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Individualized Piano Instruction enhances executive functioning and working memory in older adults

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Abstract

This study evaluates transfer from domain-specific, sensorimotor training to cognitive abilities associated with executive function. We examined Individualized Piano Instruction (IPI) as a potential cognitive intervention to mitigate normal age-related cognitive decline in older adults. Thirty-one musically naïve community-dwelling older adults (ages 60–85) were randomly assigned to either the experimental group ($n = 16$) or control group ($n = 15$). Neuropsychological assessments were administered at three time points: pre-training, following six months of intervention, and following a three-month delay. The experimental group significantly improved performance on the Trail Making Test and Digit Symbol measures as compared to healthy controls. Results of this study suggest that IPI may serve as an effective cognitive intervention for age-related cognitive decline.

Introduction

Age-related cognitive deficits are often associated with executive dysfunction in working memory, strategy maintenance, and planning and updating (Salthouse, 1994). Many studies suggest that age-related cognitive decline may be associated with a degree of disconnectivity or loss of the ability to functionally integrate multiple systems resulting in cognitive dysfunction (Dixon, Backman, & Nilsson, 2004). Functional imaging studies provide evidence regarding age-related anatomical differences in the prefrontal cortex (PFC) during working memory tasks (Nyberg et al., 2003; Rypma & D'Esposito, 2000). Additionally, the temporal relationship between PFC activation and activation of the medial parietal and posterior cingulate cortex changes in aging (Lustig et al., 2003). Structural imaging studies have shown that aging affects white matter in the brain traditionally linked to several cognitive areas such as executive functioning, visuospatial skills, motor speed, and processing speed (Almkvist, Wahlund, Andersson-Lundman, Basun, & Backman, 1992; Kertez, Polk, & Carr, 1990). A key challenge for successful aging is to discover cognitive interventions that have the capacity to integrate multiple neural networks to mitigate or prevent age-related cognitive decline.

Kramer, Bherer, Colcombe, Dong and Breenough (2004) recently reviewed the relationship between lifestyle factors and cognitive vitality in aging. Studies conducted in the US, Europe and Asia all conclude that persons with more complex occupations maintain better cognitive function as they age. Apart from the workplace, individuals who engage in new games or skills reduce the potential for age-related cognitive decline. The protective effect of mental activity seems to depend upon the variety of skills and tasks. Skilled typists, for example, learn strategies that enable them to maintain high typing performance with age, but they do not appear to obtain a general protection from cognitive decline with aging. Aerobic exercise has also been associated with slower cognitive decline in aging. An increase in growth factors related to exercise may be associated with neuro-muscular remodeling, protective effects of additional muscle mass, cognitive challenges associated with participation in a sport, completing an exercise session, and continuing to exercise regularly over time. One limitation is that the benefits of exercise are predominantly physical or domain-specific. Some cognitive training programs offer a variety of tasks and result in enhanced cognitive abilities that generalize to other cognitive domains.

Specific cognitive training programs have demonstrated some benefits including improvements in primary and secondary working memory, tasks

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specific to processing speed, strategy learning, and interference tendency (Cavallini, Pagnin, & Vecchi, 2003; Gunther, Schafer, Holzner, & Kemmler, 2003; Verhaeghen, Marcoen, & Goosens, 1992). Cognitive restructuring programs can lead to personal control over cognitive functions such as focused attention, cognitive effort, and promote strategy usage, compared to traditional memory training programs (Caprio-Prevette & Fry, 1996). While many approaches to cognitive training have been developed, there are many limitations associated with current interventions. Many training programs have been targeted at identifying age-related changes in the architecture of cognition, rather than seeking the optimal overall benefit. These studies support the view that both younger and older adults have a cognitive architecture that can be flexibly redeployed, and that task training particularly helps older adults to learn to use their cognitive resources to improve their task performance (Kramer, Hahn, & Gopher, 1999; Verhaeghen, Cerella, & Basak 2004). A significant limitation of most cognitive training interventions is the lack of transferability to everyday situations (Ball et al., 2002; Edwards et al., 2002). Since participation in a complex occupation and engagement in mentally challenging leisure activities appears to produce generalized protective effects, but rehearsal of a highly familiar task such as typing does not, there should be a cognitive training dual of a complex lifestyle. It should be possible to develop cognitive training paradigms, which produce enduring, generalized mitigation of cognitive decline with aging.

We hypothesize that one reason for lack of transferability to multiple cognitive domains lies within task complexity. Distributing task demands among several cognitive domains may contribute to the facilitation of top-down processing resulting in multiple cognitive enhancements. Most cognitive training programs focus on one training task and engage few cognitive processing systems (Stigsdotter & Backman, 1989). Engaging many cognitive information processing systems and learning and memory capacities is essential to maintaining them and preventing their decline in normal aging.

The optimal cognitive intervention would include self-efficacy, progressive difficulty, motivated practice, novel stimuli/task, and multimodal sensorimotor integration. The underlying rationale is that any progressively difficult cognitive training program that motivates participants to engage in activities, which coordinate motor activity with short-term planning, and long-term cognitive strategies will strongly contribute to maintaining cognitive skills in aging. Music education naturally motivates these interlocking activities with the intrinsic enjoyment and sense of self-esteem that stem from skilled musical performance. Musical training is therefore expected to contain the key attributes necessary to engage and preserve attention and memory systems throughout the lifespan.

The goal of this study is to evaluate the role of musical instruction as a potential cognitive intervention to prevent or maintain cognitive skills in normal aging. Active music making promotes cognitive skill and concept development directly influencing memory formation and retrieval. Music instruction has improved cognitive abilities among other demographic populations. Individualized music instruction has been directly correlated with higher verbal memory task performance among children and college students (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003). Four-year-old children receiving ten minutes of piano instruction up to twice a week performed better on spatial-temporal task performance assessments than children receiving computer training (Rauscher, Levine, Shaw, & Wright, 1997). After eight months of piano instruction, kindergartners displayed greater improvements in spatial abilities than the control group (Rauscher & Zupan, 2000; Sarnthein et al., 1997). Six-year-olds scored significantly higher on a Short-Term Memory subtest of the Standford-Binet Intelligence Battery after receiving thirty weeks of music instruction (Bilharz, Bruhn, & Olson, 2000). Participants who had five or more years of piano instruction demonstrated increased activation in the cerebral cortex and a higher degree of retention one year later (Altenmuller, 2001). In addition, differentiated tasks required to play an instrument help strengthen and form new synapses (Rauschecker, 2001).

Music therapy has been recognized as a possible intervention for cognitive rehabilitation. Although the Older Americans Act was amended in 1992 to include music therapy, most music therapy programs have consisted of listening activities, rather than active music making (Bernstein & Clair, 1990). Research has shown a significant positive correlation between music listening and cognitive functions such as verbal or declarative memory on clinical populations. Furthermore, research has shown that participation in leisure activities such as musical performance may reduce the risk for developing dementia (Verghese et al., 2003).

This research aimed to extend individualized piano instruction (IPI) as a cognitive intervention to the well elderly population (ages 60–85). We hypothesize that IPI will serve as an effective and enjoyable intervention to preserve cognitive function and prevent mild age-related memory loss.

Methods

Participants

Thirty-nine participants were recruited from an age-restricted independent residential area, from large churches with extensive community

Table I. Mean (±SD) demographic and baseline data for controls and experimental participants.

	Controls ($n = 16$)	Experimental ($n = 15$)
No. of males/no. of females	4/13	4/12
Age (years)	71.4 (6.4)	69.6 (4.7)
Education (years)	16.3	16.5
BDI	5.8 (4.6)	3.1 (2.2)
PIQ	33.4 (5.3)	32.8 (5.1)
VIQ	48.3 (6.9)	51.7 (6.2)
WMI	34.8 (5.4)	37.8 (6.7)
AMMA Tonal	24.5 (4.9)	24.4 (4.1)
AMMA Tonal percentile rank	52.4 (24.2)	52.5 (20.9)
AMMA Rhythm	26.1 (4.4)	25.7 (4.9)
AMMA Rhythm percentile rank	45.3 (21.8)	44.4 (22.1)

Notes: BDI: Beck Depression Inventory; PIQ: Performance Intelligence Quotient; VIQ: Verbal Intelligence Quotient; WMI: Working Memory Index; AMMA: Advanced Measures of Music Audiation.

outreach and other members of the Gainesville, Florida community. The University of Florida Institutional Review Board monitored compliance with local, state and federal guidelines for human subjects' research. A questionnaire excluded participants with neurological impairments such as Alzheimer's disease or other dementia, health problems affecting hand dexterity, experienced musicians with five or more years of training, and those younger or older than the target age range of 60–85 years. Depressed persons, were identified and excluded by a score $>$14 on the Beck Depression Inventory (BDI; Beck, Brown, & Steer, 1996). Individuals that reported neurological abnormalities, including a history of seizures, stroke, or taking psychoactive medications were also excluded. Participants who experienced medication changes during the study were also excluded as many medications such as anti-cholinergics for heart conditions, may adversely affect cognitive performance.

Participants were randomly assigned to an experimental group, which received six months of IPI or an untreated control group. Initially, 21 (4 male and 17 female) participants were enrolled in the experimental group and 18 (4 male and 14 female) participants were enrolled in the control group. Sixteen experimental participants and 15 control participants completed the study (Table I). Attrition was due to (A) failure to comply with the IPI regimen, (B) health problems not related to the study design, and (C) participants who had a strong preference for either the experimental group or the control group chose to voluntarily withdraw upon group assignment.

Cognitive assessments

The initial assessment battery included both tests of (A) overall cognitive and music ability and (B) working memory and executive functions. Measures of overall cognitive ability were presented to confirm that the experimental and control groups have similar mental abilities and to compare possible IPI-enhanced memory performance with cognitive or musical ability. All participants were assessed at the same time points: pre-training, post-training (six months), and following a three-month delay. Multiple cognitive assessments were administered at each time point, and were chosen based upon their association with cognitive domains thought to be related to the prefrontal cortex (PFC), an area often associated with working memory and executive function (Cohen et al., 1997; Postle, Brush, & Nick, 2004).

Assessments of musical aptitude and cognitive functioning

The *Advanced Measures of Music Audiation* (AMMA; Gordon, 1989) was administered as a baseline measure to determine initial music aptitude that may potentially affect musical learning ability. AMMA was chosen to assess musical aptitude, because it has been validated in adults with no previous musical experience. Participants listened to a series of 30 taped melodic excerpts and distinguished potential rhythmic and melodic alterations by shading the appropriate answer. Percentile rank scores were based upon Gordon's (1989) table for individuals with a minimum of 12 years of education.

Ward's seven subtests of the *Weschler Adult Intelligence Scale III* (WAIS III; Weschler, 1997) were administered to yield a Performance IQ (PIQ), Verbal IQ (VIQ), and Working Memory Index (WMI) scores. In addition to *Information, Digit Span, Arithmetic, Similarities, Picture Completion, Block Design*, and *Digit Symbol*, the *Vocabulary* and *Letter Number Sequencing* subtests were administered to verify that no significant differences ($p < 0.05$) between group performance on verbal and working memory tasks were present. Ward's abbreviated version of the WAIS III results in 47% to 50% shorter administration time and provides sufficient information to estimate VIQ, FSIQ, and WMI. The abbreviated WAIS III has shown similar psychometric properties that correlate to the full-length WAIS III assessment (Joy, Kaplan, & Fein, 2004; Pilgrim, Meyers, Bayless & Whetstone, 1999). Four subtests (*Digit Symbol, Digit Span, Block Design*, and *Letter Number Sequencing*) were repeated at all three time points. These subtests were chosen as repeated measures based upon their potential sensitivity to piano instruction with respect to spatial, visual, and sequential memory.

The *Trail Making Tests* (TMT Parts A and B; Reitan & Wolfson, 1985) were also administered at each of the three time points to assess visual processing and planning abilities. TMT Part A examines visual scanning, numeric sequencing, and visuomotor speed, while TMT Part B assesses executive functions related to the ability to plan, execute, and modify a potential plan of action. Participants alternate between selection of sequential numeric and alphabetical stimuli.

Six months after the initial testing, (±two weeks) both experimental and control participants were assessed on measures of executive function thought to be related to the prefrontal cortex, which are hypothesized to improve with music instruction. All follow-up testing sessions were conducted individually and lasted for approximately 2.5 to 3 hours. Assessments were varied in order of administration and were provided during two consecutive sessions, due to scheduling limitations at participating facilities.

Analysis of results will indicate significance levels ($p < 0.05$) by repeated measures Group × Time ANOVA for all repeated assessments; *Digit Symbol, Digit Span, Block Design, Letter Number Sequencing, and Trail Making Tests (Part A and B)*. To separately assess the dependence of TMT performance on cognitive and motor skills, the results of the TMT assessment minus the motor aspect, results of TMT B (alternate between letters and numbers) minus TMT A (numbers alone) will extract motor skill level and allow for examination of cognitive skill performance.

Individualized Piano Instruction (IPI)

The IPI program is designed to be a broad-based music education program, including instruction with progressive difficulty in musical performance, technical motor/dexterity exercises, and music theory. Specifically, the IPI program required participants to attend a half-hour lesson each week, and to practice independently for a minimum of three hours per week. Practice sessions were recorded on a tape recorder or Superscope PSD 300 CD recorder, and practice-time was logged. A typical lesson began by correcting errors in the weekly music theory assignment (*Schaum Note Speller*; Schaum, 1996) and explaining new theoretical concepts for study. Music literacy was an important focus as participants were 'musically naïve' and unable to read music prior to enrollment.

Topics in music theory consisted of basic note reading, intervallic and key relationships, and basic tertian harmony. Participants performed initial exercises presented in the *Alfred All-In-One Basic Piano Course Level 1* prior to performing their pieces (Lethco, Manus, & Palmer, 1996). These exercises are designed to familiarize the student with basic chord progressions and rhythmic challenges encountered in their pieces. Once students are familiar with the lesson's objective and have practiced a particular skill in isolation, students are ready to integrate this knowledge into performance.

Then, the participant's ability to play a musical scale, primary triads, and perform dexterity exercises (*The Virtuoso Pianist in Sixty Exercises for the Piano*; Hanon, 1900) was critiqued. Participants were taught new scales and arpeggios every two weeks. Hands separate practice was required for each scale in the first week, followed by scale completion with performance hands together the second week. Participants were taught major and minor scales using the circle of fifths and the pieces studied as guidelines. For instance, if they were to learn a new piece in A minor, their scale assignment included all three forms of the minor scale as well as performance of a basic i-iv-i-V-i chord progression. Only one Hanon exercise was assigned every week and often these required two weeks to complete at a moderate tempo. Speed was not a requirement of these exercises as the purpose was to develop finger strength and dexterity.

Finally, participants performed selections from *Alfred All-In-One Basic Piano Course Level 1* (Lethco et al., 1996) and were counseled on strategies to overcome weaknesses. Each week they received a new assignment, incrementally building on their individual cumulative achievements.

Data analysis

Data were analyzed using separate 2-Group × 3-Time analyses of variance (ANOVAs) with group as a between-subjects factor and time as within-subject factor. Only significant effects in the ANOVAs are reported. Significant effects were further examined by planned contrasts to determine the source of effects. For ANOVAs where there were more than two levels of a within-subject factor, the Huynh-Feldt epsilon adjustment (Huynh & Feldt, 1976) was used; uncorrected degrees of freedom and corrected p-values are reported. Planned and follow-up contrasts were also employed and, where appropriate, used the Bonferroni adjustment for multiple comparisons (Keppel, 1982).

Results

Demographic characteristics

Thirty-one participants (16 experimental and 15 controls) successfully completed the study. The alpha level was set at 0.05 for all statistical tests. There were no significant differences between groups on baseline measures of intelligence (WAIS-III) and music aptitude (AMMA). Baseline scores for the experimental group and control group (Table I) illustrate no significant differences between group PIQ, VIQ, and WMI. AMMA results are reported as tonal raw scores (T_{RS}), tonal percentile rank (T_{PR}), rhythmic raw scores (R_{RS}), and rhythmic percentile rank (R_{PR}).

Table II. Mean (+SD) cognitive assessment data for controls and experimental participants.

	Controls ($n = 16$)			Experimental ($n = 15$)		
Measures	T1	T2	T3	T1	T2	T3
Trail making test						
Card A	42.0 (9.0)	36.7 (10.6)	36.8 (9.7)	42.6 (10.2)	37.6 (12.7)	31.3 (10.0)
Card B	87.4 (24.4)	101.3 (35.3)	93.7 (34.5)	98.4 (29.9)	84.9 (27.7)	72.1 (19.3)
Trails delta	46.0 (23.3)	65.5 (29.8)	56.5 (32.7)	55.8 (31.7)	47.3 (24.5)	40.8 (17.5)
WAIS-III subtests						
Digit symbol (RS)	53.2 (12.0)	53.9 (15.6)	56.5 (11.9)	50.3 (14.3)	59.9 (18.0)	72.6 (11.8)
Total digit span (RS)	17.4 (3.2)	17.3 (4.2)	17.5 (2.6)	19.1 (3.8)	20.8 (4.2)	19.3 (5.0)
Block design (RS)	31.5 (9.3)	32.5 (7.0)	33.7 (5.3)	30.4 (8.5)	34.0 (11.0)	33.9 (9.0)
LNS (RS)	9.8 (2.9)	9.9 (2.1)	9.5 (2.2)	11.3 (2.7)	11.1 (1.9)	10.8 (2.9)

Note: T1: Pre-training; T2: Post-training; T3: Delay; WAIS-III: Weschler Adult Intelligence Scale; RS: Raw Score; LNS: Letter Number Sequencing.

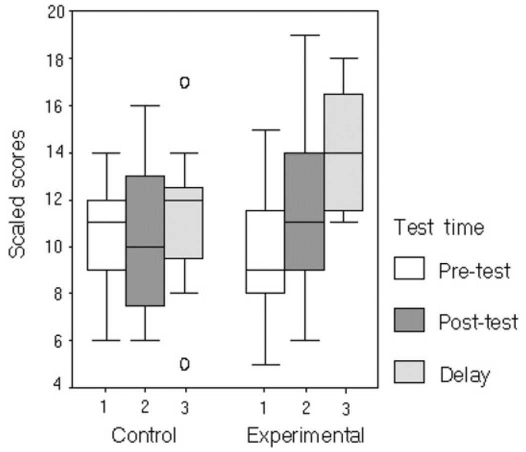

Figure 1. Results of the Digit Symbol (WAIS III subtest) Scaled Scores. The box plot contains the range of scores with the median represented by a solid line inside the box, outliers represented by points outside the box.

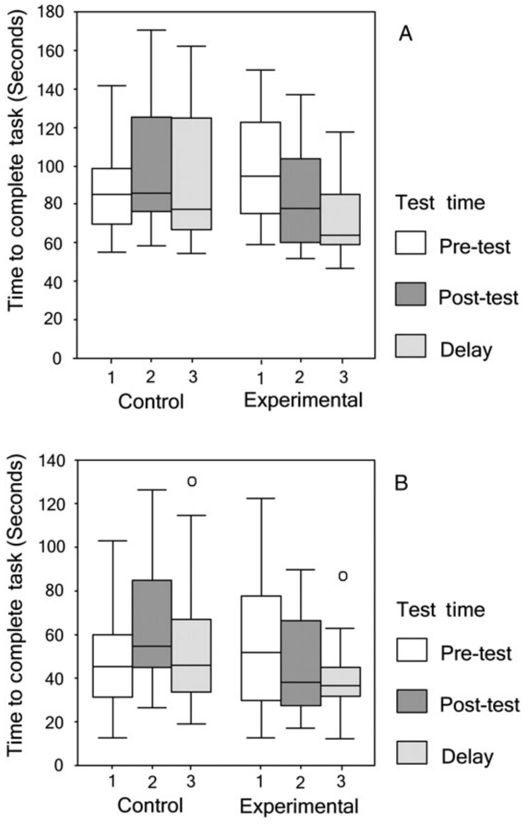

Figure 2. Results of the Trail Making Test (TMT) (A) Card B performance and (B) Trails delta scores over all time points. The box plot contains a range of scores with the median score represented by the solid line inside the box and outliers represented by points outside the box.

Post-training results

The Group × Time ANOVA on Digit Symbols yielded a significant interaction, $F(2, 55) = 4.68$, $p < 0.015$. As shown in Figure 1, experimental group scaled scores increased during training and during the post-training interval, while the control group did not show such a pattern as a function of time.

A repeated measures ANOVA showed a significant main effect for test time on TMT Card A, $F(2, 58)$, $p < 0.01$. No significant main effects were found for a Group × Time interaction on TMT Card A indicative of similar performance on motor-specific tasks. Analysis of the TMT Card B yielded a significant Group × Time interaction, $F(2, 55) = 4.44$, $p < 0.03$. As can be seen in Figure 2, the interaction effect reflected the fact that performance in the experimental group improved over time, whereas this was not the case for the control group. There were no significant main effects for time on TMT Card B. An additional ANOVA was performed on a 'delta score', wherein scores on TMT Card B were subtracted from performance on TMT Card A for each participant over each time point. A repeated measure ANOVA on 'delta scores' indicates no significant main effects for group or time. A Group × Time ANOVA revealed a trend for TMT 'delta scores', $F(2, 56)$, $p < 0.08$.

There were no significant findings on the repeated WAIS-III subtests of Digit Span Backward, Block Design, and Letter Number Sequencing (Table II). A repeated measures Group × Time ANOVA for the total *Digit Span Subtest* over all three time points yielded no significant interaction effects $F(2, 58) = 2.09$, $p = 0.13$. In addition, there were no main effects for time or Group × Time for any of these WAIS-subtests. However, a trend was found for the *Digit Span Forward* (WAIS-III subtest) after a repeated measures Group × Time ANOVA for pre- and post-testing time points, $F(1, 29) = 3.59$, $p = 0.06$. Interestingly, the experimental group does not maintain performance gains when practice is discontinued.

Discussion

The primary aim of the present research was to determine if IPI results in enhanced performance on cognitive tests of attention and working memory in healthy older adults. We predicted that IPI would either reduce the normal age-related decline in these processes or improve performance in these processes. Further, we also examined whether or not the potential cognitive benefits of IPI would be sustained over time, even after IPI was terminated. Results were generally supportive of our overall hypotheses, though not completely so.

IPI may increase cognitive abilities related to attention and concentration, contributing to overall working memory. Although the TMT contains a motor component, the pattern of results support a consistent trend affecting cognition even after motor effects are extracted. Both Digit Symbol and TMT enhancements were shown to significantly contribute to attention, concentration, and planning across all time points. Improvements in Digit Symbol performance may indicate that IPI had a beneficial influence on participants' perceptual speed, visoscanning, and memory abilities (Joy, Fein, & Kaplan, 2003). Thus, the effects of IPI not only transfer to not specifically musical cognitive domains, but also were sustained. However, the notion that IPI is a sustainable cognitive intervention must be tempered by the results of the Digit Span subtest, in which cognitive benefits were not sustained when practice and lessons were discontinued.

TMT Part A is a baseline visual scanning and motor processing task, while Part B includes cognitive flexibility through alteration of numeric/alphabetical stimuli in addition to visual scanning and motor processing. As in previous studies (Abbatecola et al., 2004), we subtract performance on Part A from Part B to isolate the contribution of cognitive flexibility. Significant decreases in time to complete the task were found for experimental participants over each time point as compared to healthy controls. IPI necessitates high levels of temporal and spatial processing, thus forcing the performer to plan, organize, and sequence musical passages into a cohesive musical event. Recent imaging research suggests patterns of functional reorganization of the sensorimotor and temporal association cortices resulting from six months of music training in novices (Kim et al., 2004).

This overall pattern of results contrasts with the achievements of traditional approaches to cognitive aging. Most cognitive training interventions fail to generalize beyond task-specific performance measures. Our findings indicate significant performance gains in general cognitive assessments that were not specifically trained in IPI. Transferability of an intervention to other cognitive domains is extremely rare in the aging literature (Ball et al., 2002; Edwards et al., 2005). Memory training paradigms also demonstrate learning in the trained task with restricted generalizability (Neely & Backman, 1995). One potential explanation underlying the transferability of IPI may be the disparity in the overall approach to cognitive training. IPI consisted of training multiple cognitive and motor domains whereas most cognitive interventions employ a unimodal training task.

Limitations and alternative interpretations

Three hours of piano practice weekly was required as part of the IPI regimen. When practice was not maintained and individual instruction discontinued, some cognitive benefits were no longer sustained at the three-month delay time point. Even though all participants who completed the study practiced a minimum of three hours per week, quality and quantity of practice varied on an individual basis. Although participants were instructed to discontinue practice during the three-month delay, we did not independently monitor their compliance beyond the self-report.

Most cognitive training research contains a rather large sample size (Caprio-Prevette & Fry, 1996). Due to the small sample size ($N = 31$), more participants may have been necessary to achieve more generalizable statistical results. One limitation of the study design included a lack of an attentional component for the control group. Individual attention was given to each participant assigned to the experimental group during each weekly 30-minute lesson. Providing an attentional component for members of the control group would further isolate the potential impact of the independent variable, individualized piano instruction. Furthermore, the pattern of results cannot be explained by increases in attention alone. Significant enhancements were found in multiple cognitive domains such as planning, information processing speed, and working memory processes.

Conclusions

Pianists integrate hand movements into an aesthetic and temporal context while engaging in a visual spatial process of reading musical notation (Meister et al., 2004). A musically naïve individual will expend extra time and effort to examine patterns, regulate rhythmic deficiencies, and correct finger movements. Rehearsal of musical skills can affect multiple integrated neural networks that require less recruitment of attentional components after the skill becomes implicit. We hypothesize that as the performer actively allocates attentional resources to musical passages or music theory exercises; the integration of multiple networks by repeated practice (bimanual coordination) is reinforced and transferred to multiple cognitive domains. This top-down processing may not be specific to music instruction, but can serve as a hypothesis for other cognitive training regimens.

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