AUDITORY LEARNING OF A PSYCHOACOUSTICAL TASK IN CHILDREN AS COMPARED TO ADULTS

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Abstract

While there is growing evidence that the performance of a given auditory task can dramatically improve with practice in normally-hearing adults, data on auditory procedural learning processes of children is very limited. On the one hand, the prolonged development of the auditory and cognitive systems during childhood may lead to inferior learning abilities in children. On the other hand, there is evidence to suggest greater brain plasticity in early childhood. The purpose of the present study was to explore the time course of auditory learning in children compared to adults using single- and multi-session training. Participants included 23 children (7-11 years of age) and 24 young adults (18-30 years of age). Each training session comprised of six estimates of Difference Limen for Frequency (DLF) at 1 kHz using an adaptive forced-choice procedure. The results show that despite considerable initial poor thresholds of the children (mean relDLF%=4.68) compared to those of adults (mean relDLF%=2.61), most children exhibited large learning effects resulting in discrimination thresholds that were very similar to those of adults at the end of the multi-session training (mean relDLF%=0.38 and 0.31 for trainable children and adults, respectively). Nevertheless, it seems that the adults needed less training than the children in order to accomplish these thresholds. These data support the hypothesis that the procedural learning mechanisms of children aged of 7 to 11 years are still in the process of maturation.

Procedural learning refers to the robust gains in performance on basic tasks that are induced by sensory experience and are dependent on practice (Karni and Bertini, 1997). Most studies on auditory procedural learning investigated normal-hearing adults, whose auditory system is matured and capable of efficient auditory analysis. These studies showed that the performance of a given auditory task can dramatically improve with repetition exposure in a single session as well as in multi-session training (e.g. Demany and Semal, 2002).

For many years, it was assumed that brain plasticity in children is superior to that of adults (Siegel, 2001). The latter notion has been invoked in relation to critical or early in life periods of increased brain plasticity and skill acquisition. These critical periods are considered maturational windows of opportunity wherein neuronal properties are particularly susceptible to shaping by experience (Hensch, 2004; Bornstein, 1987; 1989). Moreover, empirical evidence also suggests greater brain plasticity in children (Niparko, 2000) thus predicting that children may have a learning mechanism that is more efficient in early stages of life compared to that of adults.

An alternative view to the one suggested above is based on evidence that a great part of the cognitive abilities necessary for learning, such as problem solving, attention and memory skills, are less developed in children (Flavell, 1993). Furthermore, it appears that the development of the *auditory* cortex of humans is prolonged in comparison to other primary sensory cortices that mature within the first year of life (Moore and Linthicum, 2007). This extended maturational time course is ascribed to progressive myelination of the auditory cortex and maturation of the evoked cortical potentials which lasts a decade long through early and late childhood. Hence, the fact that cognitive and auditory abilities continue to evolve during childhood supports the notion that children have less efficient mechanisms of auditory procedural learning compared to adults.

Only a few number of studies tried thus far to examine the efficiency of procedural learning mechanisms of children by training on auditory-procedural tasks. Moore et al. (2008) and Halliday et al. (2008) trained children and adults on a frequency discrimination task (DLF) in a *single* session using an adaptive staircase procedure. They found poorer thresholds and very limited learning effects as well as considerable inter-individual and intra-age group variability in the DLF values of the children's group. This was mainly ascribed to children's fluctuations of auditory attention. Somewhat different results were reported in an earlier DLF study using constant stimuli (Soderquist and Moore, 1970). In this study, children presented a non-significant trend of improvement over six days of training

Overall, studies suggest that the data on procedural learning of children in the auditory modality are limited and controversial. Furthermore, recent studies with learning in children limited their practice to a single session of training. It is possible that children require more practice to exhibit gains in performance. Therefore, the goal of the present study was to explore the time course of auditory learning of a DLF task in children (7-11 years) compared to that of adults, using an adaptive staircase procedure, throughout two different courses of practice: *single* and *multi* session training.

Method

Participants

Two groups of participants took part in this study. One group included 23 children 7- to 11-years of age and the other group included 24 young adults 18- to 30-years of age. All participants had normal hearing sensitivity in both ears (ANSI 1989) and were naive to the experimental procedure.

Stimuli

All stimuli lasted 300msec and were gated with rise/fall time cosine ramps of 25msec. Stimuli were delivered from an IBM compatible personal computer, via an external sound-card and via a GSI-61 audiometer and were presented monaurally via THD-50 headphones at 53dBSL above individual thresholds. Stimuli consisted of a 1000Hz reference pure-tone and 200 different comparison tones. The comparison tones varied from 1001Hz to 1200Hz in 1Hz steps. All stimuli were digitally generated at a sampling rate of 22,050Hz and 16-bit using Sound-Forge 7.0 software.

DLF threshold measurements

For the DLF threshold measurements, a three-interval, two-alternative, forced choice adaptive procedure (3I2AFC) was used. Each trial consisted of three stimuli: two reference tones and one comparison tone. The first stimulus in each trial was the reference tone and the comparison tone was presented randomly as either the second or the third in a sequence. Participants were instructed to select the different tone between the two last ones, similar to an 'odd ball' paradigm. A two-down, one-up tracking procedure was used in order to estimate the frequency difference corresponding to the 70.7% correct point on the psychometric function (Levitt, 1971). Initial step size (40Hz) was cut by half every turn-point until reaching a minimal step size of 1Hz. Thresholds were calculated as the geometric mean of the DLFs of six turn-points at minimal step size. Stimuli were also indicated by visual lights on the computer monitor. Participants responded by clicking the computer's mouse on the light that represents the stimulus that was different. Visual feedback was provided immediately after each response, indicating the actual variant stimulus.

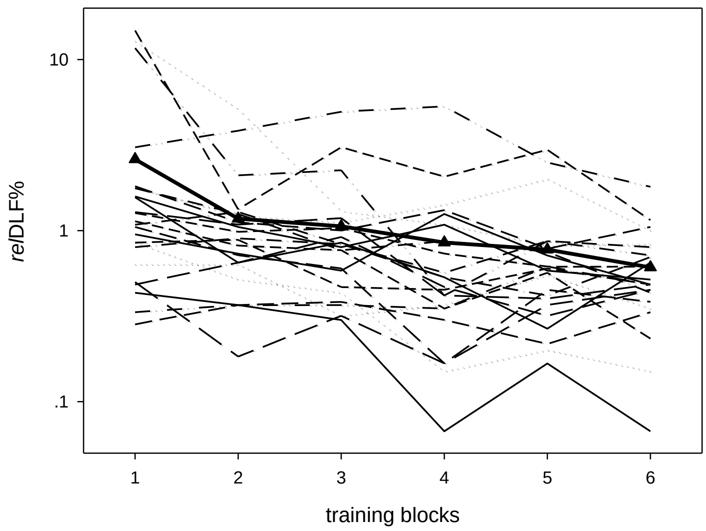
Experimental design

The participants took part in a single training session which consisted of six blocks (six DLF estimates) that were obtained monaurally to the right or left ear depending on the assigned ear. The training session lasted approximately 45 minutes with approximately 700 stimuli. All adults (n=24) and 11 of the children continued training for nine additional sessions. Each of these sessions consisted of six DLF blocks each while the tenth session consisted of three DLF blocks. Thus, the participants that took part in the multi-session training listened to approximately 6650 stimuli throughout the entire training period.

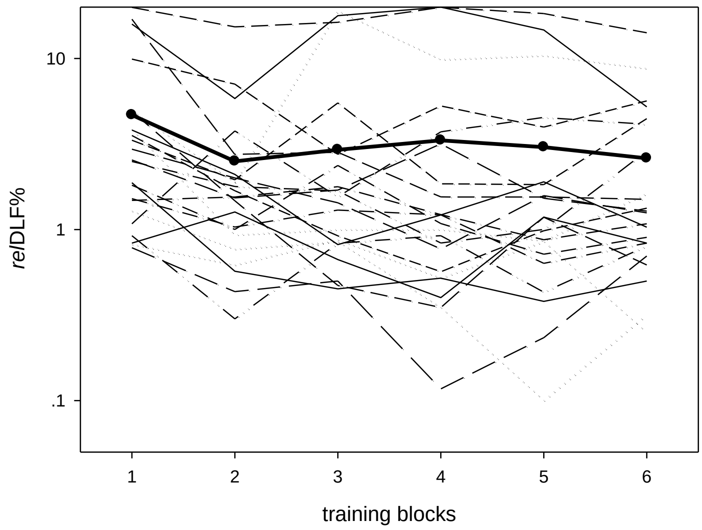
Results

The results in DLF were transformed to *relative* DLF thresholds in percent (*rel*DLF%= Δf/f*100). Our first goal was to explore the effect of a single training session on frequency discrimination thresholds of children as compared to adults. The individual thresholds as well as the group means as a function of training block in the single training session are presented in figures 1a and 1b for adults and children, respectively. For convenience sake, the group means are shown separately in figure 1c as well. It can be seen that overall, children's thresholds were considerably higher compared to that of adults. Also, within a single session of training, adults appear to show more gains in performance over six blocks of training compared to children. Specifically, in the adult group the mean improvement was 76.71% between the first block (mean *rel*DLF%=2.62 ± 4.11) and the sixth block (mean *rel*DLF%=0.61 ± 0.37) while in the children's group the mean improvement was 44.23% between the first block (mean *rel*DLF%=4.68 ± 5.53) and the sixth block (mean *rel*DLF%=2.61 ± 3.30). A one-way analysis of variance (ANOVA) with repeated measures was conducted separating the main effects of group (children, adults), training blocks (1-6), and group X training blocks interactions. The statistical analysis confirmed a significant main effect of group [F(1,45)=5.36, p=0.0252], a significant main effect of measurement [F(5,41)=3.01, p=0.0208] but no group X measurement interaction [F(5,41)=1.66, p=0.1665].

a)



b)



c)

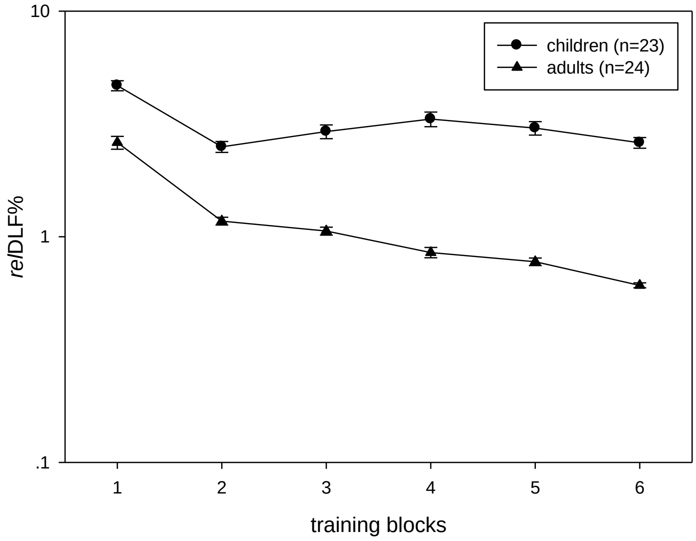


Fig 1. Individual frequency discrimination thresholds and mean groups in *rel*DLF% (Δf/f*100) in a single training session over six blocks of training for (a) the adults and (b) for the children. The thick lines indicate the group means. These mean group frequency discrimination thresholds as well as standard errors (SE) are also shown separately in (c).

Our second goal was to explore the time course of auditory learning over multi-session training of children compared to that of adults. Note that all 24 adults and 11 of the children continued training. The mean thresholds of blocks 1-6 in the first training day as well as the mean results of days 2-10 of training are shown in Figure 2 for children and adults. It can be seen from the graph that the mean DLF thresholds of the adults improved on a daily basis. Much of this learning took place in the first training days and continued smaller changes in the learning gains were observed throughout the training sessions. In the children group, however, very little improvement was evident over time. A comparison between the average of the first three measurements in the first day of training and the average of the last three measurements in the tenth day of training revealed a significant improvement of 80.86% in the mean *rel*DLFs of the adults (t=3.5 p=0.0019) (mean *rel*DLF% decreased from 1.62 to 0.31) and an insignificant improvement of only 26.89% in the mean *rel*DLFs of the children (t=1.54 p=0.1538) (mean *rel*DLF% decreased from 3.63 to 2.99). However, further analysis of the data revealed that three children did not gain from the training since their mean first three *rel*DLFs were better than their mean last three *rel*DLFs. When the data of these three participants were excluded from the mean children thresholds (dashed line-marked as 'trainable children'), the mean children's improvement dramatically increased to 82.13% (t=2.24 p=0.0602) (mean *rel*DLF% decreased from 2.13 to 0.38). A one-way analysis of variance (ANOVA) with repeated measures was conducted separating the main effects of group (all children, adults), training day (1-10), and group X training day interactions. Statistical analysis confirmed a significant main effect of group [F(1,33)=6.32, p=0.0170], a significant main effect of training day [F(9,25)=3.82, p=0.0038] and a significant group X measurement interaction [F(9,25)=2.21, p=0.0564]. However, when the same analysis was performed without the three un-trainable children no significant difference was found between the groups [F(1,30)=3.57, p=0.0684].

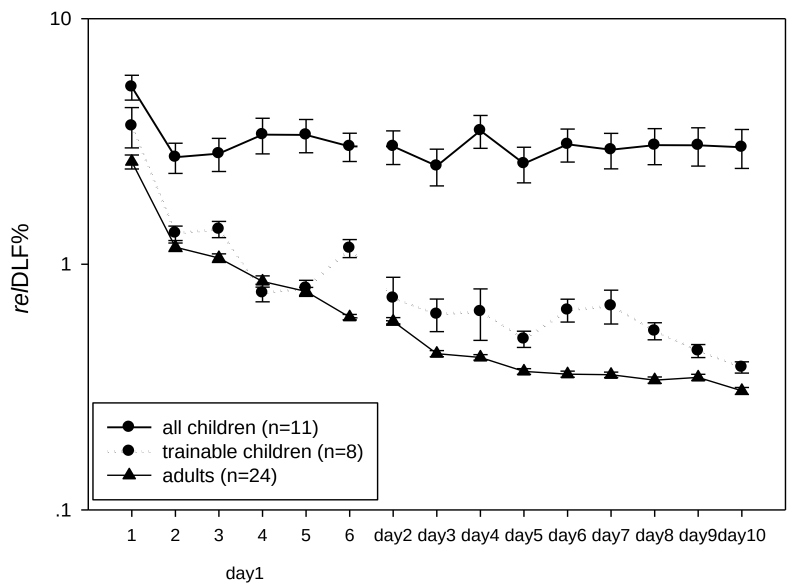


Fig 2. Mean frequency discrimination thresholds in *rel*DLF% (Δf/f*100) in blocks 1-6 in the first training day and in days 2-10 of training for both training groups (adults (n=24) and children (n =11)). Also shown in a dashed line are the mean thresholds of the trainable children (n=8) from the children group (data of three un-trainable children were excluded). Also shown are standard errors (SE).

Discussion

The purpose of the present study was to compare the time course of auditory learning in children and adults using a frequency discrimination task. Our results support three major outcomes: First, the initial discrimination thresholds of most of the children in the present study were worse than those of the adults as was expected from previous studies (Maxon and Hoschberg, 1982; Jensen and Neff, 1993). Second, it appears that despite their initial poor thresholds, most of the children showed great learning effects resulting in discrimination thresholds that were very similar to those of adults at the end of the multi-session training. Nevertheless, it seems that the adults needed less training than the children in order to accomplish these thresholds, as was indicated from their faster improvement in the first few days of training (reached a mean *rel*DLF% of 0.37 in the fifth day of training). Third, there were several participants from the children group that did not benefit from training, possibly as a result of undeveloped learning mechanisms or attention fluctuations.

Overall, the results suggest that the procedural learning mechanisms of children of the age of 7 to 11 years old were not superior to that of adults, as opposed to the 'maturational windows' assumption. However, the fact that a great part of the children managed to achieve similar learning gains as those of the adults, while others barely showed any improvement as a result of training may suggest that auditory procedural mechanisms in the age of 7 to 11 years are still in the process of maturation.

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