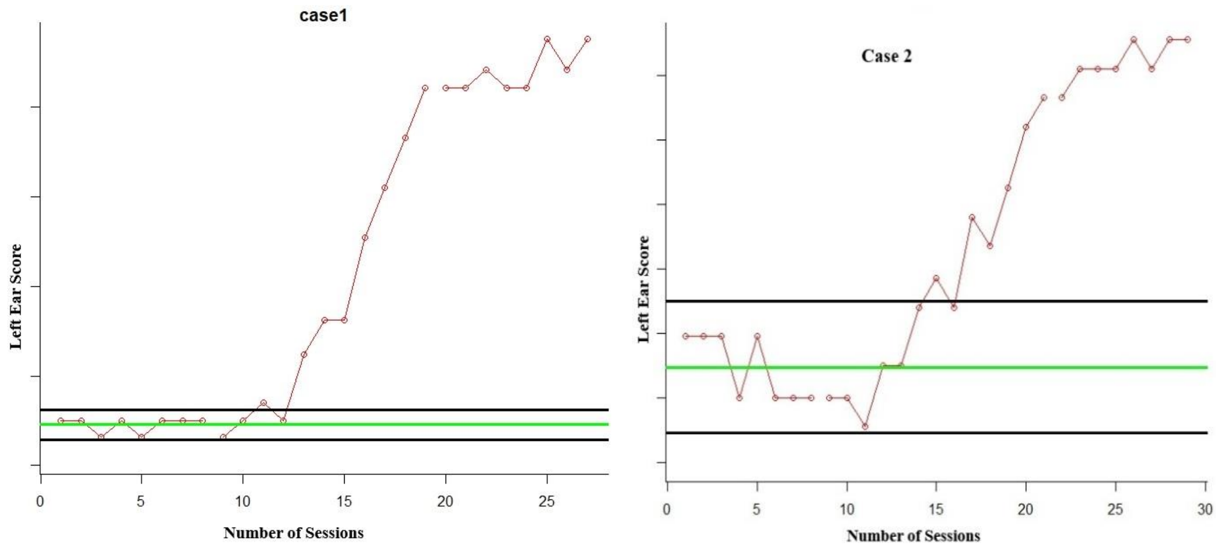

Figure 6: Two Standard deviation performance of the left ear stimulus in randomized dichotic digits test. Left side: In-person case; right side: on-line case.

Table 4: C Statistic values for the left ear variables in randomized dichotic digits test

	Baseline (Pre-treatment)		**Treatment**		**Baseline (Post-treatment)**	
Cases	C	p-value	C	p-value	C	p-value
In-person	-0.33	0.40	0.94	<0.00	0.96	<0.00
On-line	0.25	0.53	0.89	<0.00	0.96	<0.00

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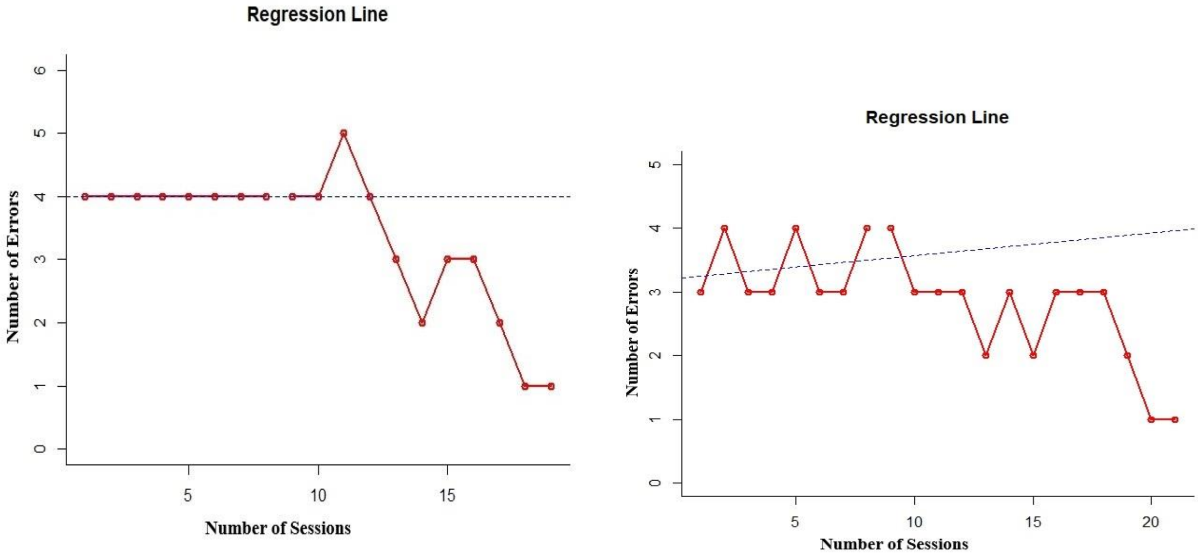

Figure 7: Ascending-descending performance line of the Integration category based on Persian buffalo model questionnaire-revised. Left side: In-person case; Right side: On-line case.

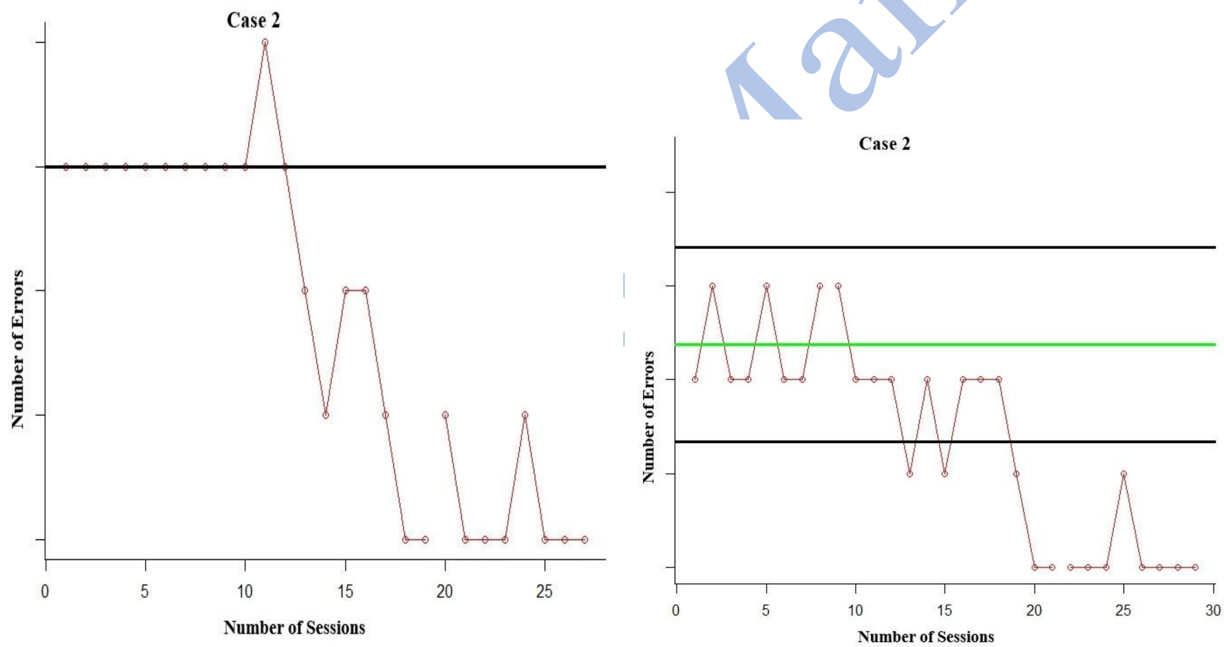

Figure 8: Two standard deviation performance based on P-BMQ-R. Left side: In-person case; Right side: on-line case.

Table 5: C-statistic values for the Integration category performance Index in the Persian buffalo model questionnaire-revised for In-person and on-line cases

	Baseline (Pre-treatment)		**Treatment**		**Baseline (Post-treatment)**	
Cases	**C**	**p-value**	**C**	**p-value**	**C**	**p-value**
In-person	NAN	NAN	0.84	0.0004	0.82	0.0006
On-line	-0.33	0.4	0.58	0.01	0.77	0.0006