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Practice with diversified repetition and its influence on bimanual synchronization in pianists

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Abstract: This study investigates the effects of diversified repetition on the synchronization between pianists' hands by comparing performances before and after a structured practice session with variations in rhythm, articulation, dynamics, and tempo. Two pianists, identified as P1 and P2, participated in the study and performed the F major pentatonic scale in three moments: pre-test, practice with diversified repetition and post-test. MIDI data, motion capture and audiovisual recordings were collected. The analysis included three aspects of performance: onset asynchrony (sound synchronization), amplitude of gestural preparation (movement) and speed of note attack (dynamics). Results show distinct effects among participants and between combinations of notes. In some cases, simultaneity and reorganization of gestures were observed; in others, the reinforcement of already consolidated patterns was observed. The analyses suggest that diversified repetition does not necessarily act as a corrective agent, but can favor subtle adjustments, motor stabilization and the intensification of preexisting interpretative strategies. In conclusion its effectiveness depends on the interaction between technical and motor factors, and should be applied in a contextualized manner and sensitive to the needs of each interpreter.

Keywords: Piano practice; Bimanual synchronization; Diversified repetition; Music performance; Gestural movement.

Prática com repetição diversificada e sua influência na sincronização bimanual em pianistas

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Resumo: Este estudo investiga os efeitos da repetição diversificada na sincronização entre as mãos de pianistas, comparando performances antes e após uma sessão de prática estruturada com variações de ritmo, articulação, dinâmica e andamento. Dois pianistas, identificados como P1 e P2, participaram do estudo e executaram a escala pentatônica de Fá maior em três momentos: pré-teste, prática com repetição diversificada e pós-teste. Foram coletados dados de MIDI, captura de movimento e registros audiovisuais. A análise incluiu três aspectos da performance: assincronismo dos onsets (sincronização sonora), amplitude de preparação gestual (movimento) e velocidade de ataque das notas (dinâmica). Os resultados mostram efeitos distintos entre os participantes e entre as combinações de notas. Em alguns casos, observou-se aproximação da simultaneidade e reorganização do gesto; em outros, o reforço de padrões já consolidados. As análises sugerem que a repetição diversificada não atua necessariamente como um agente corretivo, mas pode favorecer ajustes sutis, estabilização motora e intensificação de estratégias interpretativas preexistentes. Em conclusão, sua eficácia depende da interação entre fatores técnicos e motores, e deve ser aplicada de forma contextualizada e sensível às necessidades de cada intérprete.

Palavras-chave: Prática pianística; Sincronização bimanual; Repetição diversificada; Performance musical; Movimento gestual.

1. Introduction

Hand synchronization is a fundamental skill for piano performance, as it requires precise temporal coordination of finger movements to align notes and musical structures in an integrated manner (Goebl & Palmer, 2013). This demand highlights the motor complexity involved in piano performance, where rhythmic cohesion and technical fluidity depend on highly specialized neural and biomechanical mechanisms (Goebl, Sebastian & Widmer, 2010; Swinnen & Wenderoth, 2004). Achieving this refined coordination is essential for efficient, controlled, and expressive performance (Furuya & Altenmüller, 2013), and its development requires integration between the cerebral hemispheres combined with continuous practice, aiming for precision and improved motor control (Ito et al., 2023).

During musical practice, repetition is a strategy widely used by music students, being present both in individual practices (Barry, 1992, 2007; Rohwer & Polk, 2006) and in collective contexts (Corbalán et al., 2019). Although it contributes significantly to the automation and precision of gestures (Repp, 2005), fine motor adjustments throughout repetitions and their implications for motor learning are still little explored in the literature.

Building on a previous study that categorized different types of repetition (Monteiro, 2022), this research continues the investigation. That study showed that, although repetition served as an effective practice strategy, excessive insistence could compromise synchronization between the hands. The predominance of approaches focused on stabilizing motor patterns highlights a gap regarding the role of intentional variation during practice, particularly concerning its relationship with temporal motor coordination. This gap underscores the importance of investigating how different repetition strategies impact synchronization in piano performance.

2. Aims

This study aimed to investigate how diversified repetition influences the synchronization between pianists' hands, by comparing performances before and after practice. Specifically, we sought to: (i) Analyze how practicing the F major pentatonic scale, with variations in rhythm, tempo, articulation, and dynamics, influences bimanual temporal coordination; (ii) Identify emerging synchronization patterns after practice; (iii) Examine, based on MIDI data, possible improvements or changes in attack accuracy and,

(iv) Observe variations in the amplitude of gestural preparation, captured by the Polhemus system, in order to verify possible relationships between motor adjustments and the sound synchronization.

3. Method

In an exploratory quasi-experimental study, two pianists, both right-handed, with a high level of expertise performed the requested task. The experimental task consisted of performing the F major pentatonic scale, following a protocol divided into three main stages: pre-test, practice, and post-test. In the pre-test, P1 and P2 played the scale with both hands in 12 consecutive repetitions. Next, they completed a practice session using diversified repetition strategies, incorporating variations in rhythm, tempo, articulation, and dynamics, as well as practicing in separate hands and in blocks. Finally, in the post-test, they repeated the same scale 12 times, allowing for comparisons between performances before and after the intervention.

Data collection was performed using three resources simultaneously: MIDI data, the Polhemus motion capture system, and audiovisual recordings. MIDI (Musical Instrument Digital Interface) data were obtained from a digital piano connected to a computer via a MIDI interface, using the Reaper software to record the data.

For motion capture, the Polhemus LIBERTY system with 16 channels was used. This system enables precise and continuous tracking at high speed (240 Hz per sensor) and does not require a direct line of sight. Gestures of the upper limbs were recorded in three dimensions via an electromagnetic field (figure 1), using 15 sensors placed on the medial phalanges of each finger (10), the wrists (2), the elbows (2), and the piano (1). In this study, only the data related to finger movement were analyzed. Audiovisual recordings were used as complementary support.

Ex.1 – Polhemus sensor configuration on P2's right hand.

4. Data Processing

Data processing was a challenging step, carried out collaboratively by the research team, and required specific strategies to deal with the multimodal nature of the recordings. The analysis was conducted in the MATLAB environment, using scripts[2] developed exclusively for this investigation.

To assess bimanual synchronization, an algorithm was used that calculates the asynchrony between the onsets of notes extracted from MIDI files. The script identifies the attack time of each note and determines, in simultaneous events, which hand pressed the key first, allowing an objective estimate of the temporal deviations between the hands.

[2] The scripts used for data analysis are available at: https://github.com/palomafmonteiro

The analysis of the amplitude of the preparatory gesture was performed using the motion capture data, with a second script developed to quantify the vertical displacement of the fingers immediately prior to the key attack. This processing combines automated procedures with visual inspection of the motion graphs, note by note, to ensure accuracy in identifying events. Objective criteria were adopted to define the limits of the gesture: the beginning was considered as the point of lowest height (lowest vertical position of the finger before the upward gesture) and the end as the point of highest height, corresponding to the apex of the preparatory gesture immediately preceding the beginning of the note.

The intensity of the attack (referred to as velocity) was extracted directly from the MIDI files using Sonic Visualizer software. This data was organized by note combination and categorized according to the playing hand (left or right), enabling comparative analysis between performances.

For each of the three aspects investigated: onset asynchrony, gestural amplitude, and velocity, 12 repetitions were analyzed before and 12 after practice with diversified repetition. The data were grouped by combination of notes and by hand, and the arithmetic mean, and standard deviation measures were calculated for each condition. The descriptive analyses were represented graphically in Excel software, to highlight the effects of the intervention on different aspects of piano performance.

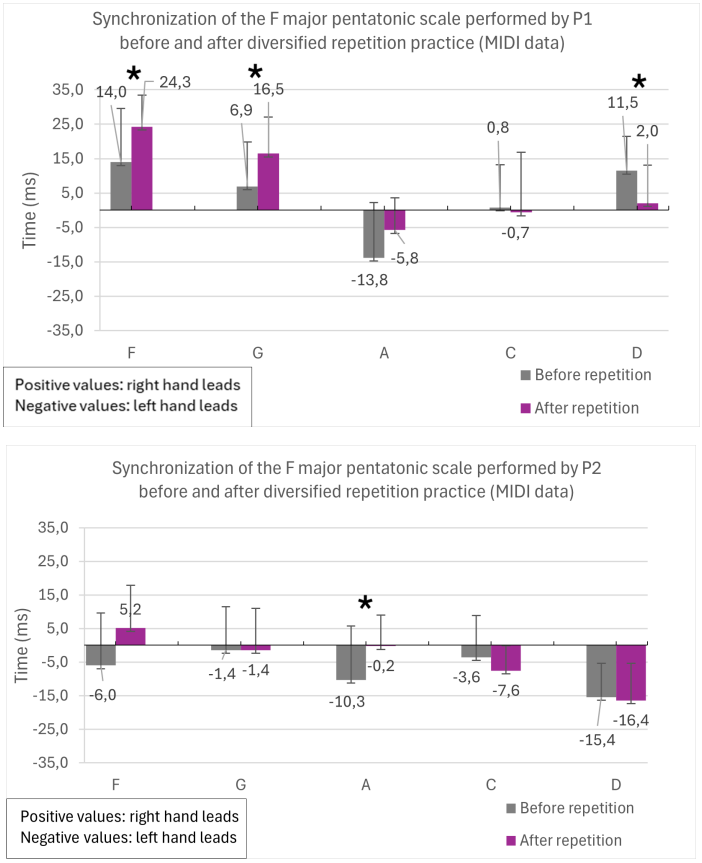
The analyses focused on identifying trends in synchronization and movement patterns between the pre- and post-practice phases, as well as comparing possible intra-participant changes. The t-test was used to statistically verify differences between conditions, with a significance level set at $p < 0.05$. Preliminary results indicate that P1 and P2 responded differently to practice with diversified repetition, revealing different patterns of adaptation and motor exploration.

5. Results and Discussion

5.1- Analysis of bimanual synchronization of the F major pentatonic scale

Bimanual attack synchronization was analyzed based on the temporal differences between note onsets, extracted from the MIDI data. The graphs presented in Ex.2 show the average values of asynchrony between P1 and P2 hands during the execution of the F major pentatonic scale, comparing the moments before and after practice with diversified repetition. Positive values indicate right-hand anticipation, while negative values correspond to left-hand anticipation. Columns marked with asterisks indicate statistically significant differences between the conditions ($p < 0.05$).

For P1, the results revealed variability between the note combinations. In the pre-test, right-hand anticipation was observed in four of the five combinations (F, G, C, and D), with emphasis on F (14.0 ms) and D (11.5 ms). After practice, the effects were distinct: there was an increase in the time lag in F and G (both with statistical significance) and an improvement in synchronization in D (reduction to 2.0 ms, also significant). Combinations A and C maintained values close to simultaneity in both conditions, without statistically relevant changes. These results suggest that diversified repetition promoted specific motor reorganizations, with gains in some combinations and an increase in the time lag in others, possibly due to the technical and biomechanical demands of each note in the scale.



Ex.2 – Synchronization data of the F major pentatonic scale before and after diversified repetition by P1 and P2.

In P2's case, the data indicated a predominance of left-hand anticipation in all combinations, both before and after practice. Only the A combination showed a statistically significant improvement, with a reduction in asynchrony from -10.3ms to -0.2ms, approaching simultaneity. In the other combinations, the changes were subtle and not significant.

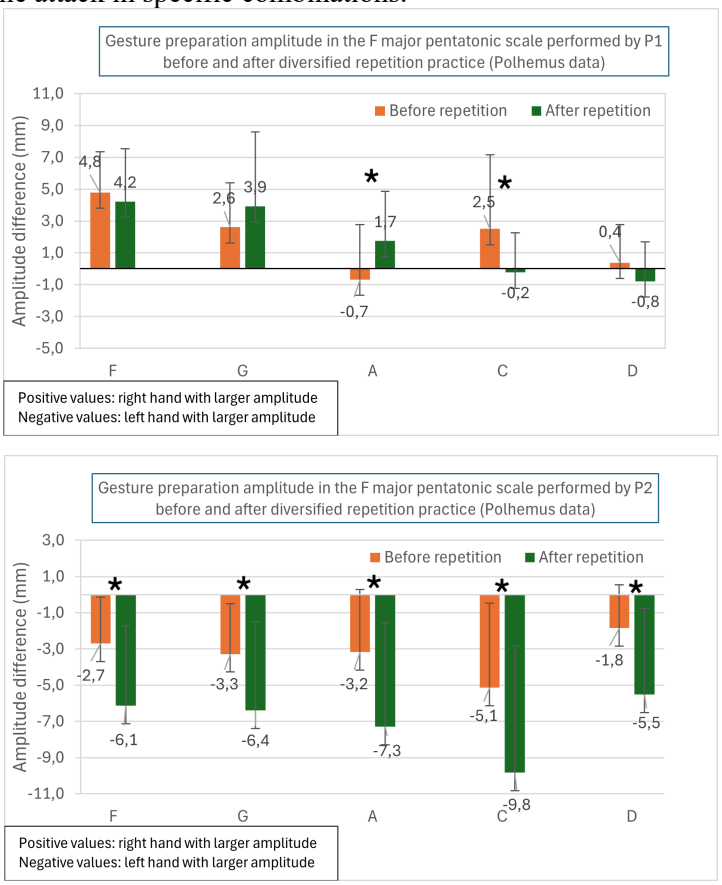
The asynchrony data reinforce the importance of considering the individual characteristics of the performance, since in some notes there was an approximation to simultaneity, while in others an increase in the time lag was observed. These findings highlight the need for a localized analysis of the effects of varied practice, considering each pianist's motor performance, as well as their expressive and biomechanical choices.

5.2- Analysis of the amplitude of gestural preparation in the F major pentatonic scale

The analysis of the data on the amplitude of gestural preparation, obtained through the Polhemus system, revealed contrasting responses between the two pianists after practice with varied repetition. The differences between the hands were expressed in terms of the average amplitude of the preparatory gesture, with the sign of the values indicating the hand that performed the widest movement before the attack of the note. The graphs in Ex. 3 illustrate the average difference in amplitude between the hands of P1 and P2 in each note of the F major pentatonic scale, comparing the pre- and post-

practice moments. Positive values indicate larger amplitude of the right hand, negative values, of the left hand.

For P1, only the notes A and C showed statistically significant differences. Before the practice, the note A was preceded by larger preparation of the right hand, while the right hand showed larger gestural amplitude in the note C. After the intervention, these patterns were reversed. These changes suggest that the practice with diversified repetition promoted a localized gestural reorganization, with changes in the way both hands prepared for the attack in specific combinations.



Ex.3 – Difference in amplitude in the preparation of the gesture of each finger in the execution of the F major pentatonic scale before and after diversified repetition by P1 and P2

In contrast, P2 presented more consistent gestural behavior. Even before practice, data indicated a predominance of larger amplitude in the left hand in all combinations, with values ranging from -2.7 mm (F) to -5.1 mm (C), and relatively homogeneous differences. After practice, these discrepancies increased in all notes, with emphasis on C (-9.8 mm), A (-7.3 mm) and G (-6.4 mm). The data suggest that, in this case, the diversified repetition intensified previously established gestural patterns, thus reinforcing already internalized motor strategies, instead of causing motor reorganization.

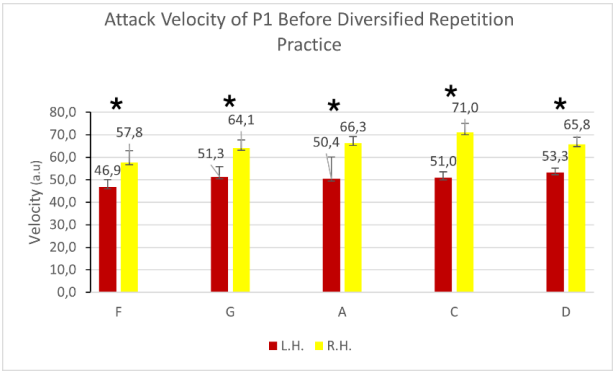
In general, the results indicate that the effects of diversified repetition on gestural preparation are not homogeneous and appear to depend on individual factors, the approach adopted during practice and the pre-existing motor organization of each pianist. In some cases, practice favored adjustments in gestural preparation between the hands; in others, it functioned as an agent of stabilization and intensification of previously consolidated strategies.

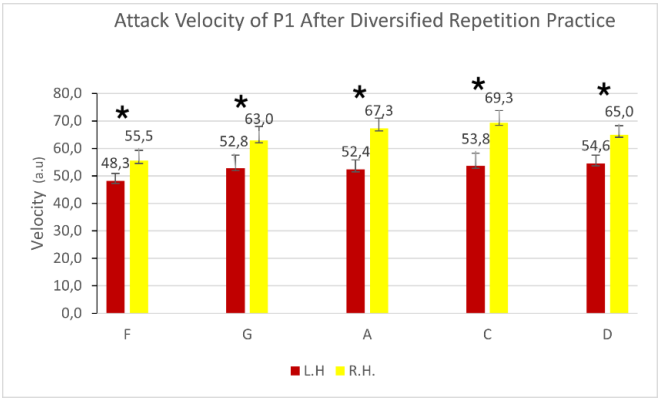
5.3- Attack Velocity Analysis of Notes – P1

The Ex.4 illustrates the average velocity values, that is, the force with which notes are struck when P1 plays the F major pentatonic scale, comparing the moments before and after practice with varied repetition. The red columns represent the data for the left hand, and the yellow ones for the right hand. In the MIDI protocol, velocity is a numerical measurement ranging from 0 to 127, corresponding to the intensity or force applied to the key: the higher the value, the greater the emphasis and the resulting sound volume. This measurement allows us to evaluate aspects of performance dynamics and potential differences in articulation between the hands.

P1's data showed that, before diversified repetition, in all five analyzed combinations, the velocity values were systematically higher in the right hand, with particular emphasis on note A (66.3 on the right and 50.4 on the left) and C (71.0 on the right and 51.0 on the left). This pattern may indicate a gestural dominance of the right hand in dynamic production, though it could also reflect an interpretive choice, such as differentiating sound planes. The variability between repetitions, represented by the error bars, was relatively low, suggesting consistency in execution.

After diversified repetition practice, the pattern of higher velocity in the right hand was maintained, with statistically significant differences in all combinations, as indicated by the asterisks in the graphs. The largest disparities were again recorded in notes A (67.3 on the right and 52.4 on the left) and C (69.3 on the right and 53.8 on the left), reaffirming a consistent pattern of greater attack intensity by the right hand.





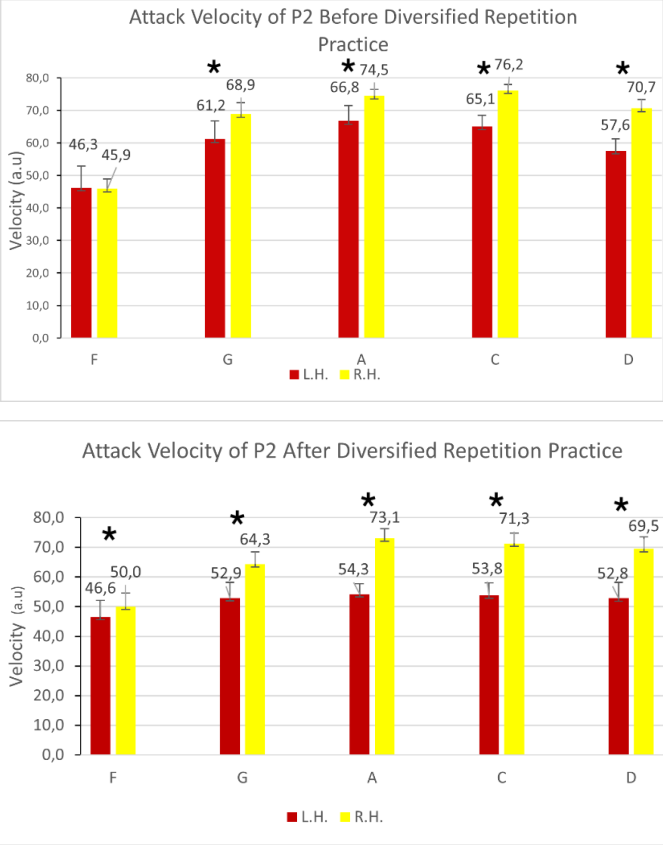
Ex.4 – Average attack velocity of notes in the F major pentatonic scale by P1 before and after practice with diversified repetition.

The comparison between conditions reveals the persistence of the dynamic pattern throughout the intervention: for all notes, both before and after practice, the right hand showed significantly higher velocity values. This pattern may reflect the participant's right-hand manual dominance, as well as a recurrent expressive choice among pianists, such as emphasizing a melodic line or differentiating functional roles between the hands. The data therefore suggest that practice with diversified repetition did not neutralize the dynamic differences but may have contributed to the refinement and stabilization of pre-existing interpretive strategies.

5.4- Attack Velocity Analysis of Notes – P2

Looking at P2's results before practice, except for the F note, the right hand presented consistently higher values across all other notes, with statistically significant differences in the notes G, A, C, and D. The most pronounced contrasts occurred in the notes C (65.1 on the left and 76.2 on the right) and D (57.6 on the left and 70.7 on the right), indicating a clear pattern of stronger attack intensity by the right hand. For the F note, the values were practically equivalent (46.3 on the left and 45.9 on the right), with no statistically significant difference.

After the diversified repetition practice, note F showed an increase in velocity, with the right hand now presenting significantly higher values than the left. This change introduced a new instance of right-hand predominance, which was already observed in all other note combinations and remained consistent after practice. Notably, the velocity values for the left hand decreased substantially across several notes, for example, from 66.8 to 54.3 in A, from 65.1 to 53.8 in C, and from 57.6 to 52.8 in D, while the right hand maintained relatively high values. The largest disparities continued to appear in notes C (53.8 left / 71.3 right), D (52.8 / 69.5), and A (54.3 / 73.1), reinforcing the persistent pattern of stronger articulation by the right hand. Although the right-hand velocities showed a slight decrease in absolute terms, the asymmetry between hands remained significant. These findings suggest that diversified repetition did not lead to a dynamic redistribution between hands but may have supported subtle refinements in attack force, particularly by reducing intensity in the left hand.



Ex.5 – Average attack velocity of notes in the F major pentatonic scale by P2 before and after practice with diversified repetition.

The significant reduction in left-hand velocity after the diversified repetition practice may reflect a more economical and refined motor strategy. Given the participant's right-hand manual dominance, the right hand maintained higher velocity values, likely due to greater control and coordination. In contrast, the left hand may have adapted its gesture to prioritize precision over intensity. This modulation could also suggest a redistribution of focus or an internalization of more efficient movement patterns as a result of the varied practice.

6. Conclusion

Repetition revealed specific, targeted effects on different dimensions of piano performance. From the analysis of data concerning inter-hand synchronization, gestural preparation, and attack intensity, it was observed that the intervention's impacts were not homogeneously distributed across note combinations or among participants.

While in some cases, an approximation of simultaneity and a reorganization of preparatory gestures were verified, in others, the practice reinforced already established patterns, both in terms of amplitude and dynamics. These variations indicate that diversified repetition doesn't necessarily act as a corrective or balancing agent, but it can favor subtle adjustments, motor stabilization, and the strengthening of pre-existing patterns.

The results point to the importance of considering the effects of this approach based on the interaction among technical, motor, and interpretive factors, respecting each

musician's individuality. In this sense, diversified repetition is configured as a potentially valuable pedagogical tool, provided it's applied in a contextualized, reflective, and sensitive manner to the interpreter's specific needs.

Future investigations could expand on these findings by including a larger number of participants, musical excerpts, and medium to long-term evaluations. This would allow for a deeper understanding of the mechanisms by which varied practice influences coordination and motor learning in the context of musical performance.

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