

# **Auditory processing disorder (APD) in children**

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A proportion of children (~ 2-4%) attending audiology clinics with 'hearing problems' turn out on audiometry not to have a sensitivity deficit. Additional children are identified by their teachers and parents as having 'listening problems'. These children and their carers typically report problems with auditory attention and hearing speech in noise. We have been studying whether these problems relate to basic abilities of spectral, temporal and binaural hearing ('auditory processing' - AP - tasks), as well as other aspects of audiology, cognition and speech perception. Our main approach is population-based. By studying large, quasi-random samples of 6-11 year old children, we expected to see some children who perform poorly on AP tasks. In this paper we focus on pure tone frequency discrimination. An initial experiment found that poorly performing children tend to be younger and could be either 'genuine' poor performers, in that their adaptive test responses were consistent, but their thresholds were elevated, or 'poor compliers', in that they responded inconsistently. Further study showed no relation between thresholds on an auditory tone frequency discrimination task and a visual spatial frequency discrimination task, supporting our working hypothesis that AP poor performers may have a specific auditory attention difficulty. We have compared two groups of children receiving a clinical diagnosis either of APD or specific language impairment (SLI), in an attempt to dissociate underpinning causes. However, we found, on our full battery of tests, that both these groups performed poorly across almost all tests and that, surprisingly, their profile was almost identical. This supports the idea that a clinical diagnosis of either a listening or a language problem is determined more by the type of professional making the diagnosis (audiologist or speech/language pathologist) than by the nature of the problem. Neither the performance nor the variability on auditory and visual frequency tasks was correlated in these children, suggesting once again a dissociation between general attention skills in a near identical task and poor auditory performance. Finally, we have conducted auditory phoneme discrimination training in typical children with a view to developing means for treating APD. In contrast to an age-matched, but untrained control group, the trained children improved not only on the trained task, but also on a broad-based test of phonological awareness. Our latest research confirms the training effect for auditory, but not for procedurally equivalent visual stimulation. These results show that auditory learning is a promising means for improving language- and listening-based skills underpinning good communication.

## WHAT IS APD?

While it is generally appreciated that children may not listen as well as adults, at least under certain circumstances, the notion that some children have a specific difficulty with auditory ‘processing’ remains controversial. One reason for this is the historical development of the concept of APD which, despite being hailed recently as ‘30 Years of Progress’ (see [www.apdcincinnati.com](http://www.apdcincinnati.com)), has been largely led by clinical observations and lacks a substantive theoretical or experimental underpinning (Cowan *et al.*, in press). A missing component of this underpinning is general agreement about the meaning of the ‘P’ word in APD. Unfortunately, there has been an assumption that ‘processing’ is purely a function of the central auditory system and, indeed, an alternate name for APD has been ‘Central APD’ (CAPD; e.g. Cacace and McFarland, 1998). This assumption appears to come from an agreed screening criterion, that children classified as APD have ‘sub-clinical’ levels of hearing sensitivity (typically  $\leq 20$  dB HL), together with the notion that the clinical hallmarks of APD, such as poor speech perception in noise, must result from impaired central function. However, as eloquently presented by Oxenham and Bacon (2003), outer hair cell (OHC) pathology can produce impaired spectral and temporal resolution due to a loss of fast acting cochlear compression, and these impairments can, in turn, account for many of the problems reported in APD. Whether OHC pathology that is audiometrically sub-clinical can impair spectrottemporal processing is an important question requiring clarification.

While APD has sometimes been defined by default – listening difficulties in the absence of abnormal audiograms – we suggest that a more active definition of auditory ‘processing’ is needed. Given existing understanding about the nature of sensorineural and conductive hearing loss as necessarily involving impaired detection of tones presented in the quiet, a suitable definition of ‘processing’ might require relative judgements between sounds. We therefore propose the following definition of auditory processing:

‘Aspects of auditory perception requiring judgements about the *relative* properties of acoustic stimuli. These aspects may include peripheral as well as central neural elements. They may involve descending pathways and forebrain areas beyond the classic auditory system.’

Note that the definition is very inclusive, neurally and functionally. In addition to acknowledging potential contributions from the ear, which may be influenced by descending auditory pathways, it includes interactions with frontal and parietal cortical regions that we have recently suggested (Moore *et al.*, 2007) should be included within the brain’s auditory system. Functionally, it attempts to capture the nature of ‘real-world’ listening as a sequential comparison of temporally and spectrally varying stimuli.

Having suggested a definition of auditory processing, it would seem an easy task to define APD. However, because of the need to distinguish APD from language and other cognitive impairments, issues we have discussed in detail elsewhere (e.g. Moore,

2006), it is important to place limitations on both the types of auditory stimuli used in tests of APD and the specificity of associated cognitive assessments. Within these limits, a British Society of Audiology (BSA) working party on APD has defined APD as follows:

‘APD results from impaired neural function and is characterized by poor recognition, discrimination, separation, grouping, localization, or ordering of *non-speech* sounds. It does not result *solely* from a deficit in general attention, language or other cognitive processes. (BSA, 2007).’

This definition leans heavily on an American Speech, Language and Hearing Association (ASHA, 2005) analysis of the underpinning basic auditory deficits in APD. It differs from the ASHA formulation in the strict exclusion of linguistic material from the diagnostic core of auditory processing tests, the explicit exclusion of generalised cognitive deficits, and the implicit inclusion of unimodal, auditory-based cognitive deficits as underpinning causes of APD. The remainder of this paper deals with recent experiments we have conducted to begin teasing apart these elements in psychophysical studies of mainly typically developing children.

## PERFORMANCE OF CHILDREN ON PSYCHOPHYSICAL TASKS

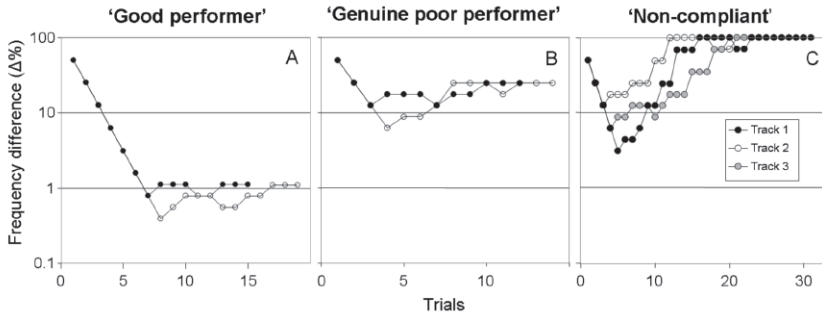
Psychophysical experiments have long recognised the intervening effect of inattention on the assessment of sensory function in children. In an attempt to separate performance from attention in listening tasks, the properties of psychometric functions relating performance to stimulus level have been measured and modelled. These properties include the slope of the function (Allen and Wightman, 1994) and the extent to which performance at high stimulus levels falls short of perfection (Bargones *et al.*, 1995). Models of children’s performance have assumed that performance varies randomly (stochastically) over time - that the psychometric function is a ‘snapshot’ of both perception and attention. The generic approach assumes that attention is essentially a singular and multimodal function; that inattention will be simultaneously and rather indiscriminately manifest in a variety of tasks.

In a recent paper (Moore *et al.*, in press), we have taken several novel perspectives on the relation between attention and listening in children. We first examined how auditory performance changes over time. Our premise was that attention is constantly varying, both within and between tasks. The degree to which inattention is contributing to listening should therefore be apparent as short or medium term changes in auditory threshold. Children who are attentive should, in a standard staircase adaptive procedure (Amitay *et al.*, 2006a), produce a consistent pattern of ‘reversals’. The staircase would be expected gradually to converge on a threshold, with little fluctuation around that point. Successive threshold determination ‘tracks’ should produce consistent estimates. Inattention, on the other hand, would be expected to lead to a greater degree of performance variability. This should be indicated both by higher thresholds and a greater range of reversals and inter-track differences. Rather than varying randomly, however, our initial observations led us to expect that inattention would lead to drift-

ing performance across successive trials – a problem of sustained attention.

### TONE FREQUENCY DISCRIMINATION IN CHILDREN

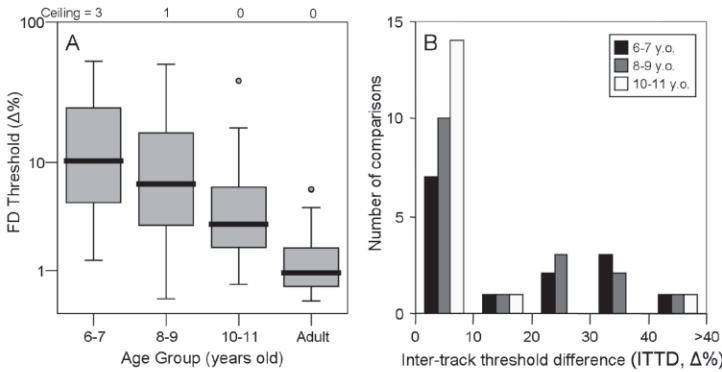
Data examining response variability in an adaptive, three interval, three alternative, forced choice (3I-3AFC) frequency discrimination (FD) task are shown for three representative 8-10 year old children in Fig. 1.



**Fig. 1:** Performance of 3 children on repeated runs ('Tracks') of a frequency discrimination task (from Moore *et al.*, in press).

The 'Good performer' (Fig. 1A) was characterised by a lead-in sequence in which a succession of correct responses resulted in a rapid approach to a threshold level that was close to that at which subsequent staircase reversals occurred. Performers of this type generally achieved the criterion number of reversals in a relatively small number of trials. A second test track typically had the same characteristics as the first and resulted in a similar threshold estimate that indicated acute discrimination relative to others of the same age (Fig. 2). A second child performed similarly to the first, except that these 'Genuine poor performers' (Fig. 1B) had much less sensitive thresholds. This pattern was seen only rarely, by the criteria used in this study (Table 1), and the example shown is the most consistent of this type we found. Nevertheless, in a broader study of children's hearing development (Ferguson *et al.*, 2006) we found several examples across a variety of listening tasks. A third pattern, seen in a larger number of children, was characterised by poor, or ceiling level (Figs. 1C, 2) final thresholds. As shown by the example in Fig. 1C, these children often performed quite accurately and consistently on the lead-in, suggesting that they could both do the task and discriminate the stimuli. However, when they began to make mistakes for more difficult discriminations, their performance declined, and they subsequently made mistakes for discriminations they had formerly achieved with ease. In a few extreme cases, as here, they performed at ceiling but, more typically, their performance varied cyclically, with one or two large excursions of threshold during the course of a test track. Their performance also often varied dramatically between tracks. This behaviour, which we call 'Non-compliant', generally resulted in the poorest thresholds (Fig. 2) and was presumably due to fluctuations of attention. The proportion of non-compliant performers was considerably higher in the 6 – 7 year old group than in any of the other groups and, among this group, non-compliance in FD was more prevalent than in any of ten other

listening tasks (Cowan, 2007).



**Fig. 2:** A: Box-plots (median centred) of children’s FD performance, compared with that of adults. B: Response variability (indexed as ITTD, see text) in each age group (from Moore *et al.*, in press).

A comparison of track thresholds across age showed that younger children had higher variability, both between (Fig. 2A) and within (Fig. 2B) individuals. Performance of more than 75% of the 6-7 year olds was outside the 95% confidence intervals of the adult group. The mean threshold (transformed logarithmically) differed significantly ( $p < 0.001$ ) between the four groups, with performance improving across each successive age group. However, half of the Good performers in the three groups of children, including two in the youngest group, had thresholds that were within the inter-quartile range of the adult group. One 7 year old had an FD threshold of 1.6%, suggesting that at least some young children have peripheral and central neural function capable of supporting mature levels of performance. The ITTD index (Fig. 2B) measured the threshold difference between successive threshold determinations (Fig. 1) on a single day of testing. It indicated that a higher proportion of the two younger groups had quantitatively greater response variability (chi-square = 9.32;  $p < 0.01$ ), within the time frame of successive adaptive tracks (separated by about 2 - 5 minutes).

Age (y.o.)	Good	Genuine poor	Non-compliant
6-7	24% (n = 4)	12 (2)	64 (11)
8-9	56 (14)	4 (1)	40 (10)
10-11	84 (16)	5 (1)	11 (2)

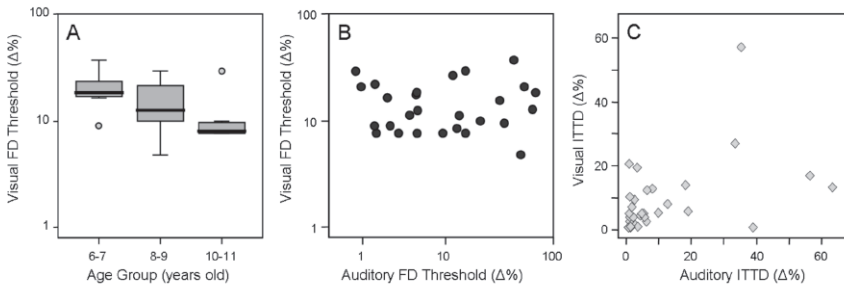
**Table 1:** Classification of FD performance sub-types (see Fig. 1) by age (from Moore *et al.*, in press).

### COMPARISON OF TONE WITH VISUAL SPATIAL FD

One of our aims has been to isolate auditory attention from supra- or multi-modal attention as contributors to children’s performance on listening tasks. We reasoned that

a visual task, closely matched to an auditory task in terms of task demands and procedure, would enable a comparison of relative performance to be made between the two modalities. Given that the lower level sensory processing of each modality is known to be largely segregated, if performance and variability on the two tasks were closely correlated, it would seem likely that each task was accessing common higher level, cognitive (especially attention) resources. On the other hand, poorly- or uncorrelated performance would seem indicative of reliance on separate resources. We designed a 3I-3AFC visual spatial discrimination task that shared every feature we could match to the auditory FD task generating the data in Figs. 1 and 2 (see Moore *et al.*, in press).

Performance of the visual FD task (Fig. 3) differed qualitatively from that of the auditory FD task (Fig. 2A). Variability, both within and between children, was much reduced for the visual task. At the group level, we found the same trends seen in auditory FD (Fig. 3A). Younger children performed more poorly and more variably than older children, but none of the children showed a ceiling effect on the visual task. However, of most interest in this work was the comparison between performance on the two tasks. As shown in Fig. 3B, there was no significant (Pearson) correlation ( $n = 32$ ;  $r = 0.26$ ,  $p > 0.1$ ); poor performers on the auditory task spanned the full range of performance on the visual task. The response variability index, ITTD, was slightly larger for the auditory than for the visual task (Fig. 3C). By this measure, however, most children performed consistently ( $ITTD < 10\%$ ) on both tasks. Across the whole sample, there was a significant correlation between auditory and visual ITTDs ( $n = 30$ ;  $r = 0.45$ ,  $p < 0.01$ ). This high correlation was due mainly to the inconsistent responders. When those 5 children who had  $ITTD > 20\%$  on either task were removed from the analysis, the correlation was not significant ( $r = 0.23$ ,  $p > 0.1$ ). Thus, while threshold discrimination was not correlated between individuals on the auditory and visual tasks, response variability within individuals was, but only because of the inconsistent responders.



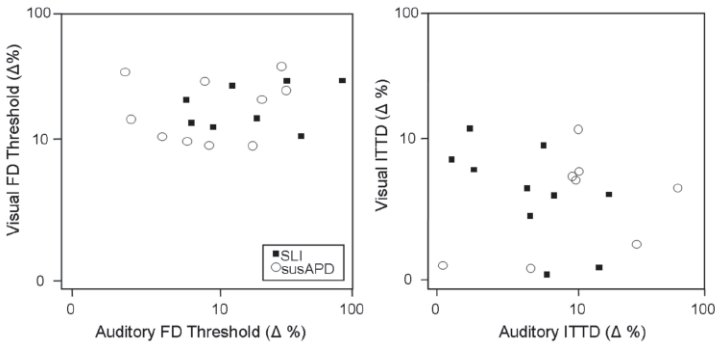
**Fig. 3:** A: Children’s visual spatial FD thresholds as a function of age. B: Comparison of auditory and visual FD thresholds for each child successfully completing both tasks. C: Comparison of response variability on each task, indexed using ITTD.

If we assume that performance of the visual task is, like the auditory task, highly dependent on attention, the threshold data (Fig. 3B) suggest that each modality of task uses predominantly separate, unimodal attention resources. On the other hand, response variability was correlated between the tasks, suggestive of multi-modal atten-

tion. However, the latter result was strongly influenced by the results of the most inconsistent performers. Overall, the results therefore suggest that better listeners may be using a predominantly auditory mode of attention while the poorer listeners need to draw on multimodal resources that are also used in the visual task.

**FREQUENCY DISCRIMINATION IN CHILDREN WITH APD**

While we have focussed our attention to date on populations of typically developing children, we have recognised the need to stay in touch with the clinical presentation of APD. Accordingly, we have conducted preliminary tests on two groups of children residing in the Nottingham area and diagnosed as specific language impaired (SLI;  $n = 8$ ) or ‘suspected APD’ ( $n = 10$ ) by speech and language therapists or audiologists, respectively. On a variety of cognitive, auditory processing, speech intelligibility and parental report measures, both groups of children performed more poorly than typically developing children of equivalent age (Ferguson *et al.*, 2007). However, there was no clear (or statistical) difference between the groups, suggesting that children with the same profile of disability could be variably diagnosed clinically. In fact, the results suggest the operation of a ‘referral lottery’ where the diagnosis received depends more on the profession of the attending clinician than on the disability profile of the child.



**Fig. 4:** Results from 6-12 year old children clinically diagnosed as SLI or ‘suspected’ APD. A: Auditory and visual spatial FD thresholds. B: Auditory and visual ITTD. No correlation was found between auditory and visual thresholds or variability in either group.

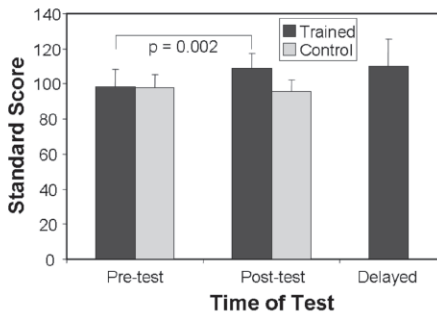
Because of the overall disabilities experienced by these groups we were, in the context of this paper, particularly interested in the relation between auditory and visual FD in these groups. In the measures described above from our typically-developing sample of children, we suggested that the positive correlation between auditory and visual FD in children who performed unreliably on either test may be evidence for a shift of resources between unimodal and multimodal attention. Data from the SLI and suspected APD groups are shown in Fig. 4. In these groups, no correlation was found between either mean performance or variability. While the sample sizes are currently small, these data suggest that, as for typically-developing and performing chil-



dren, different resources were being drawn on for the performance of each task. Further testing of this hypothesis awaits the collection of further data and the analysis of data involving other tasks.

### TRAINING AS A MANAGEMENT STRATEGY FOR APD?

We have not yet tested any remedial strategies on children with APD for the simple reason that we are still awaiting the development of a satisfactory diagnostic battery for APD. However, in a recent study in which one of our team was involved (Moore *et al.*, 2005), typically developing children were trained on a phoneme discrimination task that is being commercially marketed as the game ‘Phonomena’ (see <http://www.mindweavers.co.uk>). This game employs a 3I-2AFC (‘XAB’) adaptive staircase method to deliver discrimination trials. Twelve sets of phonological contrast continua were developed, each representing one of the major phonetic classes of English (e.g. /I/ - /ε/). The phoneme exemplars were spoken by a variety of male and female native English talkers, then synthesised and ‘morphed’ into continua that had 96 tokens between the two natural exemplars at each end of the continuum. These tokens were sampled from each end during training to provide the stimulus materials required for the staircase method.



**Fig. 5:** Phonological awareness (PhAB) in children before (Pre-test), immediately after (Post-test), and 5 weeks after (Delayed) school-based phoneme discrimination training. A ‘Control’ group took the tests at equivalent times but did not train (data reanalysed from Moore *et al.*, 2005).

Several laptop computers loaded with the resulting software were used in school based trials of 8-9 year old typically developing children at a city first school in Oxford. Children in one of two classes served as either ‘trained’ or ‘control’ groups. Both groups were initially given the receptive language tests of the Phonological Assessment Battery (PhAB), consisting of four subtests of alliteration, rhyme, spoonerisms and non-word reading (Frederickson *et al.*, 1997). Initial performance of both groups was as expected on the basis of their chronological age (re. British normalised values; Fig. 5), indicating a typically developing test cohort. The trained group practiced the phoneme discrimination task during 12 half hour sessions over four weeks. Their results revealed a modest increase in performance on the trained tasks, but a dramatic



improvement on the PhAB (Fig. 5) and on all of its subtests (Moore *et al.*, 2005). Children in the control group did not improve. When retested 5 weeks following the end of training, the trained group retained their high performance on the PhAB, but did not improve further.

The overall, highly significant improvement in phonological awareness suggested that a relatively simple task, trained for a modest amount of time, can have a dramatic impact on essential language and literacy skills, even in children of typical ability.

## GENERALITY OF TRAINING

The next issue we are currently addressing is whether other types of training can similarly improve phonological awareness. This study is based on the hypothesis that training improves general, supramodal skills, such as attention and memory, rather than specific, phoneme-related abilities. We (Halliday *et al.*, 2007) have tested four groups of children in a procedure nearly identical to that described in the previous study. Two groups, a phoneme discrimination (PD) and an untrained, control (C) group, were used to compare directly with the previous study. Two novel groups trained on pure tone frequency discrimination (FD) and on visual spatial frequency discrimination (VD), as described above. Again, the training groups were 8-9 year old children from two mainstream primary schools. Preliminary analysis of the results showed that the two auditory trained groups (PD, FD) improved significantly and specifically only on the task on which they had been trained. The other groups, including the VD group, did not show significant training on any task. On the broader based language (PhAB) measures, the PD and FD groups again showed superior performance to the other groups following training. However, reading was not improved by training. Overall, the results suggest that a broad range of auditory training, but not procedurally similar visual training, may be effective in improving phonological awareness. As in some of our lab-based work (Amitay *et al.*, 2006b), it may be that the method of training delivery is of more import than the precise stimulus materials trained. If these preliminary observations are confirmed, it will next be of interest to examine the effect of auditory training in special needs groups, including children with APD and other language-related disorders.

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