Jazz Piano Training Modulates Neural Oscillations and Executive Functions in Older Adults: A Pilot Study

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Musical improvisation is one of the most complex forms of creative behavior, often associated with increased executive functions. However, most traditional piano programs do not include improvisation skills. This research examined the effects of music improvisation in a novel jazz piano training intervention on executive functions and neural oscillatory activity in healthy older adults. Forty adults were recruited and randomly assigned to either jazz piano training (n = 20, 10 females) or a control group (n = 20, 13 females). The jazz piano training program included aural skills, basic technique, improvisation, and repertoire with 30 hours of training over 10 days. All participants at pre- and post-testing completed a battery of standardized cognitive measures (i.e., processing speed, inhibition, verbal fluency), and neurophysiological data was recorded during resting state and a musical improvisation task using electroencephalography (EEG). Results showed significantly enhanced processing speed and inhibition performance for those who received jazz piano training as compared to controls. EEG data revealed changes in frontal theta power during improvisation in the training group compared to controls. Learning to improvise may contribute to cognitive performance.

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Musical improvisation, the spontaneous generation of original and meaningful melodic, harmonic, or rhythmic material, is one of the most articulated expressions of creative behavior (Sasaki et al., 2019). Though the term improvisation is commonly associated with jazz music, improvisation exists in all forms of music (Becksted, 2013). Common fundamentals of jazz improvisation include practice, flexibility, expressivity, and musical awareness (Larsen, 2006), which rely on multiple facets of higher-order cognition.

Notably, researchers have found associations between musical improvisation and enhanced executive functions attributed to attention allocation in expert musicians (Beaty, 2015; Biasutti, 2015). Executive functions associated with musical performance entail goal-directed processes such as conflict monitoring, task switching, working memory, focused attention, and processing speed (Loui & Guetta, 2019). While many traditional music training approaches have been associated with enhanced executive functions such as response suppression, planning, working memory, and attention in children (Shen et al., 2019), adults (Criscuolo et al., 2019), and older adults (Bugos et al., 2007), few studies include improvisation as part of the training protocol (for an example, see Norgaard et al., 2019). This research seeks to examine the effects of a novel jazz improvisation piano training intervention on executive functions and neural oscillatory activity in healthy older adult novice musicians.

Musical improvisation relies heavily on a myriad of executive functions (Faber & McIntosh, 2019) as it requires the deliberate control of one's attention, often implicating the prefrontal cortex during creative processing (Dietrich, 2004). The allocation of one's sustained attention is critical for the creative thinking process and for tasks that involve the processing of novel information (Pinho et al., 2014). Neuroimaging research has shown that improvisation is linked to networks of brain regions often associated with involvement in executive functions (Beaty, 2015). High-creative ability in divergent tasks was associated with predictable functional brain connectivity patterns in frontal and parietal regions within default mode network (DMN), executive control network (ECN), and salience brain network (Beaty et al., 2018). Similarly, musical creativity was shown to involve the interaction of these networks, in addition to the motor-planning network (Bashwiner et al., 2020).

Expert jazz pianists trained in musical improvisation showed lower activity, as measured with fMRI, in frontoparietal association areas and increased functional connectivity in prefrontal, premotor, and motor areas during an improvisation task (Pinho et al., 2014). In other studies with expert pianists, explicit musical improvisational tasks were associated with higher dorsolateral prefrontal cortex (DLPFC) activity (Berkowitz & Ansari, 2008) and greater functional connectivity in premotor and parietal areas as compared with implicit improvisational tasks (Pinho et al., 2015). Professional jazz pianists were also found to have dissociated patterns of activation in prefrontal areas during improvisation compared to over-learned musical sequences (Limb & Braun, 2008). Other research using fMRI found higher neural activation in DMN and ECN for jazz musicians than in classical musicians (Belden et al., 2020). Collectively, musical performance in expert improvisers has been shown to involve areas of the DMN, ECN, and motor control networks (Belden et al., 2020; Beaty, 2015).

Musical Interventions and Executive Functions in Aging

Music improvisation has become increasingly more common in music therapy interventions (Tomaino, 2013). Most music interventions that include improvisation are for clinical populations or learning programs for children with autism spectrum disorder (Bieleninik et al., 2017; Ciambella et al., 2019;). The goals of such programs are to primarily enhance verbal communication, group socialization, or individual expressiveness.

At the same time, traditional music interventions such as piano training have been shown to benefit executive functions in novice aging adult musicians (Bugos, 2019; Bugos et al., 2007; Seinfeld et al., 2013). For example, six months of individualized piano training were found to enhance processing speed and working memory in healthy older adults (Bugos et al., 2007). Researchers in another study reported enhanced inhibition measured by a Stroop task after four months of group piano training (Seinfeld et al., 2013). Other research has found that older adults who completed four months of piano training or percussion instruction demonstrated enhanced visual scanning and working memory as compared to those enrolled in music listening (Bugos, 2019). A four-month randomized control trial examining group piano training, computer-assisted cognitive training (active control), and no-treatment controls found enhanced verbal fluency for the piano training group as compared to other groups (Bugos & Wang, 2022). These findings highlight the potential of music training to mitigate age-related cognitive decline in cognition. While traditional piano training may offer a rigorous approach as a cognitive intervention for older adults (Bugos & Kochar, 2017), the present study extends earlier research by focusing on musical improvisation.

Learning to improvise relies upon listening, imitation, and improvisational experiences (i.e., generating musical responses). Pressing's Model of Improvisation (1988) posits that musical improvisation, an important skill that requires a substantial amount of music training and practice to achieve, contains generative and evaluative processes that contribute to inhibition through conscious monitoring. This model asserts the importance of developing improvisational fluency (i.e., expressive fluency) as those without this fluency are not able to draw upon referent and domain-specific knowledge (e.g., integrated declarative and procedural information). There are several important characteristics of improvisation. First, improvisation includes "open" and "closed" skills. Open skills require interaction with the environment (e.g., improvisation with an ensemble), while closed skills do not require a reference to a specific context based upon self-produced stimuli (e.g., solo improvisation, Pressing, 1988). A second important feature of the model is the inclusion of feedback and error correction, which is important for musical achievement and can affect attention and motivation. Learning to improvise requires attention and perception of errors, response to feedback, and meaningful aural experiences that contribute to a palette from which to draw upon. Since the development of improvisation skills requires attention, decision-making, planning, and working memory, we chose to examine the effects of learning to improvise in the context of a jazz piano camp on executive functions in aging.

Musical Improvisation and Neural Oscillations

Neural oscillations may provide a sensitive metric able to capture executive functions and improvisation ability. This measure, particularly in theta and alpha frequency bands, is believed to be sensitive to changing demands during cognitive tasks requiring attentional resources (Klimesch, 1997). Resting-state theta oscillatory activity (from 4 to 8 Hz) is associated with functional inhibition sub-serving executive functions primarily in the frontal cortex (Huster et al., 2013) and has been shown to be correlated with executive control (Clements et al., 2021; Finnigan & Robertson, 2011). Greater theta power has also been associated with divergent thinking and creative cognition (Lopata et al., 2017; for a review, see Dietrich & Kanso, 2010). Alpha oscillatory activity (from 8 to 13 Hz) has been implicated in higher-order cognitive processes. Research suggests increases in alpha are associated with creative ideation and divergent thinking (Benedek et al., 2014; Fink & Benedek, 2014). For instance, EEG research has shown increased alpha power at frontal (Bazanova & Aftanas, 2008; Lopata et al., 2017) and parietal sites on tasks of divergent thinking and creative cognition (Benedek et al., 2014; Fink & Benedek, 2014). Additionally, measures of EEG complexity (i.e., the complexity of neural oscillatory time series) have been proposed to index creativity (Krug et al., 2003) particularly multiscale entropy (MSE; Kaur et al., 2020), with one study finding greater MSE associated with creative cognition in healthy older adults (Ueno et al., 2015). If resting state power and MSE in theta and alpha bands are indexing creative and divergent thinking, then these neural metrics should be modulated by music training with improvisation. Neural oscillatory activity during improvisation, in particular EEG power and MSE in theta and alpha bands, may provide more sensitive metrics to quantify neurophysiological changes attributed to training given such measures have been associated with measures of creative cognition (Lopata et al., 2017; Ueno et al., 2015).

Therefore, the purpose of this study was to examine the effects of an intensive group jazz piano training intervention on executive functions and neural oscillatory activity in older adults with little to no formal music education. Older adult participants in the present study were randomly assigned to either an experimental group that participated in jazz piano training for two weeks, or a control group who received no training. Measures of executive functions (including processing speed, inhibition, and verbal fluency) and musical improvisation on the piano were administered during pre- and post-testing sessions. Additionally, neural oscillatory activity was recorded during improvisation and at rest at pre- and post-test sessions using electroencephalography (EEG). Compared to controls, we hypothesized that older adults assigned to jazz piano training would show enhanced processing speed and cognitive control, greater changes in MSE and for the training intervention to modulate neural oscillatory activity from pre- to post-testing.

Method

PARTICIPANTS AND PROCEDURE

Forty-three older adults, aged between 60 to 85 years, were recruited from a large urban center in the Southeastern United States via recruitment posters, advertisements, and word of mouth. Criteria for study inclusion included: 1) native English speakers; 2) no history of neurological impairment (e.g., stroke, transient ischemic attack), sensory or learning disabilities; 3) not currently consuming medications affecting memory performance; 4) no difficulty with hand movements; 5) less than four years of formal music training, and 6) not currently reading or performing music. Informed written consent was obtained in accordance with the University Institutional Review Board.

Participants were randomly assigned to the experimental jazz piano training group or no-treatment control group. Data from one participant from the experimental group and two participants from the control group were excluded from the analysis due to attrition from illness or a need to return to the workforce. In addition, data collected from three participants in the experimental group were unusable due to excessive artifacts and excluded from the analysis. The final sample comprised of 37 participants (17 experimental, 20 control; Table 1). Several neuropsychological assessments and EEG measures were administered during a pre-testing visit, by an experimenter who was blind to group assignment. Participants assigned to the experimental group completed a 30-hour intensive jazz piano training intervention over two weeks, while the control group continued with usual day-to-day activities. Dependent measures of executive functions (processing speed, inhibition, and verbal fluency) along with electrophysiological measures at rest and during a musical improvisation task were administered at pre-testing and post-testing visits.

TABLE 1. *Demographic Data [M (SD)]*

	Piano Training Group (*N* = 17)	Control Group (*N* = 20)
Age (in years)	69.65 (4.90)	68.20 (4.07)
Prior Formal Music Lessons (in years)	1.47 (1.32)	0.99 (1.08)
Gender (Male: Female)	10:10	7:13
Education (in years)	16.35 (1.93)	15.70 (2.11)
Montreal Cognitive Assessment (MoCA)	27.35 (2.11)	27.35 (1.87)
Estimate of Intelligence (FSIQ)	111.20 (12.12)	113.15 (9.78)
Tonal Aptitude (AMMA)	25.90 (5.85)	25.20 (5.80)
Rhythm Aptitude (AMMA)	27.55 (5.17)	27.30 (4.32)
Music Aptitude Score (Total AMMA)	53.45 (10.41)	52.50 (9.90)

Note: FSIQ: Full scale Intelligence Quotient; AMMA: Advanced Measures of Music Audiation

JAZZ PIANO INTERVENTION

The jazz piano training intervention consisted of an intensive program of ten sessions over a two-week period, with 3 hours per session. Each session had the following components: basic piano technique and dexterity exercises (40 min, 20 in each half of the session), aural skill development (30 min), improvisation exercises (50 min, 25 allocated to each half of the session), basic piano literature (40 min), and chordal accompaniment (e.g., 12-bar blues, comping; 20 min). An additional 15-minute break was scheduled in the middle of each session. The jazz piano training intervention followed a prescribed instructor manual to administer the curriculum for each of the 10 sessions (See Supplementary Materials Table 1 accompanying the online version of this paper at online.ucpress.edu/mp). Pieces were selected and modified from the Alfred-All-In-One for Adults Course to teach improvisation skills in the context of traditional notation. Classes were held in a university Yamaha-Clavinova lab and taught by an instructor with 25+ years of teaching experience. Due to the intensity of the program, no additional outside practice was required. Upon completion of the piano intervention, participants were asked to perform and improvise the melody to "Oh When the Saints," "Rockin Tune," "Cockles and Mussels," and "Got Those Blues" as a measure of music learning.

BASELINE MEASURES

During the pre-testing visit, all participants completed the Montreal Cognitive Assessment (MoCA) as a brief assessment of cognitive status. The two-subtest short form of the *Wechsler Abbreviated Scale of Intelligence* (WASI; Wechsler, 1999) with Vocabulary and Matrix Reasoning subtests was also administered as a brief estimate of full-scale intelligence. WASI scores correspond to longer standardized intelligence assessments such as the *Wechsler Adult Intelligence Scale* III (WAIS-III; Weschler, 1997) with norms provided across a broad age range (6–89 years).

Advanced Measures of Music Audiation (AMMA; Gordon, 1989) was used to measure music aptitude with 30 paired piano melodies in which pairs of melodic phrases are judged as precisely the same, tonally altered, or rhythmically altered. The AMMA was chosen for its reliability ($r = .81$), and content validity, and is commonly used in research with novice older adult musicians with no previous musical training (Hudak et al., 2019).

DEPENDENT MEASURES

The Cued Color Word Stroop (Cohen et al., 1999; Perlstein et al., 2006) is a computerized cognitive task administered at pre- and post-testing visits to measure cognitive control (inhibition and task-switching) in the visual domain with the participants cued prior to each trial whether they should attend to the color of the word stimuli, or to the word itself. Each trial began with a 750-ms visual cue (either the word "Word" or "Color") followed by a 1000 ms delay, and a visual stimulus presented for up to 2500 ms and terminated by the participant's motor response. The stimulus was either the word "Red," "Green," or "Blue" in either red, green, or blue font color (67% incongruent, 33% congruent). For the color condition, participants responded to the ink color of the word. For the word condition, participants responded to the name of the physical word on the screen. For the mixed condition, participants either responded to the ink color or the physical word depending upon instructions of the cue, which were randomized per trial. Such a task yielded a measure of both response inhibition via the Stroop effect (time to respond to incongruent vs. congruent) and task-switching (mixed vs. color and word conditions). A total of 360 trials were presented in four blocks of 90 trials in the following order: mixed, color, mixed, and word with pseudo-randomized stimuli. Visual stimuli were presented centered against a black computer screen display and delivered on an Apple Macintosh MacBook Pro computer using E-Prime Professional 2.0 software (Psychology Software Tools, Inc.) with a PsychScope button box response apparatus, with a button corresponding to each of the three colors. Participants were instructed to respond as quickly and accurately as possible. Prior to administration, participants successfully completed a practice block of each condition (color, word, or mixed) with at least 70% accuracy.

Participants at pre- and post-testing visits were also administered the *Paced Auditory Serial Addition Task* (PASAT; Gronwall, 1977), a measure of auditory working memory and processing speed. It consisted of four blocks of 25 trials (100 trials) in which each trial includes progressively faster interstimulus intervals (i.e., 2.8, 2.4., 2.0, and 1.6 seconds). Participants were presented with strings of spoken digits presented on a digital recording with one digit every three seconds and were instructed to verbally respond with the sum of the last number heard with each new number provided. The proportion of correct responses over the entire task was calculated per participant per test session. Split-half reliability for the 100-trial PASAT is $r = .90$ (Spreen & Strauss, 1998), demonstrating good psychometric properties.

The *Delis-Kaplan Executive Function System* (*D-KEFS;* Delis et al., 2001) *Verbal Fluency* subtest includes three trials measuring letter fluency, category fluency, and category switching. For each trial, participants were instructed to continuously generate words either starting with a particular letter, or belonging to a particular semantic category, or to alternate between the two, for each subtest lasting 60 seconds. The number of correctly generated words, intrusions, and repetitions were used to generate a score for each trial. To prevent practice effects between pre- and post-testing visits, the present study used two validated forms of the measure, with a separate form administered at each time point. Reliability coefficients were $r = .88$ for letter fluency, $r = .82$ for category fluency, and $r = .51$ for category switching (Delis et al., 2001).

All participants completed the *Improvisation Continuation Task* (Belden et al., 2020) during pre- and post-testing visits. This task was chosen as a measure of creativity and is described as a musical analog to the *Torrance Test of Creative Thinking* (Arkin et al., 2019). The task encompassed the two learning phases necessary to improvise such as aural experiences and the development of melodic repertoire through imitation prior to the creation of new melodic material through improvisation (Clarke et al., 1988). Task stimuli (see Beldon et al., 2020) included 12 one-measure piano melodic motifs overlaid with a 100 bpm metronome beat throughout and were aurally presented via a computer. For each motif, participants were asked to listen (four measures), imitate (eight measures), and improvise (eight measures) in the most creative way.

During the listen phase, a one-measure motif was played four times in succession, and participants were instructed not to respond and to attend to the motif. Immediately following was the imitate phase, where participants imitated the one-measure motif for the next eight musical measures. The following eight musical measures comprised the improvise phase, where participants were to improvise based on the motif in the most creative way. This structure was then repeated in succession for each of the 12 motifs. Each motif was in 4/4 rhythmic time and became progressively more melodically and rhythmically complex over time on the task. Participants were instructed to use only their right hand to respond to each of the motifs on a Yamaha Clavinova digital piano and were given no additional instructions on how to imitate or improvise. The motifs ranged from C4 to B4 in melodic range such that they could be reasonably played by only the right hand. As the participants in the present study were novice musicians, all three phases of the task were taken as a measure of improvisational learning and performance based upon Pressing's model of improvisation (Beaty, 2015; Pressing, 1998). Participants' responses throughout the task were recorded using Musical Instrument Digital Interface (MIDI) software.

EEG ACQUISITION AND PREPROCESSING

Neuroelectric activity was measured through electroencephalography (EEG) during the Improvisation Continuation Task as well as during a separate resting-state paradigm, which lasted at least three minutes. In the latter, participants were told to maintain wakefulness and to fixate their gaze at a centered fixation point on the wall across the testing room. EEG data for both the task and at rest were recorded using an EMOTIV 14-channel wireless EPOC+ headset with a 128 Hz sampling rate. The electrode montage comprised AF3, F3, F7, FC5, T7, P7, O1, O2, P8, T8, FC6, F8, F4, and AF4 electrodes according to the 10-20 system of electrode placement. Data were recorded referenced to a common mode sense active electrode and driven right leg passive electrode at P3 and P4 locations, respectively (Figure 1), with a 45 Hz low-pass filter and then stored for offline analyses.

DATA PREPARATION

Improvisation Continuation Task

Participants' improvised responses were rated by expert musicians with an average of 12.5 years of formal musical experience who were blind to the experimental group. Raters listened to and scored the improvised responses for each of the 12 motifs according to a rubric of five categories (i.e., rhythmic variation, pitch variation, consistency of beat and motif development, and

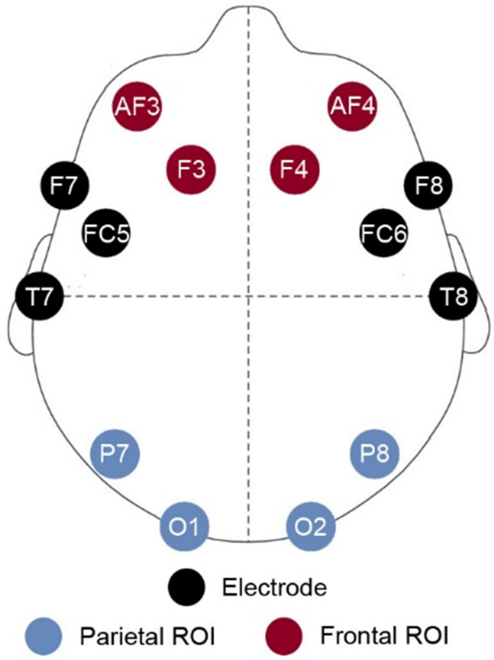

FIGURE 1. EEG Montage with frontal and parietal regions of interest (ROI).

adherence to the phrase) as described in Arkin et al. (2019). Scores were administered by assigning a score from 0 to 5 points for each of these categories except for Adherence to Phrase, which ranged from 0 to 2 points. A score of 0 implied little to no variation or improvisational development and the highest score of 5 showed a very creative interpretation of the heard musical phrase. Scores between raters demonstrated good inter-rater reliability (r = .72 pretesting, r = .72 for post-testing).

Entropy measures were extracted from participants' MIDI responses recorded during the Improvisation Continuation Task, a measure of the complexity in improvisation. Entropy measures were calculated as Shannon entropies for each participant as measured in Pinho et al. (2014). First, the probabilities for every musical note played were calculated for each participant's testing session. These probabilities were calculated by dividing the number of played notes for a particular note over the total number of notes performed across motifs. Thereafter, the base two logarithm was computed for each of the calculated probabilities. Entropy measures were obtained by taking the negative of the sum of all note probabilities multiplied by their respective base two logarithms.

EEG Preprocessing. Preprocessing was performed using Brain Electrical Source Analysis software (BESA Research, version 7.1, MEGIS GmbH, Gräfelfing, Germany). Continuous EEG data were re-referenced to an average reference (i.e., the average of all scalp EEG channels as the reference for each EEG channel) and were digitally filtered with a 2 Hz high-pass filter (forward, 6 dB/octave) to minimize contamination from movement artifacts. For each participant, a set of ocular movements was identified from the continuous EEG recording and then used to generate spatial components that best account for eye movements. The spatial topographies were then subtracted from the continuous EEG to minimize contamination from lateral and vertical eye movements as well as for eye blinks. After correcting for eye movements, data were then epoched into one-second segments for the resting state paradigm and two-second segments for the task. For each participant, data were then scanned for additional artifacts, with epochs including deflections exceeding 120 μV marked and excluded from the analysis. For the resting state paradigm, this removed on average 9.87% (SD = 6.47%) of epochs per participant, which did not significantly differ between groups, $F(1, 35) = 0.06$, $p = .814$, $\eta_p^2 = 0.002$, or session, $F(1, 35) = 0.51$, $p = .480$, $\eta_p^2 = 0.014$. For the Improvisation Continuation Task, this removed on average 23.9% (SD = 8.89%) of epochs per participant, which did not significantly differ between groups, $F(1, 35) = 0.06$, $p = .810$, $\eta_p^2 = 0.002$, or session, $F(1, 35) = 0.14$, $p = .716$, $\eta_p^2 = 0.004$.

For each participant, relative power spectral density within theta (4–8 Hz) and alpha (8–13 Hz) bands were extracted from each of the resting state paradigm and the Improvisation Continuation Task averaged over a pre-defined cluster of electrodes that formed a region of interest (ROI). Relative power (i.e., the ratio of power in one frequency to another) was used, as this metric provides a more informative measure when comparing brain activity of different individuals (Caplan et al., 2015). Theta power was calculated from a frontal ROI (Figure 1) comprising AF3, F3, F4, and AF4 electrodes, given the associations of frontal theta power with cognitive performance in healthy older adults (Cummins & Finnigan, 2007; Finnigan & Robertson, 2011; Kardos et al., 2014; Reis et al., 2016). Alpha power was calculated from a parietal-occipital ROI comprising P7, O1, O2, and P8 electrodes, given that alpha power is most prominent at parietal sites (Barry et al., 2007; Sadaghiani & Kleinschmidt, 2016)

For each participant, neural oscillatory power was computed using a mean Fast Fourier Transform (FFT) method that consisted of a set of FFTs from overlapping data segments spanning 128 points per block (1 s) for the resting state paradigm and 256 points per block (2 s) for the Improvisation Continuation Task. Theta and alpha power were normalized to the power spectrum from 2 to 45 Hz per participant.

EEG Multiscale Entropy. Entropy, a measure of "complexity" from physiological signals, attempts to capture the temporal and spatial fluctuations resulting from the interaction of structural and regulatory units within a system (Goldberger et al., 2002). In general, the complexity of a system tends to decrease as a result of aging and disease. For instance, Takahashi et al. (2009) found lower complexity from EEG data in older adults when compared to younger adults in response to photic stimulation. In another study, Park et al. (2007) observed lower complexity for individuals with severe Alzheimer's disease when compared to those with mild cognitive impairment and controls.

Multiscale Entropy (MSE) was calculated at rest and during the Improvisation Continuation Task; this metric was used over other measures of complexity to account for multiple time scales found in physiological signals (Costa et al., 2002, 2005). This technique creates coarse-grain time series from the original data according to a scaling factor, then calculates the sample entropy (SampEn) for the coarse-grained series. In the present study, theta and alpha coarse-grained series were computed from the frontal and parietal-occipital ROIs of each participant, respectively. A scaling factor of eight was selected based on the minimum data length from all participants. Thereafter, for each coarse-grained series per participant and test session, the SampEn was calculated.

DATA ANALYSIS

Dependent measures (PASAT, ratings, Shannon entropies, relative power, and MSE) were each subjected to a two-way mixed model analysis of variance (ANOVA) with Group as a between-subjects factor (Experimental, Control) and Time as a within-subjects factor (Pre, Post) with Sidak posthoc tests to adjust for multiple comparisons. Stroop error rates and RTs were also analyzed using ANOVA but with an additional within-subjects factor of Condition: incongruent and congruent for the Stroop effect; and color, word, and mixed for task-switching. Partial eta-squared was calculated as measures of effect sizes. An alpha value of .05 was used throughout. All statistical analyses were conducted using IBM SPSS Statistics Version 26.

Results

One-way ANOVAs were used to determine differences between experimental and control groups on demographic factors including age, education, estimates of full-scale intelligence (WASI), cognitive status (MoCA), years of previous music training, and music aptitude (AMMA). There were no significant differences on any of the demographic variables between groups (Table 1). The mean age for the experimental group was 69.65 years (SD = 4.90) and 68.20 years for controls (SD = 4.07). Both experimental (M = 27.35, SD = 2.11) and control (M = 27.35, SD = 1.87) groups demonstrated high scores on the MoCA, suggesting that older adults enrolled in the study did not show pre-existing symptoms of cognitive impairment.

Previous educational and musical experiences (such as years of previous music training and age-of-onset) did not differ between groups (p = .12). Participants' prior musical experiences were limited to formal instruction of less than four years on the following instruments: piano, violin, oboe, French horn, accordion, cornet, guitar, and percussion. Eleven participants reported no prior formal musical instruction as this research study offered an opportunity to begin formal music training.

EXECUTIVE FUNCTIONS

Mixed model (Group x Time) ANOVAs were conducted with Stroop errors on all trials, PASAT composite scores (total correct across trials), and D-KEFS Verbal Fluency composite (total correct across trials). A group by time interaction was found for PASAT, $F(2, 35) = 5.09$, $p = .03$, $\eta_p^2 = 0.13$; Stroop (total errors), $F(2, 35) = 4.61$, $p = .04$, $\eta_p^2 = 0.12$, (Figure 2); however, no significant interaction was found for Verbal Fluency, $F(2, 35) = 3.53$, $p = .069$ (Table 2). Posthoc analyses showed that the jazz piano training group scored higher on the PASAT at post-testing as compared to controls, whereas PASAT scores were not significantly different between groups at pre-testing ($p = .83$). A main effect of time was found for the PASAT, $F(1, 35) = 9.87$, $p = .003$, $\eta_p^2 = 0.218$; Stroop, $F(1, 35) = 9.65$, $p = .003$, $\eta_p^2 = 0.216$, but not for Verbal Fluency, $F(1, 35) = 1.18$, $p = .29$.

Verbal Fluency. Since prior research showed that traditional piano training enhanced verbal fluency in aging (Bugos & Wang, 2022), we performed an exploratory analysis to observe whether this was the case for a jazz piano training program. Results of an exploratory ANOVA (Group x Time) on all conditions of the Verbal Fluency subtest showed an interaction for the Category Fluency condition, $F(2, 35) = 4.34$, $p = .04$, $\eta_p^2 = 1.02$. No significant interactions were found for Letter Fluency, $F(2, 35) = 3.18$, $p = .08$; or Category Switching conditions, $F(2, 35) = .13$, $p = .72$. No main effect of time was found for verbal fluency conditions (Letter Fluency, $p = .36$; Category Fluency, $p = .08$, Category Switching, $p = .95$).

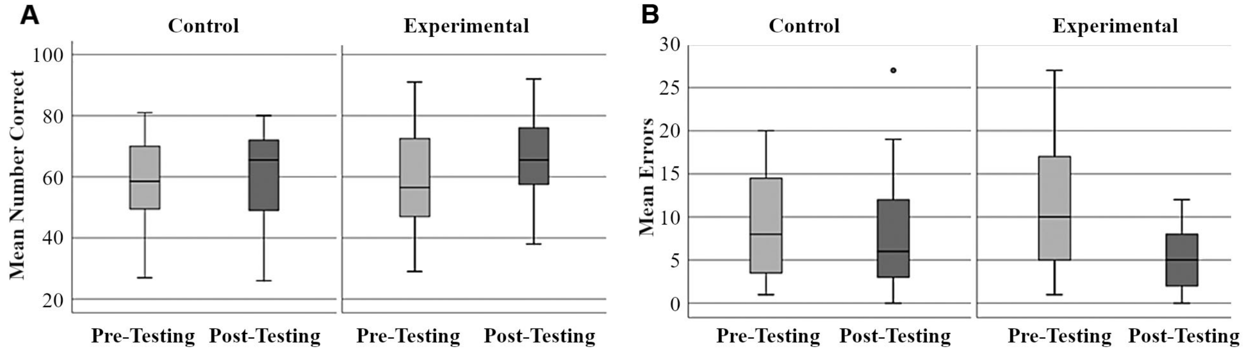

FIGURE 2. A) PASAT total number correct, and B) mean Stroop errors on mixed conditions.

TABLE 2. *Measures of Executive Functions [M (SD)]*

Measures	Piano Training (N = 17)		Control Group (N = 20)	
	Pre-Testing	Post-Testing	Pre-Testing	Post-Testing
PASAT Number Correct*	57.39 (17.94)	67.33 (14.75)	57.58 (16.12)	59.21 (14.12)
Stroop Errors- Mixed Condition*	11.50 (8.15)	5.44 (3.78)	9.47 (6.56)	8.37 (7.13)
Stroop Errors Color Condition	2.06 (3.44)	1.00 (1.37)	1.58 (2.01)	1.16 (2.04)
Stroop Errors Word Condition	0.78 (1.11)	1.39 (1.94)	1.37 (2.71)	1.26 (2.18)
Stroop Mean RT Mixed (ms)	1272.17 (175.66)	1234.47 (199.65)	1190.53 (133.69)	1159.29 (207.47)
Stroop Mean RT Color (ms)	1087.19 (191.73)	1010.99 (208.89)	976.12 (154.88)	953.99 (141.13)
Stroop Mean RT Word (ms)	1038.08 (158.38)	1032.36 (201.21)	978.90 (153.14)	960.49 (194.32)
D-KEFS Letter Fluency	41.28 (14.70)	43.72 (14.43)	43.53 (8.59)	42.00 (10.48)
D-KEFS Category Fluency$^+$	37.67 (9.12)	41.39 (9.81)	39.89 (8.85)	39.47 (8.44)
D-KEFS Category Switching	14.39 (2.55)	14.33 (3.93)	14.26 (2.49)	14.58 (3.27)

Note: Paced Auditory Serial Addition Task (PASAT); Delis Kaplan Executive Function System (D-KEFS)
* denotes significant (p < .05) difference between groups, $^+$ denotes a trend

Cued Color Word Stroop. We analyzed the effects of jazz piano training on Cued Color Word Stroop task performance with an ANOVA (Group x Session x Block) on Stroop errors. Results showed a significant interaction for errors on the Mixed block condition (requires switching between Color and Word cues), $F(2, 35) = 4.31$, $p = .04$, $\eta_p^2 = 0.110$, but no effects were found on Color, $F(2, 35) = 0.77$, $p = 0.39$, or Word conditions, $F(2, 35) = 0.055$, $p = .82$. A significant main effect of time was also found for the Mixed block condition, $F(1, 35) = 10.22$, $p = .003$, but not for the Color block condition, $F(1, 35) = 2.30$, $p = .14$, or Word block condition, $F(1, 35) = 0.34$, $p = .57$. The jazz piano training group committed significantly fewer errors on the Stroop task than controls at post-testing, which indicate that music training did influence task performance.

In addition, a similar analysis was conducted on reaction times by condition. No interactions were found for task-switching reaction times for Color, $F(2, 35) = 2.05$, $p = .16$; Word, $F(2, 35) = 0.19$, $p = .67$, or Mixed conditions, $F(2, 35) = 0.09$, $p = .76$. Results showed a significant main effect of time for the Color condition, $F(1, 35) = 6.79$, $p = .01$, $\eta_p^2 = .163$, but no other main effects of time were found for Word, $F(1, 35) = 0.19$, $p = .67$, or Mixed conditions, $F(1, 35) = 1.60$, $p = .22$.

Interference Effects. We calculated the difference scores between incongruent and congruent conditions for errors and reaction times on the Stroop task. Difference scores were entered into a mixed model ANOVA (Group x Time) to measure the interference effect. The Group x Session interaction was not significant for error rates, $F(2, 33) = 1.13$, $p = .29$, or reaction times, $F(2, 33) = 0.18$, $p = .68$. However, participants from both groups showed lower error rates during the second test session, $F(1, 33) = 10.81$, $p = .002$, $\eta_p^2 = .247$. The main effect of session for reaction times was not significant, $F(1, 33) = 3.01$, $p = .09$.

MEASURES OF IMPROVISATION

Scores from two independent raters were averaged for each motif for overall improvisation achievement scores at pre- and post-testing. At pre-testing, total

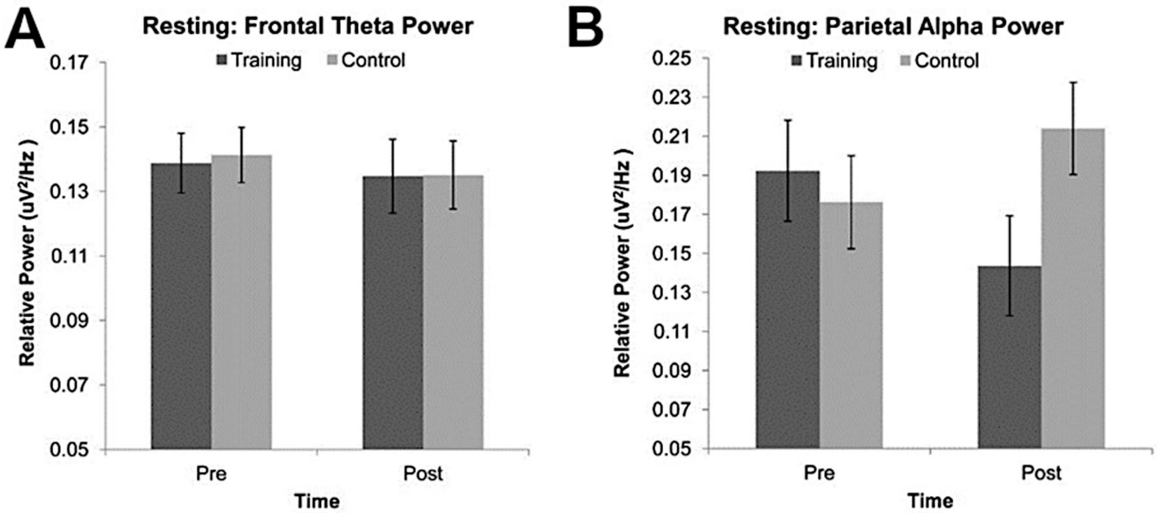

FIGURE 3. A) Resting state frontal theta power, and B) resting state parietal alpha power.

improvisation achievement scores included experimental, M = 111.06, SD = 62.36, and control, M = 92.23, SD = 31.02. The overall pattern of results suggested that both groups increased performance at post-testing, experimental, M = 142.94, SD = 42.66, and control, M = 128.29, SD = 36.08.

Results of an ANOVA with difference scores from pre- to post-test yield no significant group interaction, $F(1, 35) = 1.22$, $p = .29$. Results of a Group x Time ANOVA for Shannon entropy measures showed similar performance by both groups with no main effect of time, $F(1, 29) = 2.29$, $p = .14$, and no group interaction, $F(2, 29) = 0.73$, $p = .40$.

MUSIC LEARNING ACHIEVEMENT

Upon completion of the piano training program, experimental participants independently performed each of four progressively challenging test pieces: "Oh When the Saints," "Rockin Tune," "Cockles and Mussels," and a more challenging, "Got Those Blues." Recordings were evaluated to document music learning, monitor progress in the program, and track successful completion of test pieces which required the ability to perform pieces with fewer than three pitch or rhythmic errors. Two independent raters (with 15–20 years of music teaching expertise) listened independently to music achievement recordings to quantify error (notes/rhythmic errors). Based upon the number of errors quantified by raters (interrater reliability, $r = .90$), participants were either scored as passing (score of 1) with fewer than three notes or rhythmic errors or if more than three errors were indicated (unsuccessful = 0). The percentage of participants who successfully completed each of the graded pieces are as follows: "Oh When the Saints" (95%), "Rockin Tune" (88%), "Cockles and Mussels" (83%), and "Got Those Blues" (76%). Thus, despite a lack of near transfer to a measure of musical improvisation, the intervention was nevertheless effective at improving musical performance.

We examined whether music achievement scores in the experimental group were related to increases in processing speed and inhibition in experimental participants. No significant correlations were found between processing speed, inhibition, and music achievement, $r = .268$, $p = .09$.

ELECTROPHYSIOLOGICAL DATA

Resting State

Results of mixed model (Group x Time) ANOVAs for resting state frontal theta and parietal alpha power showed a significant group by time interaction for parietal alpha, $F(1, 35) = 10.096$, $p = .003$, $\eta_p^2 = 0.224$, with those in jazz piano training showing decreased alpha from pre- to post-testing, and the control group showing increased alpha from pre- to post-testing ($p = 0.048$; Figure 3). Furthermore, there were no significant differences between groups at pre-testing ($p = .649$). There was no interaction found for resting state theta, $F(1, 35) = 0.031$, $p = 0.86$, $\eta_p^2 = 0.001$. There was no main effect of session for theta; $F(1, 35) = 0.719$, $p = .402$, $\eta_p^2 = 0.020$, or for alpha power; $F(1, 35) = 0.162$, $p = .690$, $\eta_p^2 = 0.005$.

MSE. A mixed model (Group x Time) ANOVA for resting state alpha and theta MSE revealed a marginally

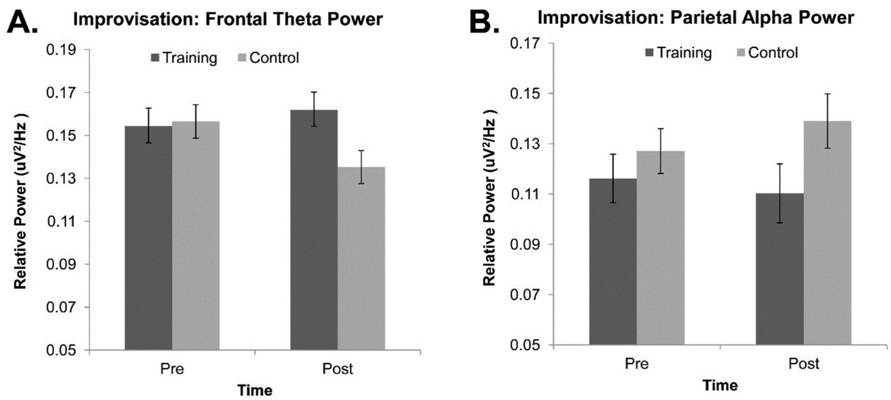

FIGURE 4. A) Frontal theta, and B) parietal alpha power during the Improvisation Continuation Task.

significant interaction for resting state alpha MSE, $F(1, 35) = 3.81$, $p = .054$, $\eta_p^2 = 0.623$ and resting state theta, $F(1, 35) = 3.92$, $p = .053$, $\eta_p^2 = 0.614$. We observed an increase in alpha and theta MSE at post-testing as compared to a stable control group. However, the main effect of session on alpha, $F(1, 35) = 0.109$, $p = .74$, and on theta MSE were each not significant, $F(1, 35) = 0.378$, $p = .54$.

IMPROVISATION CONTINUATION TASK

A mixed model (Group x Time) ANOVA for theta and alpha power on the Improvisation Continuation Task showed a group by time interaction for theta power, $F(1, 35) = 7.725$, $p = .009$, $\eta_p^2 = 0.181$ (Figure 4). Post-hoc comparisons for frontal theta revealed significantly greater power in the experimental group than the control group at post-testing ($p = .024$) and no significant difference between groups at pre-testing ($p = .848$).

The Group x Session interaction for alpha power was not significant, $F(1, 35) = 1.748$, $p = .195$. However, we found a main effect of session on parietal alpha, $F(1, 35) = 12.954$, $p = .001$, $\eta_p^2 = 0.270$. In addition, the main effect of session on frontal theta was not significant, $F(1, 35) = 1.739$, $p = .196$.

A mixed model ANOVA as conducted for MSE during the Improvisation Continuation Task for each of theta and alpha bands that revealed no significant group interaction for theta, $F(1, 35) = 1.02$, $p = .32$, or alpha, $F(1, 35) = 0.92$, $p = .34$. There were no main effects of time for theta, $F(1, 35) = 0.23$, $p = .63$, or alpha, $F(1, 35) = 0.56$, $p = .46$.

Since theta power has been linked to inhibition and to a lesser extent processing speed as a function of age (Pscherer et al., 2021), we conducted bivariate correlations to examine the relationship between theta power recruited during the Improvisation Continuation Task, processing speed, and inhibition performance. While no significant correlation was found at pretesting, analyses with these measures at post-testing revealed a significant negative correlation between errors committed on the Stroop task and PASAT scores (i.e., number correct for processing speed) as theta power increased ($r = -.446$, $p = .014$).

Discussion

This is the first study to our knowledge to examine an intensive jazz piano training program in older adult novice musicians. At pre- and post-test, older adults completed measures of executive functions, as well as a musical improvisation task on the piano during which EEG and behavioral responses were recorded. Improvisation responses were subjectively rated and quantitatively measured using Shannon entropies, and frontal theta and parietal alpha EEG activity during improvisation and at rest were quantified as well as MSE. Findings revealed improvements in executive functions via performance on the Stroop task, as well as PASAT scores after training. Furthermore, training was found to modulate neural oscillatory activity, namely frontal theta power during a musical improvisation task. Results suggest the development of improvisation skills could improve processing speed and task-switching as denoted by reduced errors during mixed trials of the Stroop task in healthy older adults.

Musical improvisation involves not only generating novel responses, but also listening and imitation—all three facets of performance captured by the training intervention and the Improvisation Continuation Task used in the present study. When performing jazz music, effortful attention is devoted towards perception of the beat and rhythm (Larsen, 2006) and perceiving which temporal objects (i.e., musical notes) are combined to form larger musical elements, such as phrases (Loui & Guetta, 2019). Furthermore, the learning of jazz improvisation technique depends on the use of short- and long-term memory and continuous appraisal of one's retrieval of musical sequences (Belden et al., 2020). Our findings are consistent with Pressing's model of improvisation that suggests an increase in automatized processes (rather than controlled processes) through the development of improvisational fluency with experience. Our research included beginner musicians who are developing fluency through listening, imitation, and finally improvisation experiences. Thus, refinement of improvisation skills depends upon practice of controlled processes (i.e., executive functions) in a variety of contexts leading to patterns of redundancy (i.e., a musical sequential memory and motor memory) in which improvisers must direct attention to make decisions leading to a successful extemporization (Pressing, 1988).

The ability to make musical decisions based upon contextual features and musical expertise is an important part of improvisational learning. Although ten days of intense piano improvisation training is a relatively short-time, older adults successfully learned to extemporize based upon a basic 12-bar blues progression post-training when given the opportunity to choose their own tempo (See Supplemental Materials accompanying this paper at online.ucpress.edu/mp for sound examples). Many adults chose slower tempi to enable time for musical decisions in the right hand while performing the walking bass in the left hand. Older adults preferred to play the familiar song (e.g., "Oh When the Saints") without improvisation and then to add riffs to held notes (see Supplemental Materials). Although we found no significant difference in improvisation on the Improvisation Continuation Task, several adults mentioned in our qualitative exit survey "feeling anxious" during this task as compared to improvisation in the context of a familiar tune. Therefore, the Improvisation Continuation Task may not be an optimal measure for beginning level older adults.

Interestingly, the jazz piano intervention in the present study was found to enhance executive functioning post-training—namely task-switching and processing speed. Musical improvisation has shown associations with neural activity from regions underlying executive functions, such as the anterior cingulate cortex (ACC), inferior frontal gyrus (IFG), and premotor cortex (PMC), which suggests that rhythmic and melodic improvisation greatly increases activity in several overlapping brain networks (Berkowitz & Ansari, 2008). These brain regions in expert jazz musicians may underlie refined perceptual skills necessary for professional musical performance (Vuust et al., 2012). In the context of novice musicians, these training effects for enhanced attentional processing may be acquired in the short-term, though future research should explore the long-term effects of short-term music improvisation training.

Our findings showed that both groups demonstrated increased performance at post-testing with respect to their overall improvisation achievement scores, with scores being higher for the experimental group than controls, and highest for the former group at pretesting. It is important to mention, however, that participants were not trained on the task and levels of formal musical training varied. Moreover, results of Shannon entropies were similar to entropies reported in other studies (Limb & Braun, 2008; Pinho et al., 2014), revealing no significant difference in terms of complexity between groups using data from the MIDI-recorded responses on the piano. Perhaps other quantitative measures besides entropy are to be explored in future research.

Findings from neural oscillatory activity suggest learning musical improvisation may assist older adults in more efficient short-term recruitment of cognitive resources with modulations of theta power during the improvisation task. Here, the jazz piano training group showed a maintenance in relative theta power over frontal areas whereas the control group showed reductions in relative theta power over frontal areas. The change in theta activity between groups may be attributed to greater attention and the use of more resources for cognitive control after training. Indeed, research by Klimesch and colleagues (1994, 1996) suggests theta activity to be related to the successful encoding of new information and memory demands. Theta power has also been associated with cognitive control (Cavanagh & Frank, 2014), inhibition (Clements et al., 2021), working memory, and sustained attention (Kardos et al., 2014; Klimesch et al., 2006) with a decrease in power (primarily over frontal areas) usually interpreted as a decrease in cognitive control, attention, or periods of boredom (Katahira et al., 2018). Therefore, the present findings in theta power, and supported by our exploratory correlational analysis, may account for differential recruitment of cognitive resources for executive control during improvisation post-training.

Alpha activity during resting state has been suggested to act as a preparatory mechanism for attention with greater task-relevant demands associated with a stronger modulation of alpha activity (Klimesch, 1997; Klimesch et al., 1993). Alpha increases for the control group when compared to the experimental group could suggest the recruitment of additional cognitive resources by controls. There is also evidence in the literature of increased alpha activity associated with higher creativity and creative ideation (Benedek et al., 2018). Due to lack of increased improvisation scores and alpha by the experimental group, we did not see this pattern of results. Moreover, creative ability such as musical improvisation can be predicted from the strength of the resting-state fMRI functional connectivity within the DMN, ECN, and salience networks, with greater individual creativity associated with greater dynamic coupling between DMN and ECN (Beaty et al., 2015, 2018). Therefore, future studies may explore the use of neural connectivity to quantify changes attributed to short-term training interventions for older adults. Lastly, MSE results showed resting state changes in neural oscillatory activity, but MSE was not able to index changes during the improvisation task. Perhaps, a longer-term improvisation training program is necessary to demonstrate changes in MSE in alpha and theta bands during improvisation tasks. Higher complexity values have been associated with younger age or lower severity of age-related pathology (Cassani et al., 2018; Goldberger et al., 2002). To the best of our knowledge, this is the first time a measure of entropy has been used to quantify neural oscillatory changes from a music training intervention in older adults. MSE does have limitations that could have influenced our results. For instance, the coarse-graining procedure of MSE decreases the time series length that contributes to the number of data points available for entropy estimation (Borin et al., 2021). This may have reduced the sensitivity of the MSE analysis in the present study.

Limitations of this study include a lack of an active control group, as only a passive no-treatment control group was implemented. Future research with a larger sample and active control tasks are necessary to examine the role of improvisation and disambiguate extraneous factors (i.e., social elements, level of engagement) on cognitive performance in adults with little to no previous music training. Additionally, older adults in the present study were not required to practice as part of this intervention program, due to a three-hour per session time commitment. Since many did not own pianos or keyboards, practice opportunities were limited. Additional research is necessary to examine practice quality and time allocation on cognitive outcomes in aging. Moreover, given that EEG activity can differentiate between improvisational and non-improvisational musical performance in expert improvisers (Sasaki et al., 2019), future research may opt to explore the unique value of music training approaches that incorporate improvisation over traditional approaches.

In conclusion, the present study suggests that jazz piano training may enhance executive functions and modulate theta oscillations in older adults. This result is consistent with other studies examining music training interventions on neural oscillatory activity (Lu et al., 2022; Wang et al., 2022). Since most traditional piano training protocols offer little opportunity for musical creativity through improvisation (Bugos, 2018; Hudak et al., 2019; James et al., 2020), these data provide evidence on the value of improvisation in aging. Jazz piano training may produce similar results that are consistent with research in adults who received longer-term traditional piano training (Seinfeld et al., 2013). Those who received short-term jazz piano training were observed to have enhanced cognitive flexibility, working memory, and complex processing speed when compared to the control group. In addition, modulations in theta oscillations during musical improvisation were observed post-training. These neurophysiological and cognitive changes from training may contribute to enhancing cognitive reserve, thus highlighting the usefulness of short-term music training in promoting successful aging. Lastly, initial results including jazz improvisation training for older adults suggest that similar training may increase executive functions, thus improving brain health in older populations.

Author Note

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