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Asynchrony within Sessions in Improvised Active Music Therapy with Individuals with Parkinson's Disease

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Abstract

This study investigates the dispersity of asynchrony measures within Improvised Active Music Therapy (IAMT) sessions for individuals with Parkinson's disease (PD). Three right-handed participants with PD played a simplified electronic drum-set during multiple improvisation sessions (average 22.2 minutes per), accompanied by a music therapist on acoustic guitar. Musical content was converted into Musical Instrument Digital Interface (MIDI) data, segmented into 25 intervals (53.28 seconds per segment), and analyzed for asynchrony dispersity. The downward trend in mean asynchrony in segments 1 - 7 suggests shifts in timing magnitude for participants and music therapists, possibly due to engagement, followed by fluctuations in segments 8 - 25 indicating motor variability or fatigue. The music therapist's asynchrony showed a slight upward trend and significant positive correlations with participants' asynchrony. Despite a small sample size, these findings offer insights into IAMT's therapeutic mechanisms for PD, with implications for motor synchronization. Further research is needed to identify common asynchrony patterns in larger PD cohorts.

Keywords

Improvised Active Music Therapy, Parkinson's Disease, Asynchrony, Musical Instrument Digital Interface, Drum-Set

1. Introduction

Parkinson's disease (PD) is a prevalent neurodegenerative condition characterized by progressive motor and non-motor symptoms that impair quality of life [1]-[3]. Symptoms like bradykinesia, muscle stiffness, and postural instability challenge mobility, impacting daily activities and well-being [4]. As PD progresses, these limitations reduce independence and increase emotional distress, necessitating innovative interventions [5] [6].

Individuals with PD struggle with rhythmic and synchronized activities due to impaired motor and temporal coordination [7]. Bradykinesia and rigidity hinder consistent timing and smooth movements, critical for collaborative tasks [8]. Meta-analytic evidence from recent syntheses indicates that neurologic music therapy, including rhythmic auditory stimulation, yields moderate improvements in gait and motor function for people with Parkinson's disease [9]. Broader music-based interventions have been shown to enhance key aspects of walking performance and functional mobility in PD, supporting the utility of rhythm-coupled therapeutic approaches [10]. Moreover, prior research in Improvised Active Music Therapy (IAMT) showed that PD patients achieved negative synchrony, indicating effective drum-set synchronization during treatment [11]. Building on our prior work establishing IAMT methodology in neurological rehabilitation [12] and its feasibility for PD clients [13], this study extends the analysis to dispersity of asynchrony, specifically the mean of asynchrony across sessions within a segment.

IAMT leverages musical improvisation to enhance coordination and engagement in PD [11] [14]. By involving clients in active music-making, IAMT fosters real-time synchronization with the therapist, supporting personalized therapeutic experiences that may alleviate motor and temporal deficits while promoting social interaction and emotional well-being [11] [12]. This manuscript examines asynchrony in IAMT sessions to illuminate therapeutic dynamics and optimize interventions for PD.

Purpose of the Study

Objective music measures in IAMT sessions are vital for evaluating therapeutic efficacy, identifying musical elements linked to positive outcomes, assessing motor and temporal symptoms, and tailoring interventions. While Musical Instrument Digital Interface (MIDI) data analysis is growing, no prior studies have specifically explored asynchrony dispersity within IAMT sessions. Dispersity of asynchrony, encompassing both the mean temporal misalignment and its variability (measured as standard deviation), reveals patterns of rhythmic interaction stability. This study analyzes existing data to quantify asynchrony dispersity, which here represents the mean asynchrony (averaged across sessions within each segment) in IAMT sessions for PD, elucidating the dynamic interplay between participants and therapists to advance therapeutic knowledge.

2. Ethical Considerations

Ethics approval was obtained from the Health Sciences Research Ethics Board at Western University, Canada (#108090), and informed consent/assent was secured from participants.

3. Methods

This tertiary analysis uses data from a proof-of-principle feasibility study assessing syncopation density as a rhythmic complexity indicator in PD [13]. Employing a single-subject multiple baseline design, the study included three right-handed participants with PD (two males, mean age 70 years, SD = 1), with a Modified Hoehn and Yahr Scale score of 2.66 (SD = 0.47), indicating middle-stage disease (<5 years since diagnosis). Participants exhibited bradykinesia and engaged in home-based IAMT sessions twice weekly, and each session, which averaged to 22.2 minutes due to varying session lengths, involved continuous improvisation under low-to-moderate and moderate-to-high syncopation conditions [12].

3.1. Data Processing

Baseline and treatment sessions were aggregated (61 sessions: P1 = 20, P2 = 17, P3 = 24) and segmented into 25 equal intervals (1 - 25), averaged at 53.28 seconds per segment. Varying session duration, averaged at 22.2 minutes per session, was measured from first to last note, excluding before and after silent periods. Python (version 3.9) processed MIDI data recorded via Logic Pro.

Asynchrony was computed from MIDI data using the following step-by-step procedure:

1) MIDI note-onset events were extracted for participant drum-set strikes (categorized by trigger codes into upper extremities—UE: combined drum pads/cymbals; left foot—LF; right foot—RF) and music therapist guitar notes.

2) The reference stream was the ideal metronome grid at constant tempo, with inter-beat interval in seconds derived from the BPM value provided by Logic Pro software (denoted here as bpms for the interval in seconds; *i.e.*, bpms = 60/BPM).

3) For each note timestamp t1 (in seconds), the nearest beat time on the grid was calculated as intquantize = bpms × round(t1/bpms).

4) Asynchrony for each event was the signed difference t1—intquantize (in seconds), with negative values indicating anticipation (note played before the beat) and positive values indicating delay (note played after the beat).

5) Only events with absolute asynchrony ≤ threshold were retained, where threshold = bpms/8 (equivalent to half the minimum inter-onset interval of bpms/4, providing a symmetric acceptance window around each beat to exclude off-beat or non-metrical events).

6) Retained asynchrony values were averaged within each of the 25 segments, separately by participant, music therapist, limb category (UE, LF, RF), and across all events (total average); segment means were then averaged across sessions to obtain the reported dispersity measures (here representing the mean asynchrony across sessions within a segment). Final asynchrony values were converted to milliseconds by multiplying by 1000 for reporting and interpretation.

The music therapist used in-ear headphones with a metronome to maintain rhythmic consistency, meaning participants responded to the music therapist's guitar accompaniment, which was influenced by the music therapist's asynchrony relative to the metronome [13]. Participants played a simplified electronic drumset, encouraged to use all limbs freely, while the music therapist accompanied on acoustic guitar [11] [15].

3.2. Data Analysis

Visual inspection, standard for single-subject designs, analyzed asynchrony dispersity using Microsoft Excel. Pearson correlations (r) explored synchrony relationships using IBM SPSS Statistics (Version 28.0.1.1), with significance at 0.05 and 0.01 (2-tailed). Effect sizes were interpreted as large ($r > 0.5$), moderate ($r = 0.3 - 0.5$), or small ($r < 0.3$) [16].

Because the 25 segments are sequential within each session, potential temporal autocorrelation could violate the independence assumption of Pearson correlations. The present analysis is therefore treated as exploratory, describing within-session trends rather than providing formal inferential tests. Sessions were aggregated across baseline (low-to-moderate syncopation) and treatment (moderate-to-high syncopation) phases due to the staggered, multiple-baseline design. The introduction of moderate-to-high syncopation occurred at different points for each participant (between sessions 4 and 8 across the sample), reflecting the study's aim to observe changes in rhythmic interaction whenever the music therapist increased rhythmic complexity, rather than at a fixed session number or after a predetermined number of baseline sessions. Because the transitions from low-to-moderate complexity to moderate-to-high complexity were not temporally aligned across participants, condition-specific aggregation by segment was not methodologically feasible. Therefore, all available sessions were pooled and segmented uniformly into 25 intervals (average 53.28 seconds each) to enable consistent within-session trend examination across the full sample.

4. Results

Asynchrony dispersity was analyzed per segment, averaged across sessions, and by extremity. UE data were not graphed due to overlap with average asynchrony trends, reflecting UE dominance in drumming [15]. Pearson correlations examined relationships between music therapists (MT1, MT2, MT3), participants (P1, P2, P3), specific limbs (LF, RF, UE), and total averages. The strong positive correlations between participant and music therapist asynchrony (e.g., Total Avg-MT Total, $r = 0.674$, $p < 0.001$) suggest that participants' timing was influenced by the music therapist's asynchrony, as participants responded to the music therapist's guitar accompaniment, which was shaped by the music therapist's metronome-guided performance.

4.1. Average Asynchrony

P1's average asynchrony (**Figure 1(a)**) showed variability (−9.32 to −16.20 ms), with a slight upward trend across 20 sessions, suggesting modest synchronization improvement. P2's asynchrony (**Figure 1(b)**) exhibited variability (−1.83 to −10.17

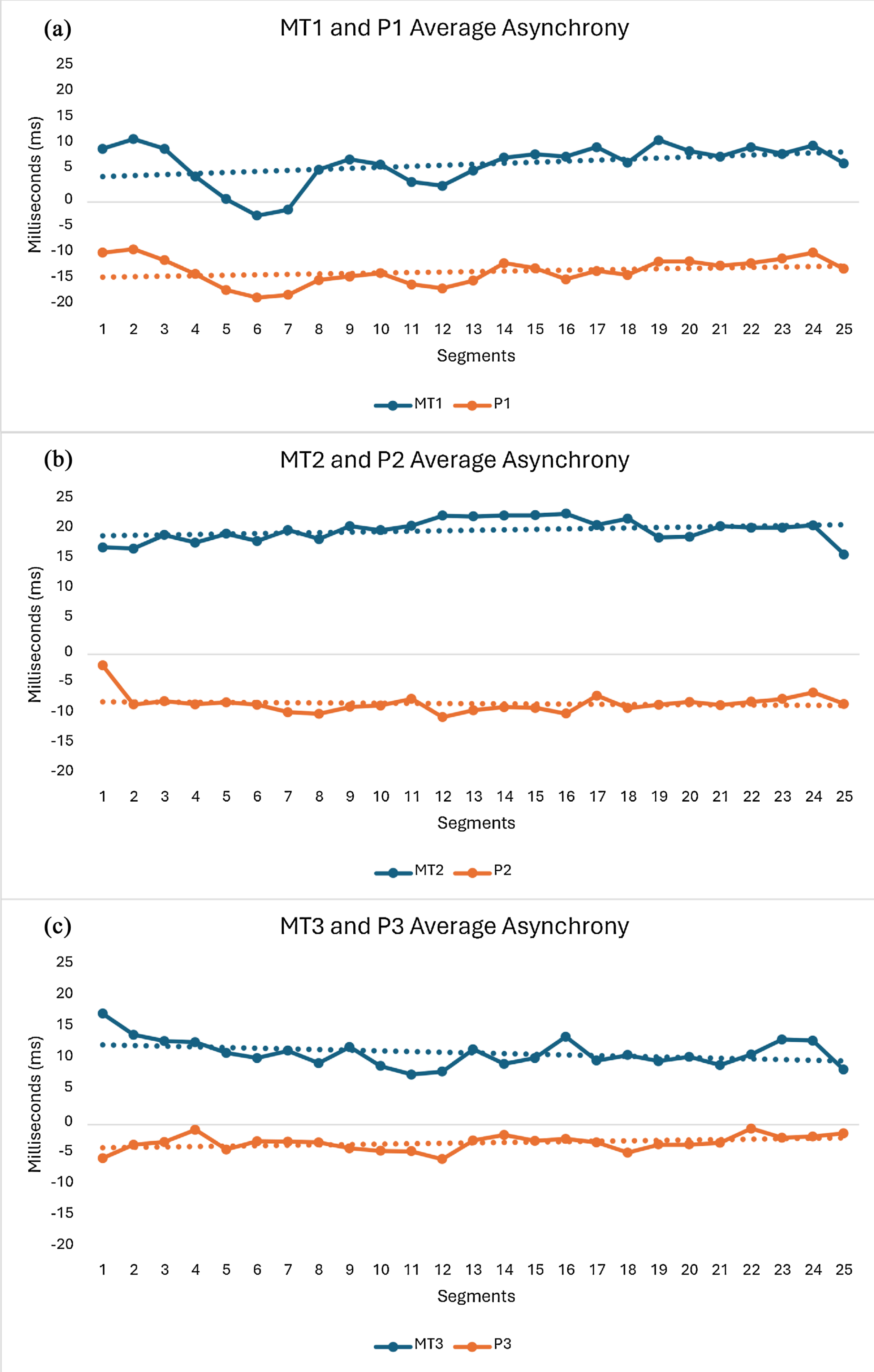

Figure 1. Average asynchrony over time for (a) Participant 1 (P1) and Music Therapist 1 (MT1), (b) Participant 2 (P2) and Music Therapist 2 (MT2), and (c) Participant 3 (P3) and Music Therapist 3 (MT3).

ms), with no clear improvement across 17 sessions, indicating inconsistent performance. P3's asynchrony (Figure 1(c)) trended toward 0 ms across 24 sessions (−5.29 to −0.61 ms), suggesting potential synchronization gains. The average asynchrony across all participants and music therapists (Figure 2(a)) showed a downward trend in segments 1 - 7 (participants: −5.48 to −7.23 ms; music therapists: 14.87 to 12.62 ms), followed by fluctuations in segments 8 - 25 (participants:

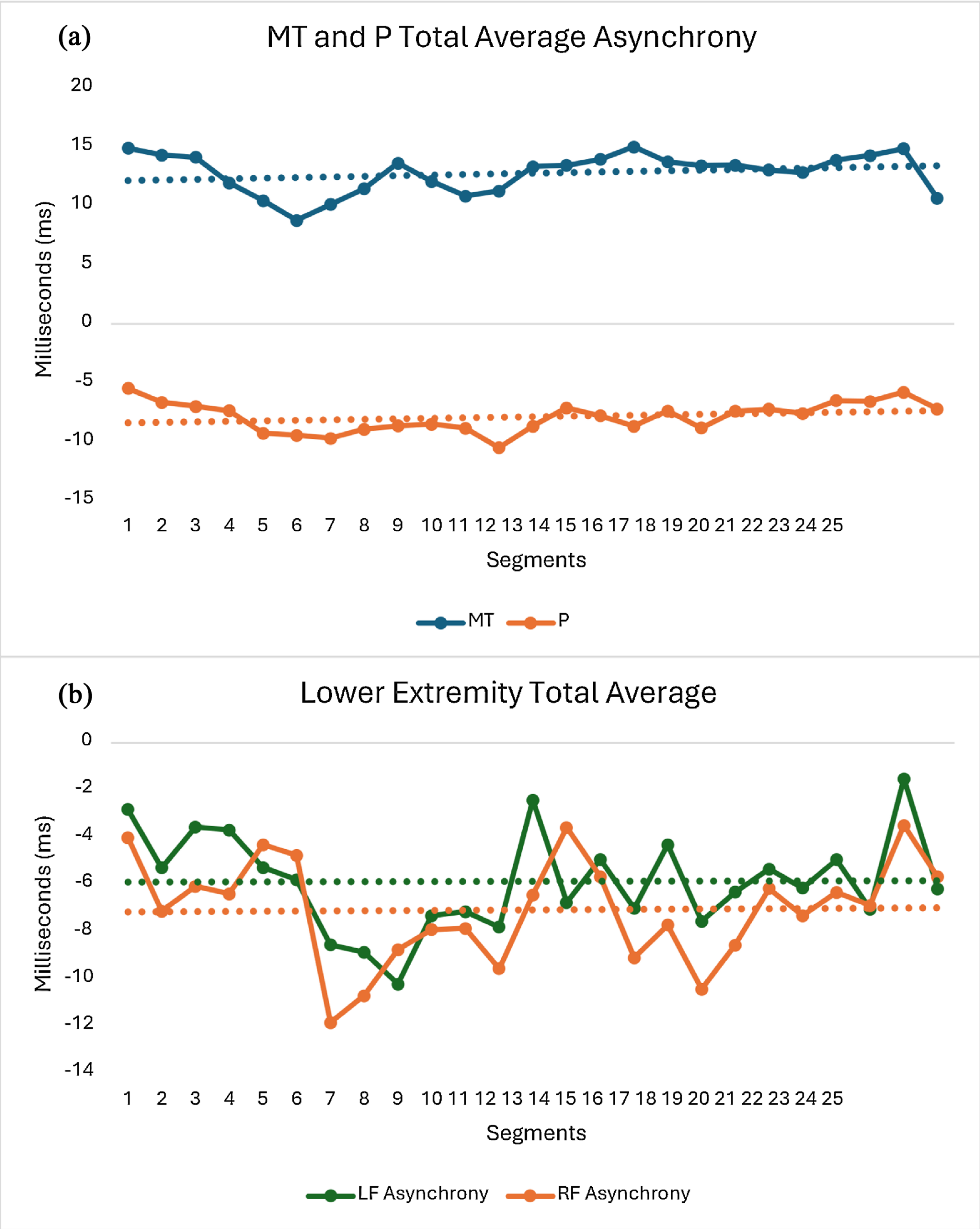

Figure 2. Multi-panel plot showing (a) the average of average asynchrony across all participants and music therapists (total average), with a downward trend in segments 1 - 7 followed by fluctuations in segments 8 - 25, and (b) the average of average asynchrony across all participants' lower extremities (LF and RF), showing variability with no clear trend.

to −5.80 ms; music therapists: to 13.87 ms). The average asynchrony across participants' lower extremities (LF and RF, **Figure 2(a)**) showed variability (LF: −2.82 to −7.04 ms; RF: −4.01 to −6.89 ms) with no clear trend, reflecting inconsistent LE coordination. These trends reflect averages across multiple sessions (P1: 20, P2: 17, P3: 24), which may obscure session-specific patterns. Additionally, because rhythmic complexity phases were introduced at different session points across participants, these averaged segments include a mixture of low-to-moderate and moderate-to-high syncopation conditions.

4.2. Music Therapist Asynchrony

The asynchrony of music therapists (MT1, MT2, MT3) was analyzed across 25 segments (**Figures 1(a)-(c)**). MT1 (with P1) showed positive asynchrony (7.16 to 11.65 ms), with a slight upward trend, possibly adapting to P1's anticipatory timing. MT2 (with P2) maintained stable positive asynchrony (16.13 to 20.84 ms), suggesting consistent rhythmic guidance. MT3 (with P3) exhibited fluctuating positive asynchrony (8.67 to 17.49 ms), reflecting P3's variable synchronization. Music therapists' positive asynchrony contrasts with participants' negative values, highlighting their possible guiding role. As music therapists used a metronome via in-ear headphones, their asynchrony influenced the guitar accompaniment heard by participants, likely contributing to the observed participant asynchrony patterns and correlations.

4.3. Correlation Analysis

Correlations used a sample size of 25, corresponding to the 25 almost-one-minute segments per session (53.28 seconds). P1 showed strong correlations: P1-MT1 (r = 0.900, $p < 0.001$, large effect), UE-MT1 (r = 0.870, $p < 0.001$, large effect), Avg-UE (r = 0.931, $p < 0.001$, large effect, expected due to UE dominance), RF-LF (r = 0.640, $p < 0.001$, large effect), and moderate LF-MT1 (r = 0.451, $p = 0.024$, moderate effect). P2 showed strong Avg-UE (r = 0.981, $p < 0.001$, large effect), moderate LF-RF (r = 0.492, $p = 0.012$, moderate effect), and negative UE-MT2 (r = -0.410, $p = 0.042$, moderate effect). P3 showed strong Avg-UE (r = 0.981, $p < 0.001$, large effect), but no significant MT3 correlations (e.g., Avg-MT3: r = 0.015, $p = 0.943$, small effect). Combined correlations included Total Avg-MT Total (r = 0.674, $p < 0.001$, large effect), UE-MT Total (r = 0.677, $p < 0.001$, large effect), LF-RF (r = 0.692, $p < 0.001$, large effect), LF-Total Avg (r = 0.594, $p = 0.002$, large effect), RF-Total Avg (r = 0.577, $p = 0.003$, large effect), and RF-UE (r = 0.493, $p = 0.012$, moderate effect). Non-significant correlations included MTs' Total Avg-LF (r = 0.354, $p = 0.082$, moderate effect) and MTs' Total Avg-RF (r = 0.169, $p = 0.419$, small effect). These correlations reflect the influence of the music therapists' metronome-guided accompaniment on participants' timing, as participants responded to the music therapists' music rather than the metronome directly.

These correlations reflect the shared coupling pathway in the setup: the music therapist maintained timing via an in-ear metronome, while participants synchronized to the therapist's guitar accompaniment (itself shaped by the therapist's metronome asynchrony). To distinguish whether the therapist primarily adapts to the participant versus the participant following the therapist would require additional evidence such as cross-lagged correlations, directional phase-locking analyses, or experimental designs that manipulate leadership roles.

4.4. Non-Significant Correlations

Non-significant correlations included: MT2-P2 Avg (r = −0.394, $p = 0.051$, moderate effect); MT3-P3 Avg (r = 0.015, $p = 0.943$, small effect); MT1-P1 RF (r = 0.386, $p = 0.056$, moderate effect); MT2-P2 LF (r = 0.132, $p = 0.529$, small effect); MT2-P2 RF (r = −0.068, $p = 0.747$, small effect); MT3-P3 LF (r = 0.056, $p = 0.792$, small effect); MT3-P3 RF (r = −0.133, $p = 0.525$, small effect); P3 RF-LF (r = 0.073, $p = 0.727$, small effect); P3 UE-MT3 (r = 0.071, $p = 0.735$, small effect); MTs Total Avg-LF (r = 0.354, $p = 0.082$, moderate effect); and MTs Total Avg-RF (r = 0.169, $p = 0.419$, small effect). These findings delineate non-robust interrelations.

5. Discussion

Quantitative asynchrony analysis provides insights into therapeutic dynamics in IAMT sessions for individuals with PD. Averaged across multiple sessions (P1: 20, P2: 17, P3: 24), the study revealed variable synchronization patterns. The downward trend in mean asynchrony (**Figure 2(a)**) in segments 1 - 7 suggests shifts in timing magnitude for participants and music therapists, possibly due to engagement, followed by fluctuations in segments 8–25 indicating motor variability or fatigue. Strong positive correlations (e.g., Total Avg-MT Total, r = 0.674, $p < 0.001$) suggest music therapists adapt to participants' anticipatory timing, reflecting a dynamic interplay rather than convergence toward synchronization. The variability in LE average asynchrony (**Figure 2(b)**) reflects inconsistent lower limb coordination across participants. Individual trends (**Figures 1(a)-(c)**) show P1's modest reduction in anticipation, linked to musical skills [13], suggesting potential for targeted interventions; P2's inconsistent timing, indicating motor consistency challenges, possibly due to less musical experience; and P3's trend toward reduced misalignment, suggesting motor learning [17], though averaging obscures session-specific patterns. The music therapists' positive asynchrony (**Figures 1(a)-(c)**) reflects adaptive guidance to participants' anticipatory timing. The upward trend in LE dispersity (**Figures 3(a)-(c)**) indicates increased variability early in sessions, stabilizing later, suggesting adaptation to rhythmic tasks. Participants provided qualitative feedback that enriches the quantitative findings. P1 reported improvements in hand dexterity and orientation, aligning with the modest reduction in anticipation observed (**Figure 1(a)**). P2 expressed enjoyment, describing sessions as fun, and noted that her walking watch recorded 2500 steps post-session, approaching her doctor's daily recommendation, suggesting enhanced engagement and mobility. P3 discussed challenges with independence, as family members urged relocation to a long-term care facility, highlighting

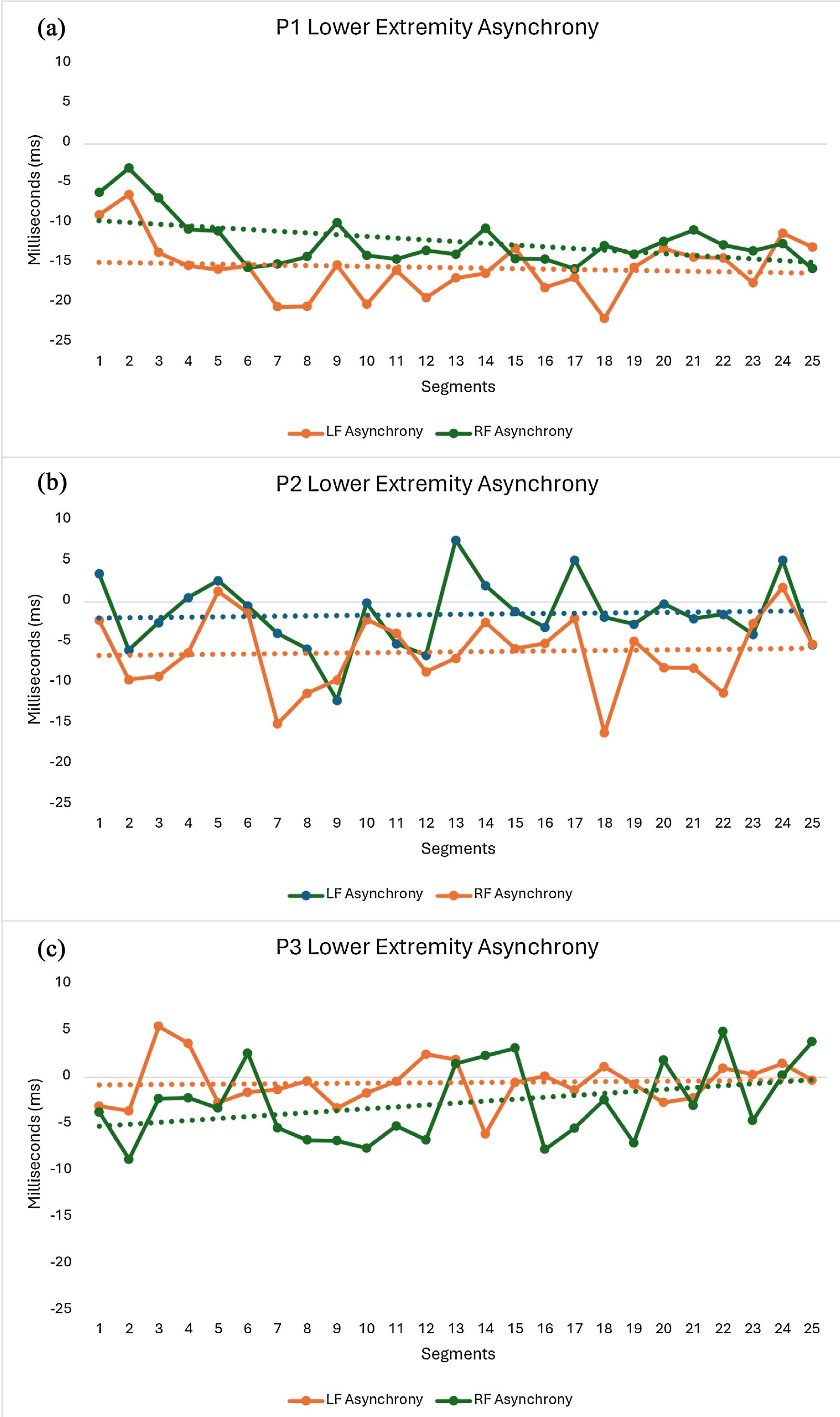

Figure 3. Dispersity for lower extremities (mean standard deviation of LF and RF across participants) for (a) Participant 1 (P1); (b) Participant 2 (P2); and (c) Participant 3 (P3).

emotional and social concerns relevant to PD. These insights suggest IAMT's potential to support both motor and emotional well-being, though the small sample limits generalizability.

5.1. Clinical Applications

IAMT can enhance motor synchronization in PD, particularly for upper extremity tasks [18]. The trend in **Figure 2(a)** suggests structuring sessions to capitalize on early engagement (first 7 minutes), using rhythmic cues like clapping or drumming to stabilize timing, while simplifying patterns later to manage fluctuations due to fatigue or motor challenges. The LE dispersity trend (**Figures 3(a)-(c)**) supports incorporating lower extremity exercises, such as foot-tapping to rhythmic cues, to improve gait and balance, complementing rhythmic auditory stimulation (RAS) to reduce fall risk [19] [20]. Music therapists can monitor asynchrony in real-time by listening for timing inconsistencies in client responses relative to their accompaniment, adjusting tempo or complexity based on observed motor variability or client feedback (e.g., P2's enjoyment, P1's dexterity improvements). For clients with musical experience (e.g., P1), complex rhythms can leverage skills to enhance engagement [13], while simpler, repetitive cues may benefit clients with inconsistent timing (e.g., P2, P3) [21]. Music therapists should collect qualitative feedback through post-session discussions to assess engagement, emotional outcomes (e.g., P3's independence concerns), and motor gains (e.g., P2's step count), tailoring interventions to individual needs. In low-resource settings, music therapists can use basic instruments (e.g., hand drums) or vocal cues to replicate rhythmic guidance without technology, ensuring applicability across diverse clinical contexts. Music therapists can collaborate with physical therapists or neurologists to share asynchrony insights, integrating findings into broader care plans to address motor and emotional needs. Integrating IAMT with physical therapy may enhance neuroplasticity, improving daily function [22]. Clinicians should assess clients' musical background and motor abilities to tailor interventions and monitor dispersity to adjust session pacing.

5.2. Future Directions

Larger studies should explore variability factors (e.g., motor skills, therapist training) and longitudinal designs to assess synchrony development. Qualitative data on participant and therapist experiences could enrich findings with emphasis on reflective practice. Investigating IAMT in diverse PD populations globally could enhance applicability, given the international scope of music therapy. Investigating tempo and rhythm complexity may inform targeted PD interventions.

5.3. Limitations

The small sample (n = 3) limits generalizability. Averaging across sessions may obscure individual trends. Unmeasured factors (e.g., musical experience, fatigue) influence outcomes. Asynchrony focus may overlook emotional benefits. Further research is needed to validate findings. Additionally, the study did not collect data on participants 'length of time since diagnosis, which may have influenced motor variability and synchronization patterns. Another limitation is the lack of specificity in distinguishing upper extremity contributions, as the analysis did not differentiate between individual upper limb movements, reducing the precision of interpretation.

A further limitation is the pooling of baseline (low-to-moderate syncopation) and treatment (moderate-to-high syncopation) sessions due to the staggered multiple-baseline design, which prevented clean separation of conditions for within-session analysis. This pooling may confound the observed within-session trends in asynchrony and timing variability, as rhythmic complexity is a direct driver of timing variability [11] [23]. Future studies should introduce rhythmic complexity at the same time point across participants or systematically vary its order to better separate the effects of complexity from general within-session changes.

6. Conclusion

This study highlights asynchrony dispersity in IAMT for PD, with an early increase in LE dispersity variability and later plateau, offering therapeutic insights. The variable timing trends (**Figure 2(a)** **&** **Figure 2(b)**) and LE dispersity variability (**Figures 3(a)-(c)**) suggest IAMT's potential to enhance motor coordination, particularly for musically skilled participants, but session averaging requires cautious interpretation. Larger studies are needed for clinical application.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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