How can Musical Training Improve Cognition

Helen Neville and (in alphabetical order)
Annika Andersson, Olivia Bagdade, Ted Bell, Jeff Currin,
Jessica Fanning, Linda Heidenreich, Scott Klein
Brittni Lauinger, Eric Pakulak, David Paulsen, Laura Sabourin
Courtney Stevens, Stephanie Sundborg, and Yoshiko Yamada

Brain Development Lab, University of Oregon

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Christine Petit

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There is universal agreement that learning to make music and experiencing meaningful musical events are inherently and uniquely valuable. Recently, motivated in part by cuts to school budgets for education in arts and music, a burgeoning literature has sought to provide evidence of potential benefits of music instruction on cognitive and academic development in children. The vast majority of these studies have compared cognitive functions in trained musicians and non-musically trained individuals. There have been several reports that musicians have higher verbal skills, visuo-spatial skills, numeracy skills and IQs than non-musicians (summarized in Schellenberg 2006 and Norton et al. 2005). Virtually all such reports interpret these correlations as showing that music causes improvements in cognition. However, it is of course equally likely that people with strong cognitive skills are more likely to make the considerable cognitive effort to learn music. Learning music requires focused attention, abstract, relational thinking and fluid intelligence (executive control). Therefore, it is highly likely that a major factor in producing the positive correlations between music and cognition are the result of the fact that people with better cognitive skills choose to learn music.

It is also likely that learning music also trains and builds cognitive resources. In order to assess this hypothesis it is necessary to randomly assign individuals to either receive music training or other comparison training or no training. Very few studies have taken this approach. Moreover, these few studies typically only studied a limited number of cognitive abilities. Thus, for example, Rauscher reports that individual piano lessons result in improvements on spatial and spatial temporal skills in young children (Rauscher et al. 1997, 2002). Gardiner et al (1996) report that six year olds who receive music and visual arts training display larger improvement on standardized tests of reading and arithmetic than children receiving the standard curriculum. Schellenberg (2004) reported that six-year-old children who received music lessons (voice or keyboard) in a small group displayed larger improvements in all verbal and non-verbal subtests of the Wechsler Intelligence Scale than children receiving drama lessons or no lessons. If these results are upheld they would suggest that music training causes improvements in cognition. Additionally, they would raise the question of how music training might produce such effects. The effects reported are not specific to one type of cognitive skill but appear across a diverse array of abilities. This would suggest that music training may result in improvements of cognitive processes that operate to amplify processing across several domains. One such process is attention. In the research reported here we are investigating the hypothesis that music training causes improvements in several diverse aspects of cognition and that one mechanism whereby it does so is by training attention. Below we briefly summarize what is known about the architecture, development, plasticity, vulnerability and training of attention.

1. Attention

Over the last several decades research in cognitive science and cognitive neuroscience has converged on an understanding of the different components of attention (Driver et al. 2001, Raz and Buhle 2006, Shipp 2004). While different models/groups differ somewhat in their subdivisions and terminology, all recognize the importance of a basic level of arousal/alerting, and the importance of focused selection of specific stimuli/signals for further processing either transiently or in a sustained manner. Attentional selection includes processes of enhancing selected signals (signal enhancement) and, in the presence of salient non-signals, the suppression of irrelevant information or distractor suppression. Distracter suppression is a part of early selection and is also considered to be part of executive or inhibitory control including self-regulation. Executive control is important in suppressing predominant responses generally and also in switching attention between different sets and in dividing attention between different tasks.

2. Development of Attention

Several studies attest to the centrality and relevance of constructs of attention to child development in general, and school readiness in particular (Blair 2002, Early Child Care Research Network 2003, Posner and Rothbart 2000). Studies of the development of attention document a very prolonged maturational timecourse, even for aspects of attention that may be present in some form in infancy. Thus, while alertness is clearly present in infancy, the ability to maintain alertness for effortful processing has a protracted developmental timecourse that extends to young adulthood (Gomes et al. 2000, Rueda et al. 2004). Whereas exogenously driven, transient, selection may mature within the first decade of life (Rueda et al. 2004), the development of endogenous (covert) selection continues until at least the third decade of life (Schul et al. 2003).

In a review of both behavioral and ERP studies of the development of selective attention, Ridderinkhof and van der Stelt (2000) proposed that the abilities to select among competing stimuli and to preferentially process more relevant information are essentially available in very young children, but that the speed and efficiency of these behaviors and the systems contributing to these abilities improve as children develop. To test this hypothesis more directly, we adapted the event-related brain potential (ERP) paradigm employed by Hink and Hillyard (Hink and Hillyard 1976) to make dichotic listening more interesting and engaging for three- to eight-year-old children (Coch et al. 2005. Sanders et al. 2006). As seen in Figure 1 the morphology of

--INSERT FIGURE 1 HERE--

the auditory ERP to these stimuli differed markedly as a function of age. Nonetheless when these listeners were asked to selectively attend to one of two simultaneously presented stories that differed in location (left/right), voice (male/female), and content, children as young as age three years showed an amplification of the ERPs to probe stimuli (i.e. an auditory selective attention effect) with similar onset latency to that observed in adults (100 ms) (see figure). This finding suggests that, if given strong attentional cues, children as young as three years old can selectively attend to auditory information and that the nature and timing of these effects on processing auditory information are similar to those found in adults.

3. Plasticity and Vulnerability of Attention

Our previous behavioral, ERP, and fMRI studies document considerable plasticity of the neural systems important in selective attention. For example, visual selective attention is markedly enhanced in deaf compared to hearing individuals (Bavelier et al. 2000, 2001, Neville and Lawson 1987a, 1987b, 1987c). We have reported similar enhancement of auditory selective attention in congenitally blind adults (Röder et al. 1999, 2003). However, we have recently reported that there appear to be limits on the timeperiod in development when the early (100 ms) mechanisms of auditory selective attention can be enhanced, since late blind individuals do not display these effects (Fieger et al. 2006). These results showing the modifiability (enhancements) of particular aspects of selective attention in congenitally deaf and blind individuals raise the hypothesis that these aspects of attention, like other systems that display a high degree of neuroplasticity (Bavelier and Neville 2002), may develop relatively slowly and may be particularly vulnerable during development. Employing the ERP paradigm described above, we have recently observed attentional deficits in at-risk populations including specifically-language impaired (SLI) (Stevens et al. 2006) and lower SES (Lauinger et al. 2006) children.

4. Training Attention

Since the late 1980s research in the field of cognitive rehabilitation has assessed the effects of training aspects of attention in different adult populations including individuals with traumatic brain injury, those treated for brain cancer and individuals who have had cerebral vascular accidents (e.g., Sohlberg and Mateer 1987, 2001, 2003, Niemann et al. 1990). Many of these studies report improvements in sustained attention and executive function (Ethier et al. 1989, Finlayson et al. 1987, Gray and Robertson 1989). Different investigators have focused on training different aspects of attention in attempts to tailor training to different and specific deficits displayed by individual patients, and this has rendered it difficult to compare results across studies. A recent meta-analysis of this literature calls for more stringent use of control groups in these studies (Park and Ingles 2001). Very recent studies of normal adults show pronounced effects of training (video game playing) on virtually every aspect of attention (Green and Bavelier 2003). In addition, a small literature reports efforts to train attention and working memory in the treatment of children with attention deficits/hyperactivity disorder (ADHD) (Kerns et al. 1999, Klingberg et al. 2002). These studies report significant gains following several weeks of training that occurred daily or every other day.

Recently, Posner and colleagues have investigated the impact of attention training in typically-developing, higher SES preschoolers (Rueda et al. 2005). The activities were adaptive (i.e. progressive increases in the amount of challenge on attentional skills), computer-based activities that were based on a study that showed significant gains in non-human primates following their implementation (Rumbaugh and Washburn 1995). In the Posner study, while the training was only five days, the experimental group showed significantly greater pre-post change in executive control and non-verbal IQ than the control group.

In summary, research has shown that processes of attention are central to every aspect of cognition and school performance. Moreover, processes of attention display a high degree of neuroplasticity and display both enhancements (following sensory deprivation) and vulnerabilities/deficits in many at-risk populations, including those with developmental disorders and from lower SES backgrounds. A handful of carefully designed studies suggest that attention can be significantly improved after specialized training in both at-risk and TD adults and children. In view of these results, the goal of the ongoing research described here is to determine whether music training in preschoolers will produce significant improvements in cognition and school performance that are comparable to the effects produced by attention training.

Hypotheses

We tested the hypothesis that, following eight weeks of 40 minutes per school day of music or attention training in a small group, Head Start preschoolers would display gains in a number of cognitive domains including language, pre-literacy and visual-spatial skills, numeracy and nonverbal IQ and that these gains would be larger than those observed in controls in either large or small groups. Children were randomly assigned to one of the four groups and were matched on variables known to be important in cognitive performance. The effects of the interventions were assayed employing a range of reliable and valid measures of cognition and literacy administered by testers who were blind to the group to which children belong.

Participants

To begin we are keeping the groups homogeneous: all participants are low socio-economic status (SES), three to five years old, right-handed, monolingual, and free of neurological or behavioral disorders. Children are recruited from local Head Start preschools. Head Start is a federally-funded preschool program for children in families with very low household income. Within one month prior to and following the interventions the following tests are administered.

1) **The Clinical Evaluation of Language Fundamentals-Preschool:2nd Ed**. (Wiig et al. 2004)
2) **Stanford-Binet Intelligence Scales-5th Ed. (SB-5)** (Roid 2003)
3) **The Peabody Picture Vocabulary Test-Third Edition (PPVT-III)** (Dunn and Dunn 1997)
4) **Letter Identification** (Clay 1993)
5) **Developmental Numeracy Assessment** (Ginsburg and Baroody 2003)

Interventions

Children in the music-training group received eight weeks of small group (5:2 student/teacher ratio) classes focused on music activities including listening to music, moving to music, singing, and making music. Classes ran for 40 min./day, four days/week, during the regular Head Start school day. To examine whether any effects observed were specific to music training (i.e., whether other types of training would have the same effect), several control-comparison groups were included. The control-comparison groups include: (1) large group control--students receiving regular Head Start instruction with an 18:2 student/teacher ratio; (2) small group control--students participating in regular Head Start activities but in a small group format with a 5:2 student-to-teacher ratio, and (3) attention group--students receiving small group instruction in focusing attention, awareness to details, etc. All control-comparison groups (except the large group control) were taught by the same teachers as the music intervention, and lasted for the same amount of time as the music intervention. To the extent that students in other control-comparison groups show different (or no) gains in the outcomes measured, specificity of the effects of music training can be inferred. If students in other groups display a similar pattern of outcome to those observed in the music group, this will suggest mechanisms whereby music training improves cognition. We hypothesize that learning music may train attention, and that the effects of these two interventions may be similar.

1. Large Group Controls

The children in the regular Head Start classrooms (N = 19, 18:2 student/teacher ratio) also displayed similar improvements in the CELF tests of receptive ($p < .01$), expressive language ($p < .01$) and phonological awareness ($p < .03$). However there were no significant improvements in the other tests.

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2. Music Training

Following the music training program, children (N=26) displayed significant improvements on the CELF tests of language including receptive language ($p<.01$) and expressive language ($p < .001$) (see Fig. 2). They also improved significantly in letter identification ($p < .01$) and receptive vocabulary. They also displayed robust increases on the object assembly subtest of Wechsler Intelligence Test ($p < .01$), which is consistent with Schellenberg's findings. In addition, on the test we developed to assess numeracy in preschoolers, the music group improved significantly ($p < .007$). The specific subtests in which they improved were verbal counting and estimating magnitudes. Finally, this group also improved on overall Stanford Binet non-verbal IQ test ($p < .03$) including the fluid and quantitative reasoning subtest of the Stanford Binet IQ test ($p < .03$) and also the "knowledge" or "critical thinking" subtest ($p < .01$). An example of an item on the latter subtest is to ask the child what is amiss in a picture showing two children in sunshine who cast shadows that are in different directions.

3. Attention Training

The results from the group trained in attention (N=23) displayed gains of comparable magnitude and in similar domains as the children trained in music. They improved significantly in receptive (.01) and expressive ($p < .004$) language and phonological awareness (.01) (see Fig 2). They also improved in the object assembly test of visual cognition ($p < .007$), in numeracy ($p < .001$) and the fluid reasoning, quantitative reasoning, visuo-spatial and working memory and critical thinking subtests of the Stanford Binet (all $p < .01$).

Taken together these results suggest that gains in language observed in the music group may have been due to Head Start itself, or to test-retest effects. Further controls will be necessary to determine which variables are key. They also suggest that the gains in spatial cognition (object assembly) and IQ observed here and in other studies may derive from the fact the music training typically involves time being individually tutored or being in a small group, which may itself increase opportunities for training attention, since improvements were observed in all small group interventions but not the large group controls.

4. Small Group Controls

The children who spent 40 minutes per day in a group smaller than the regular Head Start classroom, but engaging in similar activities (N = 20), also displayed gains in receptive ($p < .01$) (see Fig 2), expressive ($p < .002$), language and phonological awareness ($p < .01$). In addition, they improved on the object assembly test ($p < .004$), and on overall non-verbal IQ ($p<.001$), including several subtests.

We have recently added new data from an additional 27 children. We continue to see strong and significant within group pre/post improvements in non-verbal IQ and numeracy and spatial cognition in the music and attention trained children that are not observed in the regular Head Start ‘large’ control group. However, the group differences still do not display robust ‘between group’ statistical significance. In addition, the ‘small’ Head Start control group is now displaying large effects in these same areas. This suggests that many of the effects that we hypothesized were due to music and/or attention training may instead be a consequence of an increase in time in a small group with good adult attention. The central and powerful role of adult attention and guidance is also underscored by the results of a separate study conducted by us in which children did not receive any intervention, but their parents received training that improved parenting practices, which in turn improved children’s conduct and produced large and significant improvements in each of the measures reported here (Fig. 2 and Fanning et al 2007). These changes are highly significant even in ‘between group’ statistics.

Finally, in 2008 we conducted a hybrid intervention that included a once per week small group training of attention and music for the preschoolers and a weekly parent training for their parents. The data to date suggest this approach may be the most powerful we have seen. After 8 weeks the children show improvements in language, preliteracy, numeracy and IQ that are significantly greater than changes observed in the control group.

-- INSERT FIGURE 3 HERE --

In summary, by studying the role that music might play in improving cognition, we have learned not only about the powerful effects of music but also about the related and interacting roles of attention and parenting.

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Dehaene chapter figures

Figure 1

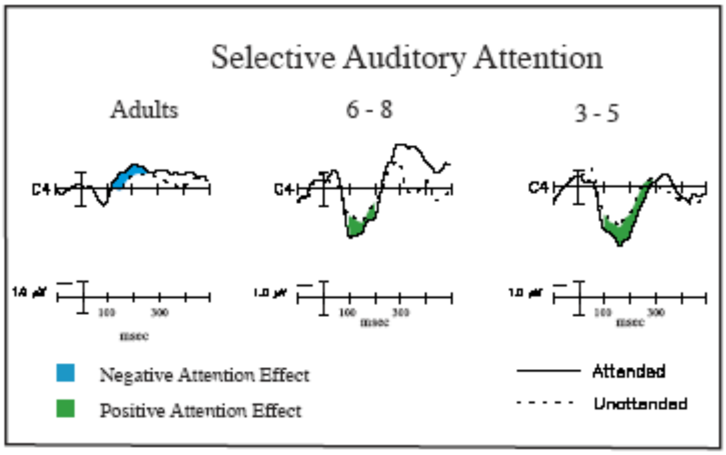


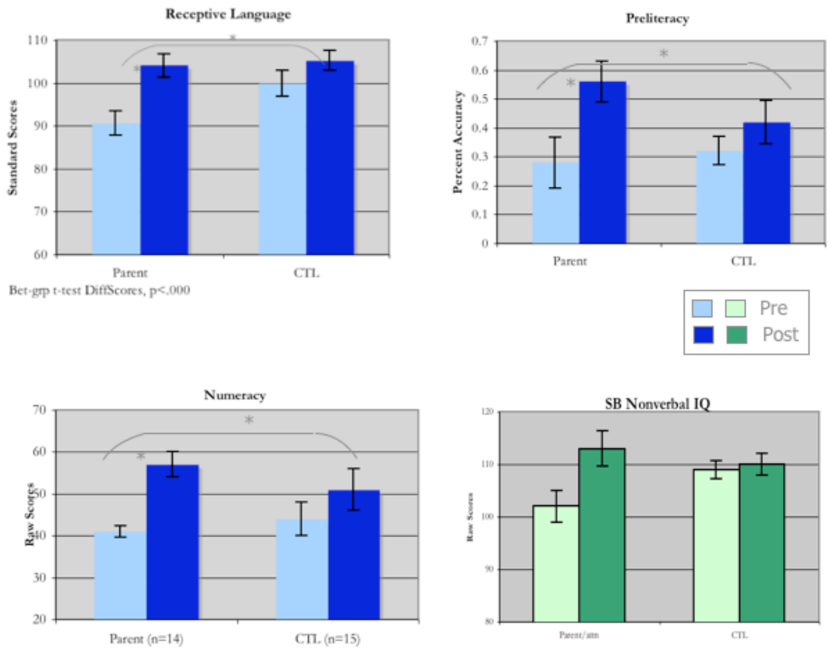
Figure 2

Behavioral Data

Group:	Receptive Language	Pre-Literacy	Numeracy	Spatial Cognition	Nonverbal IQ
HS Large Group (19)	*	*			
Music (26)	*	*	*	* †	*
Attention (23)	*	* *	* *	*	*
HS Small Group (20)	*	*	*	*	*
Parent (14)	* *	* *	*	*	* *

Significance
* within-group pre to post
** between group

Figure 3


Receptive Language
Standard Scores
Parent
CTL
Bet-grp t-test DiffScores, p<.000
Preliteracy
Percent Accuracy
Parent
CTL
Pre
Post
Numeracy
Raw Scores
Parent (n=14)
CTL (n=15)
SB Nonverbal IQ
Raw Scores
Parent/attn
CTL