Developing the Auditory Processing Domains Questionnaire (APDQ): A differential screening tool for auditory processing disorder

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Keywords: auditory processing disorder; screening questionnaire; attention deficit; language deficit

Acronyms

AAA: American Academy of Audiology

ADHD: Attention deficit hyperactivity disorder

AP: Auditory processing scale

APD: Auditory processing disorder

APDQ: Auditory processing domains questionnaire

APR: Auditory processing scale raw score

ASHA: American Speech-Language-Hearing Association

ATT: Attention scale

CANS: Central auditory nervous system

CHAPPS: Children's Auditory Processing Performance Scale

CHAPS: Children's Auditory Performance Scale

CHILD: Children's Home Inventory for Listening Difficulties

DDT: Dichotic digits test

DSM-IV: Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition

EAA: Educational Audiology Association

ECLiPS: Evaluation of Children’s Listening and Processing Skills

Lang: Language scale

LIFE: Listening Inventory for Education

LD: Learning disability

MANOVA: Multivariate analysis of variance

MAPA: Multiple auditory processing assessment

NC: Normal controls

SAB: Scale of Auditory Behaviors

SIFTER: Screening Instrument for Targeting Educational Risk

TLI: The Listening Inventory

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Objective: The aim of this study was to develop a screening questionnaire for auditory processing disorder.

Design: Fifty-two questions were created to enable parent/teacher proxies to rate students’ listening skills in terms of auditory processing, attention, and language factors.

Study Sample: Parents rated their child’s frequency of competent performance (regularly, often, sometimes, or rarely) on 52 questions. Scores were calculated for three scales: auditory processing, attention, and language. Data was collected from 198 normal controls, 20 students with auditory processing disorder, 40 students with attention deficit hyperactivity disorder, and 10 students with a learning disability. Subjects were split into a younger group (7-10 years) and an older group (11-17 years).

Results: Factor analysis revealed substantial internal validity. Analysis of external validity using a regression model revealed significant differences between normal and clinical groups for all scales ($p < 0.001$), and also significantly separated the three clinical groups. A group differential analysis of scale score results clearly demonstrated inter-group differences at 89% (on average) sensitivity and specificity levels.

Conclusions: The APDQ appears to be an effective screening questionnaire for APD with scale score patterns likely to be helpful in making appropriate clinical referrals.

Keywords: auditory processing disorder; screening questionnaire; attention deficit; language deficit

Introduction

Listening skills are critically important for young students as over 60% of elementary classroom time is spent ‘learning by listening’ (Hunsaker, 1990). Listening difficulties are not uncommon and relate to both audiological factors (e.g. hearing acuity and auditory processing) and non-audiological factors (e.g. attention control and cognitive-language abilities). Auditory processing disorder (APD) refers to a variety of dysfunctions whereby a person’s processing of auditory information is impaired in the central auditory nervous system, despite them having normal hearing thresholds (American Speech-Language-Hearing Association (ASHA), 2005). APD is thought to affect around 7% of children (Bamiou, Musiek, & Luxon, 2001), which is comparable to the estimated 7% incidence of attention deficit hyperactivity disorders (ADHD; Willcutt, 2012) and the estimated 7% incidence of children with a specific language impairment (Tomblin et al., 1997).

Screening questionnaires have the advantage of providing behavioural contexts for auditory deficits. Indeed, the American Academy of Audiology (AAA) APD Consensus Conference recommended ‘the development and validation of screening questionnaires for school age children based on accepted psychometric principles with clearly defined pass/refer criteria’ (Jerger & Musiek, 2000). Bellis and Ferre (1999) have emphasized multidisciplinary approaches to identify the most important aspects of a student’s listening problems since they may or may not be in the auditory domain. We decided that a screening questionnaire which juxtaposes a child’s auditory, attention, and language performances would highlight behavioural contrasts and best clarify the true nature of his or her listening difficulty.

With the exception of the Children’s Auditory Performance Scale (CHAPS; Smoski, Brunt & Tannahill, 1992, also known as the Children's Auditory Processing Performance Scale (CHAPPS)), APD questionnaires published before the year 2000 were largely designed to rate the educational, social, and communication skills of children with impaired hearing. When used for APD screening, the Fisher Auditory Problem Checklist (Fisher, 1976), the Screening Instrument for Targeting Educational Risk (SIFTER; Anderson, 1989), the Children's Home Inventory for Listening Difficulties (CHILD; Anderson and Smaldino, 2000), the Listening Inventory for Education (LIFE; Anderson and Smaldino, 1999), and CHAPS have all been effective in differentiating normal listeners from those with listening difficulties. These questionnaires were favoured by Educational Audiology Association members, with the Fisher and CHAPS used by 63% and 51% of these audiologists respectively (Emanuel, 2002). Generally, they were not useful in screening for different types of listening difficulties or correlating questionnaire results with auditory processing test findings (e.g. CHAPS and SIFTER as reported by Wilson, Jackson, Pender, Rose, Wilson, Heine & Khan, 2011). However, there were exceptions. In one study, Fisher's check list scores did have weak chi square correlations with the dichotic Staggered Spondaic Word test (Katz, 1998) ($\chi^2(1) = 22.5$, $p < .05$) (Strange, 2009). A more recent non-parametric psychometric study which involved 96 children aged 11-12-years-old reported some significant inter-group correlations between CHAPPS subscales and auditory processing tests (Iliadou & Bamiou, 2012). The clinical APD group in this study performed significantly lower than normal controls on all six CHAPPS subscales ($p < .0001$), and below the clinical non-APD group on the noise, multiple inputs, and attention subscales ($p < .0001$)..

Since 2000, several questionnaires have been developed with excellent psychometric characteristics and the potential to detect at-risk APD candidates from both normal and clinical groups (although they still have had mixed success in demonstrating significant correlations with auditory processing tests (Barry, Moore, Dillon & Tomlin, 2015)). These questionnaires include the Scale of Auditory Behaviors (SAB; Schow, Seikel, Brockett & Whitaker, 2007), The Listening Inventory (TLI; Geffner & Ross-Swain, 2009), and the Evaluation of Children's Listening and Processing Skills (ECLiPS; Barry & Moore, 2013). The SAB was featured in a Portuguese study involving 51 children aged 10-13-years-old and showed strong correlations with Multiple Auditory Processing Assessment (MAPA) Speech In Noise test (Schow et al., 2007; $r = 0.47$ $p < 0.001$), Duration Pattern Test (Musiek et al., 1990; $r = 0.5$ $p < 0.001$, and Gaps-In-Noise test Musiek et al., 2005; $r = 0.47$ $p < 0.001$) (Nunes, Pereira & Carvalho, 2013). These correlations are surprising in that the SAB only has 12 items, five of which are not auditory in nature.

A break-through adult study of 58 clinical subjects (with difficulty listening and normal audiograms) and 30 normal controls aged 18 to 60 years old was recently reported in the JAAA (Bamiou, Iliadou, Zanchetta & Spyridakou, 2015). Three self-report auditory questionnaires (The Modified Amsterdam Inventory for Auditory Disability (Meijer, Wit, TenVergert, Albers, Muller Kobold, 2003), the Hyperacusis Questionnaire, and the Speech, Spatial and Qualities of Hearing Scale (Gatehouse and Noble, 2004)) had consistent and sometimes strong correlations with most of the auditory processing tests (Gaps-In-Noise Test (Musiek et al., 2005) $p < .001$, Dichotic Digits Test (Musiek, 1983) $p < .01$, Duration Pattern Test (Musiek et al., 1990) $p < .01$, and Frequency Pattern Test (Musiek & Pinheiro, 1987) $p < .05$). The clinical subjects with negative AP test results had intermediate questionnaire scores between the normal controls and the clinical APD group, suggesting a continuum for APD as others have proposed (Phillips, Comeau & Andrus, 2010). However, none of the post-2000 screening questionnaires were designed for differential screening for ADHD or language disorders since no clinical groups with these conditions were included in their normative study populations.

Hence, the goal of our study was to develop a parent/teacher proxy rating questionnaire called the Auditory Processing Domains Questionnaire (APDQ) to screen children aged 7 to 17 years old who may have APD due to their listening difficulties. This paper describes the conceptualization of the APDQ, normative and clinical data collection, results, analysis, and conclusions.

Method

Questionnaire Development

Questions

Fifty-two behavioural items were selected for the APDQ following a cross-disciplinary literature search (ASHA, 1996; Chermak, Musiek & Weihing, 2017; Barkley, 2006; Conners, 1996; Levine, 1990; Bellis and Ferre, 1999). Thirty-one of these questions related to auditory processing, of which 18 referred to auditory decoding, three to speech prosody , and five to auditory integration(relating to the auditory processing profiles of case study children described in the model of Bellis and Ferre, 1999). Only auditory localization and qualities of sound were missing from the eight APD perceptual functions listed by ASHA (2005).

Attention control items included six out of nine behaviours required for the diagnosis of ‘inattentive’ ADHD from the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV, 1994). Language items included expressive and receptive communication skills as well as such verbal academic skills as reading and writing.

Originally, the readability of the questionnaire was rated at a tenth grade reading level (Atcherson, Richburg, Zriack & George, 2013). The items were then revised to give a fourth to fifth grade, i.e. ‘fairly easy’ reading level (according to the formula of Kincaid, Aagard, O’Hara & Cottrell, 1981). The questionnaire takes 10 minutes or less to complete.

Scoring

Parents or teachers are asked to rate a child’s ‘frequency of observed performance’ on 52 items. Scoring is as follows:

- 4 points if behaviour is performed ‘most times’ (> ¾ of the time)
- 3 points if behaviour is performed ‘often’ (½-¾ of the time)
- 1 point if behaviour is performed ‘sometimes’ (¼-½ of the time)
- 0 points if behaviour is performed ‘rarely’ (< ¼ of the time)

The break in the hierarchical continuity of scoring between three points and one point represents a gap from competency to incompetency.

Three scales were constructed: Auditory Processing (AP scale) with 31 items; Attention Control (ATT scale) with 10 items (one overlapping with the AP scale); and Language (Lang scale) with 11 items (one overlapping with the AP scale). Two additional questions were not included on a scale but are used for listening in quiet versus noise comparisons. A fourth scale, Targeted Auditory Processing (TAP) was formed using 18 auditory decoding items. It has uncomplicated scoring in contrast to the AP scale which has complicated scoring due to points being subtracted for major differences between listening in quiet versus noise and auditory versus non-auditory attention-fatigue. TAP mean scores and standard deviations are within three points of similar AP scores across all clinical and the normal groups. TAP scale scores are available as a substitute for the AP scale for research purposes or should manual scoring of this questionnaire be necessary due to unavailability of the Excel scoring program.

Scale Score Calculations

Scale scores are reported as a ‘percent of perfect score’ so they are comparable across all conditions. They are calculated as: (sum of item scores in scale) ÷ (4 x the number of items in scale) x 100. Scale scores are positively distributed, hence higher scores reflect greater competency. Note that if a question is left unanswered on any scale, the denominator is adjusted accordingly to reflect the number of questions answered. They have some face value since scores above 75% suggest skill competency > ¾ of the time, while scores below 25% suggest skill competency < ¼ the time.

Language Scale. The Lang scale has 44 total possible points and is calculated as:

- Total points from 11 questions ÷ (4 x 11) x 100.

For example, if a Lang raw score is 31 then that scale score is 70% (i.e. 31 ÷ 44 x 100 = 70%).

Attention Scale. The ATT scale has 40 possible points and is calculated as:

- Total points from 10 questions ÷ (4 x 10) x 100.

However, Question 1 and Question 42 are only included in the scoring if rated ‘sometimes’ or ‘rarely’. This is because these questions do not represent core ADHD symptoms and are not supported by factor analysis (although item 42 is associated with hyperactive ADHD in the literature).

Auditory Processing Scale. The AP scale has 124 possible points and is calculated as:

- (Total points from 31 questions + minus values from 7 item-pair comparisons (see below)) ÷ (4 x 31).

Question 49 is only included in the scoring if rated ‘sometimes’ or ‘rarely’ because it does not represent a core APD symptoms and was not supported by factor analysis.

The AP scale has seven item pairs: five item pairs where listening in quiet is contrasted with listening in noise, and two item pairs that contrast sustained attention fatigue on non-listening versus listening tasks. Points are subtracted from the initial raw AP scale (APR) if a child is exceptionally challenged by ‘listening in noise’ or ‘listening fatigue’. Further details of AP scale scoring are discussed in Appendix A.

Targeted Auditory Processing Scale. The TAP scale has 72 possible points and is calculated as:

- Total points from 18 questions ÷ (4 x 18) x 100.

An Excel spreadsheet is available to calculate all scores. The spreadsheet also generates a report which graphically summarizes the scale scores and differential risk factors for APD, ADHD, and language disorders (see Appendix B).

Data Collection

Participants

Research approval was obtained from the Kaiser Hawaii Center Health Research Institutional Review Board in 2007. Two thousand medical records were reviewed to select 1,700 candidates for normal control (NC) and clinical groups. Two hundred and fifty parent informants responded to the mail outs (a 14.7% return rate) and these comprised the NC, ADHD, and learning disability (LD) groups. An additional 20 subjects were recruited from audiologist colleagues for the APD group. Group selections were further informed by a medical and education checklist which accompanied each questionnaire (see Appendix C).

Normal Controls. The NC group included parents of 198 students (101 females and 97 males) without medical record evidence of ADHD or parent evidence of APD, LD, or special education services. There were 104 students in the younger group (7- to 10-year-olds) and 94 in the older group (11- to 17-year-olds). The racial distribution was 25% Caucasian, 33% mixed race, 24% Asian, and 18% Hawaiian/Pacific Islander/other. One participant did not answer this question. This distribution is representative of Hawaii but very different from United States census data (US census, 2009). Thirty-five percent of parents (*N* = 70) had high school or some college education while 65% (*N* = 128) were college graduates or above. This 2:1 high school/college ratio differs from the national 1:2 ratio (US Census, 2009) and the 1:1 ratio present in our ADHD and APD clinical groups. The effect of gender, race, and parent's education level on the scores were assessed using a regression model in the *External Discriminate Reliability* subsection of the *Results*.

Attention Deficit Hyperactivity Disorder Group. The parents of 40 students with ADHD medical diagnoses (DSM-IV, 1994; American Psychiatric Association) by a psychiatrist or pediatrician comprised the ADHD group. They were predominantly of the inattentive subtype. This group numbered 15 female and 25 male students. There were 19 students in the younger group and 21 in the older group. The racial distribution was 13% Caucasian, 25% mixed race, 13% Asian, and 35% Hawaiian/Pacific Islander/other. Six participants did not answer this question. Forty-three percent of parents (*N* = 17) had high school or some college education, 43% (*N* = 17) were college graduates or above, and 14% did not indicate their education level (*N* = 6).

Auditory Processing Disorder Group. The parents of 20 students with auditory processing test evidence of APD recruited from collaborating audiologists comprised the APD group. These audiologists followed the diagnostic guidelines of the 2000 APD consensus statement (Jerger and Musiek, 2000). Thus, the test battery used for an APD diagnosis included tests of dichotic listening, monaural low-redundancy speech, gap detection, speech in noise, and frequency patterns. Subjects were diagnosed with APD if they performed at least two standard deviations below the mean on two or more tests of the above recommended test battery. The APD group had 10 females and nine males (plus one without gender identified). There were 10 students in the younger group and 10 in the older group. The racial distribution was 5% Caucasian, 20% mixed race, 20% Asian, and 5% Hawaiian/Pacific Islander/other. Ten participants did not answer this question. Twenty-five percent of parents (N = 5) had high school or some college education, 25% (N = 5) were college graduates or above, and 50% did not indicate their education level (N = 10).

Learning Disability Group. The parents of 10 students attending special education comprised the LD group. The medical-educational history check list indicated that two children had dyslexia, three had a language learning disability, and five had learning disabilities not further specified. None had ADHD or APD checked on the list. There were four females and six males. Six students were in the younger group and four were in the older group. The racial distribution was 20% Caucasian, 30% mixed race, 30% Asian, and 20% Hawaiian/Pacific Islander/other. Seventy percent of parents (N = 7) had high school or some college education and 30% (N = 3) were college graduates or above.

Retest Reliability Check

Twenty-six parents from the NC group re-rated their questionnaires after a three-week interval so retest reliability could be checked.

Data Analysis

An Excel spreadsheet program was developed to calculate the scale scores and report findings including scale score rank percentiles and patterns indicative of APD, ADHD, and LD risks. Data were analyzed statistically using SPSS 15 (SPSS 1982) and later SPSS 23 (SPSS 2015), Statistica version 10, and R version 3.3.1. NC scale scores were not normally distributed and not appropriate for standard scoring. As is typical for behavioural rating scales, ceiling effects created negative skews and a positive kurtosis (Pallant 2005).

Results

Questionnaire Psychometrics

Internal Reliability. Cronbach’s alpha measures how closely related a set of scale items are as a group. Cronbach’s alpha was 0.96 for the AP scale indicating excellent consistency between the items on that scale. Cronbach’s alpha was 0.88 for the ATT and Lang scales, indicating good consistency between the items on each of these scales.

External Reliability. Twenty-six parents from the NC group re-rated their questionnaires after a three week interval. Test-retest Pearson R correlation was strong (R = 0.88, $p \leq$ 0.00001) indicating good test-retest reliability.

Internal Validity. A principal component factor analysis (with oblimin rotation and Kaiser normalization) was conducted using the data from the NC group to assess the internal validity of the questionnaire. Only forty-nine of the 52 questions were examined as Q1, Q42, and Q49 could not be included in the factor analyses since by design these questions were only recorded if scored ‘sometimes’ or ‘rarely’. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.915, which is well above the commonly recommended value of 0.6. Bartlett’s test of sphericity was significant (χ^2 (1176) = 6757.54, $p < .001$). Initial eigenvalues of 19.3, 2.7, and 2.6 indicated that the first three factors explained 39.5%, 5.5%, and 5.4% of the variance respectively. Subsequent eigenvalues each explained less than 4% of the variance and showed levelling-off on the scree plot. Therefore, a three-factor solution representing the three scoring scales was used for the analysis. These three factors explained 50.3% of the variance. Factor items matched AP, ATT and Lang scales 33 out of 49 times when taking into account the highest factor loadings above 0.3. (Note, the score is out of 49 as Q3 and Q28 are assigned to two scales and Q2 and Q8 are not assigned to a scale). Factor items matched AP, ATT and Lang scales 40 out of 49 times when matching any factor loadings above .3. The factor loadings for the questions (in abbreviated form) are shown in Table 1.

[Insert Table 1 here]

External Discriminate Validity. Table 2 shows the mean score and standard deviation for each group on each scale (using the original scale allocations for the questions).

[Insert Table 2 here]

A regression model was fitted to the data using R version 3.3.1 rms package version 4.5-0 to assess what factors affected children’s scores on each scale, and compare scores across the normal and clinical groups. The AP, ATT, and Lang scores were transformed using the multcomp package version 1.4-5 (which uses the method described in Hothorn, Bretz, and Westfall (2008)) so that the assumptions of linear regression would be better satisfied. The transformation is shown by equation (1)

$$y = \log\{[(x/100) + 0.01]/[1 - (x/100) + 0.01]\} \qquad (1)$$

where *x* is the original score, *y* is the transformed score, and ‘log’ is the natural logarithm. Transformations of this type are suggested by Warton and Hui (2011).

For each of the three scores, a regression model was fitted with the transformed score as the response variable and group (four categories), age (continuous), gender (two categories), race (four categories), and rater’s education level (two categories) as the explanatory variables. Missing data was handled using multiple imputation with the Amelia package version 1.7.4. This involved generating 50 completed data sets, fitting the models on each completed data set, and combining the results across the 50 data sets.

Table 3 gives the *p*-value for the test of the null hypothesis of no effect of each explanatory variable on each score. The df column shows the number of degrees of freedom for the tests. Since group and race each have four categories, they were each represented by three binary variables, and the test is of the null hypothesis that the coefficients of the three binary variables are all zero. Normal/clinical group differences as well as age group differences for the younger (7- to 10-year-olds) and older (11- to 17-year-olds) groups were significant for each scale. Gender and race did not have statistically significant effects on any scale scores. Parent educational levels had a significant effect on only the Lang scale (though note that the APD group was underrepresented in this analysis as only 50% (i.e. N =10) of the parents indicated their education level).

[Insert Table 3 here]

Differences in scores between pairs of normal/clinical groups for each scale when the values of the other explanatory variables were held constant are shown in Table 4. The predicted difference in score for Group 2 (g_2) relative to Group 1 (g_1) on the original 0 to 100 scale is shown in each row. A negative value indicates that the predicted score for g_2 is lower than the predicted score for g_1. The estimates are based on the g_1 score being the median score for that group (the predicted difference depends on this score because of the non-linear transformation). The table also shows a 95% confidence interval for the difference and a *p*-value for the test of the null hypothesis that the true difference is zero. The *p*-values and confidence intervals have been adjusted for the six comparisons within each score (but not for comparisons across scores).

Significant differences were found between the normal and clinical groups for all scales. Poorer performance on the ATT scale differentiated the ADHD and APD groups. Poorer performance on the Lang and AP scales differentiated the LD and APD groups. Poorer performance on the Lang and ATT scales differentiated the LD and ADHD groups.

[Insert Table 4 here]

Age Group Scale Score Percentile Ranks

Rank percentile scoring was chosen since the data did not fit a standard distribution curve. Percentile ranks for the younger and older age groups are shown in Table 5.

Moderate ‘at risk’ levels were set at < 1 standard deviation from the mean, which, due to the distribution not being normal, corresponds to a student being below the 15th percentile rank for AP and Lang scales and 20th rank percentile for the ATT scale. These levels clearly separated the normal controls from the clinical groups. However, there was much overlap between the clinical groups. Seventy percent of the APD subjects were at risk for ADHD on the ATT scale while 80% of the ADHD group was at risk for APD on the AP scale. All LD children were at risk for APD and ADHD on the AP and ATT scales. However, different deficit patterns, including the difference between ATT and AP scores, clearly separated the three groups (see next section).

[Insert Table 5 here]

Differentiating Between Groups

The individual scores on each scale for the subjects in the normal and clinical groups were plotted against each other for younger and older groups. Examination of this data and receiver operator curves enabled the scale score cut-offs to be determined for each group on each scale. The AP, ATT, and Lang scale scores along with scale score differences (ATT minus AP) clearly differentiated the APD, ADHD, and LD clinical groups. Cut-off values for both sensitivity and specificity were mostly above the 80% level. High ‘at risk’ cut-off levels for APD, ADHD, and LD are summarized below and plotted graphically in Figure 1, along with the moderate risk cut-offs described in the previous section. Scale scores are expressed as a percent (of the maximum or perfect scale score). Percentiles refer to percentile rank scale scores and are *italicized.* Sensitivity/specificity levels for each clinical group relative to the normal controls are noted by % / %.

- APD Group
    - Younger Group
        - AP scale ≤ 45 *(~5th percentile)* (90%/90%)
        - Lang > 45 *(3rd percentile)*
        - ATT-AP ≥ 0
    - Older Group
        - AP scale ≤ 55 *(~5th percentile)* (80%/91%)
        - Lang > 44 *(3rd percentile)*
        - ATT-AP ≥ 0
- ADHD Group

- Younger Group
  - ATT scale ≤ 37 *(~10th percentile)* (89%/90%)
  - Lang > 45 *(3rd percentile)*
  - ATT-AP ≤ -10
- Older Group
  - ATT scale ≤ 50 *(~5th percentile)* (86%/91%)
  - Lang > 44 *(3rd percentile)*
  - ATT-AP ≤ -10

- LD Group
  - Younger Group
    - Lang Scale ≤ 45 *(3rd percentile)* (100%/99%)
    - AP scale ≤ 54 *(10th percentile)*
    - ATT scale ≤ 42 *(10th percentile)*
  - Older Group
    - Lang Scale ≤ 44 *(3rd percentile)* (75%/99%)
    - AP scale ≤ 62 *(10th percentile)*
    - ATT scale ≤ 53 *(10th percentile)*

We also assigned a criteria for a child who may have an unclear profile or mixed APD/ADHD due to equally poor scores on both the AP and ATT scales.

- Unclear or Mixed APD/ADHD
  - Younger Group
    - AP scale ≤ 45 *(~5th percentile)*
    - ATT scale ≤ 37 *(~10th percentile)*
    - Lang > 45 *(3rd percentile)*

    - ATT-AP between -10 and 0
- Older Group
    - AP scale ≤ 55 *(~5th percentile)*
    - ATT scale ≤ 50 *(~5th percentile)*
    - Lang > 44 *(3rd percentile)*
    - ATT-AP between -10 and 0

[Insert Figure 1 here]

Key APD Listening Skills

AP scale items of greatest difficulty (i.e. lowest mean score) for students with APD are listed in Table 6. These APD core symptoms all relate to difficulty listening in noise, multi-task listening, and listening to unclear speakers. They did not relate to difficulty decoding and encoding words phonetically, using prosodic language cues, following oral instructions in quiet, or being more attentive in non-listening versus listening situations.

Table 6 also reflects the contrasting types of difficulties students with APD and ADHD have on the AP and ATT scales. On the AP scale subjects with ADHD had maximum difficulty with auditory attention, auditory memory, and noise distractions, which are not core APD symptoms. This could be interpreted as a qualitative difference versus the APD group on this scale. On the ATT scale APD students had less difficulty with all the core ADHD issues of sustained attention, working memory, motivation and impulse control and most difficulty with organization, attentive listening, and listening fatigue. This could be interpreted as a qualitative difference from the ADHD group on this scale.

Such core symptom differences supports the conclusions of Chermak, Tucker, and Seikel (2002) and Riccio, Hynd, Cohen, Hall, and Molt (1994) that despite behavioural overlaps and frequent co-morbidity, APD and ADHD are clinically distinct entities which require different management strategies.

[Insert Table 6 here]

Discussion

The purpose of this questionnaire was to differentiate children at risk primarily for APD, from those more likely to have ADHD or a language disorder. The psychometric characteristics of the APDQ largely met the criteria of McCauley and Swisher as outlined by Friberg and McNamara (2010) for judging the diagnostic accuracy of language and hearing tests, namely: normative sample size > 100; clearly defined demographics; Pearson r test-retest reliability > 0.9 (0.88); and most pass-fail cut off values > 80% sensitivity and specificity. The AP, ATT, and Lang scale scores along with the ATT minus AP values correctly classified over 80% of subjects in the four NC, APD, ADHD, and LD diagnostic categories. Unmet criteria included not having nationally representative demographics and inter-rater reliability or concurrent validity measures.

APDQ data has the potential to serve a bell-weather function in the controversy between bottom up and top down APD constructs since both approaches support their viewpoint by having significant behavioural correlations with cognitive/language versus central auditory test factors (or both). The APD Position Statement and Practice Guidance by the British Society of Audiology (BSA, 2011) favors a more top down, cognitive-sensory construct of APD due to their research evidence of cognitive-working memory factors impacting performance on central AP tests. Furthermore, they propose a new diagnostic category of 'children with listening difficulties' for those listeners who pass (rather than fail) AP test batteries. Such children with listening difficulties are then to be afforded such non-specific APD help as listening strategy information, preferential classroom seating, remote FM microphone technology, as well as more function specific testing and careful monitoring (Dillon, Cameron, Glyde, Wilson & Tomlin, 2012). It also is possible that many of these children with listening difficulties could meet diagnostic criteria and treatments for ADHD or LD. APDQ screening data can suggest whether assessments should be carried out for these alternative disorders.

The more traditional APD model outlined by consensus reports from The American Academy of Audiology (AAA, 2010) and The American Speech-Language-Hearing Association (ASHA, 2005) favors a bottom-up central auditory nervous system (CANS) approach where a battery of audiological tests useful in detecting CANS lesions are the designated diagnostic instruments along with multidisciplinary clinical input. Chermak (2017) and others have pointed out that auditory test correlations with cognitive and language measures increase significantly when the APD group has lower cognitive capacities. This was the case in Barry’s report on the ECLiPS questionnaire where the 12 subjects with positive AP test results were significantly more cognitively limited than the 23 subjects with negative AP test results (Barry et al., 2015). Our own data showed that LD subjects receiving special education who were below the third percentile on the Lang scale had the lowest mean scale scores on both the AP and ATT scales. The Lang scale played a very useful function throughout in recognizing children with listening difficulties who appeared to have more than straight forward auditory processing deficits with very poor performance on all three scales.

As mentioned in the introduction, pre-2000 APD screening questionnaires were not able to correlate results with auditory processing test findings (with one exception where two groups of 11- and 12-year-old students with listening difficulties who passed or failed APD tests were well differentiated by the CHAPPSquestionnaire (Iliadou and

Bamiou, 2012)). Post-2000 screening questionnaires have reported psychometric evidence of reliability and validity but have had mixed success in demonstrating significant correlations with auditory processing tests (Barry et al., 2015). Given the promising results of this study, we are hoping that future studies with the APDQ will demonstrate significant correlations between the questionnaire scale scores and auditory processing test results.

Study Limitations

This study was able to use the resources of the Hawaii Kaiser Medical Center and collaborating audiologists to recruit research subjects where medical records could guide selection of normal controls versus clinical groups. This method, however, had its limitations. Although the children in the APD and ADHD groups had a formal clinical diagnosis of their disorder (following the guidelines of the APD consensus statement (Jerger & Musiek, 2000) or the DSM-IV (1994)), detailed information about their specific test results and other clinical data were often lacking. Furthermore, the LD group, which had the smallest number of subjects, only had parent data regarding special education services and/or learning disability diagnoses. Therefore, it would be beneficial to include a larger, more specific language disorder group in future research and correlate the APDQ scores with the scores children receive on specific clinical APD, ADHD, or language tests to help us better understand what tests particular APDQ questions are sensitive to. While the number of subjects recruited with APD and in particular LD was not sufficient to draw definitive conclusions, there were some promising trends as reported. Therefore, it would be worthwhile to use and monitor the results of the APDQ in a broad range of clinical settings and foremost, do a prospective study with a large number of children with listening difficulties including those with detailed documentation of their auditory, attention, and language status.

In reviewing the data collected from the current experiment and feedback we have received on the questions, we have now revised the APDQ to a 50-item questionnaire. This revision includes the removal of redundant questions, minor rewording of questions to make them clearer, and some scoring and scale assignment adjustments given the results of the factor analysis and differential analysis. Plans are currently underway to conduct a study that addresses the above limitations and provide normative and clinical data for this new version.

Conclusions

The APDQ demonstrates psychometric evidence of the internal and external reliability and validity required for it to be an effective screening tool for auditory processing difficulties in children aged 7 to 17 years old. Children with listening difficulties are readily identified when they are rated below the 15^{th} to 20^{th} percentile on different scales. Our data supports the ability of the questionnaire to be sensitive and specific to individuals with APD and ADHD. At-risk factors for APD include an AP scale score less than the 15^{th} percentile and an ATT-AP difference ≥ 0. At-risk factors for ADHD include an ATT scale less than the 20^{th} percentile and ATT-AP ≤ -10. Typically, children with APD and ADHD will be rated above the third percentile on the Lang scale. A very low language rating, in addition to low scores on the AP and ATT scales is most likely related to cognitive-language factors. Future research is needed to evaluate the sensitivity and specificity of the questionnaire for individuals with language issues.

The APDQ is readily scored by an Excel spreadsheet program and will be published as a slightly revised 50-item questionnaire by the Educational Audiology Association in the United States in 2018. This 50-item version is now available online (apdq.nal.gov.au). An online report with the child’s results and suggested further steps is available for the parent upon completion of the questionnaire. A 32-item version for 4.5- to 7-year-olds is also under development.

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Professional meeting and online report details

O’Hara, B. (2003, July). Concepts and Goals Regarding the APDQ: Novel differential screening for APD. Oral presentation at the Educational Audiology Association Conference, St. Louis, Missouri.

O’Hara, B. (2007, April). The Listening Questionnaire: Effective screening for APD? Poster presentation at the American Academy of Audiology Conference, Denver, Colorado.

O’Hara, B. (2007, July). The Listening Questionnaire. Poster presentation at the Educational Audiology Association Conference, Phoenix, Arizona.

O’Hara, B. (2009, November). The Listening Questionnaire Update. Oral presentation at the American Speech-Language-Hearing Association Conference, Boston, Massachusetts.

O’Hara, B. (2012, March). The APDQ: Novel differential screening for APD. Poster presentation at the American Academy of Audiology Conference, Boston, Massachusetts.

O'Hara, B.A. (2016). Overview of the Auditory Processing Domains Questionnaire http://hearinghealthmatters.org/pathways/2016/auditory-processing-questionnaire-differential-screening-apd-overview.

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References

American Academy of Audiology (AAA). (2010). *Diagnosis, treatment and management of children and adults with central auditory processing disorder*. pp. 1-53. http://www.audiology.org/resources/documentlibrary/

American Speech-Language-Hearing Association. (2005). *(Central) auditory processing disorders* [Technical report]. Rockville, MD: J.Ferre/working group. Available at http://www.asha.org/members/deskref-journals/deskref/default.

Anderson, K.L., and Smaldino, J.J. (1999). Listening Inventories For Education: A classroom measurement tool. *Hear. J. 52*(10), pp.74-76.

Anderson, K.L., and Smaldino, J.J. (2000). *Children's Home Inventory of Listening Difficulties (CHILD)*. Tampa, FL: Educational Audiology Association.

Anderson, K.L., 1989. *Screening identification for targeting educational risk.* Tampa, FL: Educational Audiology Association.

Atcherson, S.R., Richburg, C.M., Zriack, R.I. and George, C.M. (2013). Readability of questionnaires assessing listening difficulties associated with (central) auditory processing disorders. *Lang Speech Hearing Serv Sch,* 44(1), pp. 48-60.

Bamiou, D.E., Iliadou, V.V., Zanchetta, S. and Spyridakou, C. (2015). What can we learn about auditory processing from adult hearing questionnaires? *J Am Acad Audiol,* 26(10), pp. 824-837. doi:10.3766/jaaa.15009.

Bamiou, D.E., Musiek, F.E., and Luxon, L.M. (2001). Aetiology and clinical presentations of auditory processing disorders – a review. *Arch Dis Child*, 85, pp. 361-365.

Barkley, R. (2006). *Attention Deficit Hyperactivity Disorder: A Handbook for Diagnosis and Treatment.* New York: The Guilford Press.

Barry, J., Moore, D., Dillon, H. and Tomlin, D. (2015). Use of questionnaire-based measures in the assessment of listening difficulties in school-aged children. *Ear Hear,* 36(6), pp. 1-14. doi:10.1097/AUD.0000000000000180.

Barry, J.G. and Moore, D.R. (2013). *Evaluation of Children's Listening and Processing Skills (E.C.L.I.P.S.)*. Medical Research Council: United Kingdom. https://www.nottingham.ac.uk/mrcihr/documents/eclips-faw03.pdf

Bellis, T.J. and Ferre, J.M. (1999). Multidimensional Approach to the Differential Diagnosis of Central Auditory Processing Disorders in Children. *J Am Acad Audiol,* 10, pp. 319-328.

Chermak, G.D., Musiek, F.E. and Weihing, J. (2017). Beyond controversies: The science behind central auditory processing disorder. *The Hearing Review.* http://www.hearingreview.com/2017/05/beyond-controversies-science-behind-central-auditory-processing-disorder/

Chermak, G.D., Tucker, E. and Seikel, J.A. (2002). Behavioral characteristics of auditory processing disorders and attention deficit hyperactivity disorder predominantly inattentive type. *J Am Acad Audiol.* 13, pp. 332-338.

Conners C.K. (1996). *Conners Rating Scales-Revised (CRS-R).* Pearson Assessment: The Psychological Corporation.

Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). (1994). American Psychiatric Association.

Dillon, H., Cameron, S., Glyde, H., Wilson, W. and Tomlin, D. (2012). An opinion on the assessment of people who may have an auditory processing disorder. *J Am Acad Audiol*, *23*(2), pp. 97-105. DOI: 10.3766/jaaa.23.2.4 23:97–105

Emanuel, D. (2002). The auditory processing battery: Survey of common practices. *J Am Acad Audiol,* 13, pp. 93-117.

Fisher, L.I. (1976). *Fisher’s auditory problems checklist.* Bemidji: Life Products

Friberg, J.C. and McNamara, T.L. (2010). Evaluating the reliability and validity of (central) auditory processing tests: A preliminary investigation. *J Educ Audiol,* 16, pp. 4-17.

Gatehouse, S. and Noble, W. (2004). The Speech, Spatial and Qualities of Hearing Scale (SSQ). *Int J Audiol.* 43(2), pp. 85-99.

Geffner, D. and Ross-Swain, D. (2006). *The Listening Inventory.* United States: Academic Therapy Publications.

Hothorn, T., Bretz, F., and Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, 50(3), pp. 346-363.

Hunsaker, R. (1990). *Understanding and Developing the Skills of Oral Communication: Speaking and Listening.* Englewood Colorado: Morton Press.

Iliadou, V. and Bamiou, D.E. (2012). Psychometric evaluation of children with auditory processing disorder (APD): Comparison with normal-hearing and clinical non-APD groups. *J Speech Lang Hear Res,* 55, pp. 791-799.

Jerger, J. and Musiek, F. (2000). Report of the consensus conference on the diagnosis of auditory processing disorders in school-aged children. *J Am Acad Audiol*, 11, pp. 467-474.

Katz, J. (1998). The SSW test manual. Vancouver, WA: Precision Acoustics.

Kincaid, J.P., Aagard, J.A., O'Hara, J.W, and Cottrell, L.K. (1981). Computer Readability Editing System. *IEEE Transactions on Professional Communications*, 24(1), pp. 38–42. Tests available at http://www.readabilityformulas.com/flesch-grade-level-readability-formula.php

Levine, M.D. (1990). *Keeping a Head in School.* Educators Publishing Service, Inc: Cambridge, MA.

Meijer, A.G., Wit, H.P., TenVergert, E.M., Albers, F.W., and Muller Kobold J.E. (2003). Reliability and validity of the (modified) Amsterdam inventory for auditory disability and handicap. *Int J Audiol,* 42(4), pp. 220-226.

Musiek, F.E. (1983). Assessment of central auditory dysfunction: the dichotic digit test revisited. *Ear Hear,* 4(2), pp. 79-83.

Musiek, F.E., Baran, J.A., and Pinheiro, M.L. (1990) Duration pattern recognition in normal subjects and patients with cerebral and cochlear lesions. *Audiology,* 29(61), 304-313.

Musiek, F.E. and Pinheiro, M.L. (1987). Frequency patterns in cochlear, brainstem, and cerebral lesions. *Audiology,* 26(2), pp. 79-88.

Musiek, F.E., Shinn, J.B., Jirsa, R., Bamiou, D.E., Baran, J.A., and Zaida, E. (2005). GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear Hear,* 26(6), pp. 608-618.

Nunes, C.L., Pereira, L.D. and Carvalho, G.S.D. (2013). Scale of Auditory Behaviors and auditory behavior tests for auditory processing assessment in Portuguese children. *CoDAS*, 25(3), pp. 209-215.

Pallant, J. (2005). *SPSS Survival Guide: A Step by Step Guide to Data Analysis Using SPSS for Windows. 3rd Edition.* Open University Press: New York.

Phillips, D.P., Comeau, M. and Andrus, J.N. (2010). Auditory temporal gap detection in children with and without auditory processing disorder. *J Am Acad Audiol,* 21(6), pp. 404-408.

R Core Team (2016). R: A language and environment for statistical computing (version 3.3.1). http://www.r-project.org.

Riccio, C.A., Hynd, G.W., Cohen, M.J., Hall, J. and Molt, L. (1994). Comorbidity of central auditory processing disorder and attention-deficit hyperactivity disorder. *J Am Acad Child Adolesc Psychiatry*, 33, pp. 849–857.

Schow, R.L., Seikel, A., Brockett, J.E., and Whitaker, M.M. (2007). *Multiple auditory processing assessment.* St. Louis: Auditec.

Smoski, W.J., Brunt, M.A., and Tannahill, J.C. (1992). Listening characteristics of children with central auditory processing disorders. *Lang Speech Hear Serv Sch,* 23, pp. 145-152.

Strange, A.K., Zalewski, T.R. and Waibel-Duncan, M.K.W. (2009). Exploring the usefulness of Fisher’s auditory problems checklist as a screening tool in relationship to the Buffalo model diagnostic central auditory processing test battery. *J Educ Aud,* 15, pp. 44-52.

The British Society of Audiology. (2011). *An overview of current management of auditory processing disorder (APD).* Retrieved March 31, 2011, from http://www.thebsa.org.uk/

Tomblin, J. B., Records, N. L., Buckwalter, P., Zhang, X., Smith, E., and O’Brien, M. (1997). Prevalence of Specific Language Impairment in Kindergarten Children. *J Speech Lang Hear Res*, 40(6), pp. 1245-1260. doi: 10.1044/jslhr.4006.1245.

U.S. Census Bureau (2009). *Research Report: Center for Economic Studies and Research Data Centers.* U.S. Government Printing Office: Washington, DC.

Warton, D.I. and Hui, F.K.C. (2011). The arcsine is asinine: The analysis of proportions in ecology. *Ecology*, 92(1), pp. 3-10.

Willcutt E.G. (2012). The prevalence of DSM-IV attention-deficit/hyperactivity disorder: a meta-analytic review. *Neurotherapeutics*, 9, pp. 490-499.

Wilson, W.J., Jackson, A., Pender, A., Rose, C., Wilson, J., Heine, C. and Khan, A. (2011). The CHAPS, SIFTER, and TAPS–R as predictors of (C)AP skills and (C)APD. *J Speech Lang Hear Res*, 54(1), pp. 278-291.

Appendix A – Complex scoring calculations for AP scale

Minus points are taken from the AP scale if:

- Rating for item (e.g. noise) = 0 and rating for trigger (e.g. quiet) = 4, 3, or 1; or
- Rating for item (e.g. noise) = 1 and rating for trigger (e.g. quiet) = 4 or 3.

Minus values are calculated as follows:

- If trigger was ‘regularly’ (i.e. 4) and item was ‘sometimes’ (i.e. 1) = -3
- If trigger was ‘regularly’ (i.e. 4) and item was ‘rarely’ (i.e. 0) = -3
- If trigger was ‘often’ (i.e. 3) and item was ‘sometimes’ (i.e. 1) = -1
- If trigger was ‘often’ (i.e. 3) and item was ‘rarely’ (i.e. 0) = -3
- If trigger was ‘sometimes’ (i.e. 1) and item was ‘rarely’ (i.e. 0) = -1

These minus values are used to emphasize performance differences between subjects in the critical areas of listening in noise and listening attention/fatigue. Minus values were included for Q3 vs. Q2, Q5 vs. Q4, Q37 vs. Q7, Q15 vs. Q14, Q18 vs. Q17, Q23 vs. Q22, and Q27 vs. Q 26.

If a question is left unanswered on any scale, the denominator is adjusted accordingly to reflect the number of questions answered. For example, if only eight questions were answered on the 11 item Lang scale, the calculation becomes:

Total points from eight questions ÷ (4 x 8) x 100.

This is called n/a (not applicable) scoring. Two items on the ATT scale (Q1 and Q42) and one item on the AP scale (Q49) have n/a scoring unless they are rated “sometimes” or “rarely”. This is because these items were not scale assigned by factor analysis or are symptoms of only a subgroup of students with ADHD or APD.

Appendix B – Sample of Excel report form

APDQ REPORT FORM

2/28/2016

Subject Information

Subject Number:		Rater:	
Subject Name:		Rating Date:	
Age:			
Sex:			

Questionnaire responses

Scoring: Regularly=4, Often=3, Sometimes=1, Infrequently=0

(MS Excel™ scores items 1, 42 and 49 "n/a" unless they are rated "sometimes" or "infrequently")

1	Listens attentively 1:1		27	Answers questions promptly (noise)	
2	Listens attentively in group (quiet)		28	Follows sequential directions	
3	Listens attentively in group (noise)		29	Organizes tasks	
4	Listens OK when attentive (quiet)		30	Understands slang	
5	Listens OK when attentive (noise)		31	Not forgetful	
6	Listens carefully to important info		32	Understands less clear speakers	
7	Understands instructions (quiet)		33	Understands soft speakers	
8	Understands instructions (noise)		34	Listens accurately on phone	
9	Listens OK i in crowd noise		35	Hears OK away from speaker	
10	Listens OK to multiple speakers		36	Discriminates similar word sounds	
11	Listens OK while doing something else		37	Understands instr. when attentive (noise)	
12	Listens OK without visual cues		38	Uses new words right	
13	Listens OK during a related visual task		39	Spells OK phonetically	
14	Avoids distractions when working		40	Reads OK phonetically	
15	Avoids distractions when listening		41	Story reading rate OK	
16	Understands written instructions		42	Controls impulses/activity levels	
17	Studies long w/o fatigue-fidgets		43	Remembers directions OK	
18	Listens long w/o fatigue-fidgets		44	Auditory/visual learning parity	
19	Explains things clearly		45	OK with musical patterns	
20	Concentrates w/o high interest		46	Varies speaking voice OK	
21	Hears OK when back turned etc.		47	"Gets" key words/voice cues	
22	Does not say "what?" (quiet)		48	Understands w/o simpler words	
23	Does not say "what?" (noise)		49	Listens w/o louder volumes	
24	Avoids careless errors		50	OK word finding fluency	
25	Understands/uses longer sentences		51	No need extra noise control	
26	Answers questions promptly (quiet)		52	No need speak extra clearly	

Scale Scores

Raw Score (% of max. possible for scale)

		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Auditory Processing (AP)												
Attention (ATT)												
Language (L)												
Targeted AP (TAP)												

Percentile Rank (from age norms)

	Percentile Rank*	0	10	20	30	40	50	60	70	80	90	100
Auditory Processing (AP)												
Attention (ATT)												
Language (L)												
Targeted AP (TAP)												

Very problematic level (specific) — Problematic level (general)

ATT minus AP Value

ATT - AP =

ATT minus AP Analysis

>=+1,= High APD risk

<=-9, = High ADD risk

(above only applies if AP value is equal to or less than 15 percentile)

* Percentile ranks are determined by percentile thresholds in the Percentile Grid worksheet. If a score falls between two thresholds, the system uses the lower threshold value as the percentile rank.

Appendix C – Demographic and medical checklist for parents

PERSONAL INFORMATION

Student’s Name________________________
Case Number_____________

1. Today’s Date________ 2. Student’s Age in years____ months____ 3. Sex ___

4. Grade___

5. Person completing questionnaire: a. father___ b. mother ___ c. teacher____ d. other ____

6. Student’s Ethnicity (can check more than one but circle main racial identity if possible)

a. White ___ d. Asian (including Philippine Islanders ___

b. Black/African American __ e. Hawaiian or other Pacific Islander___

c. Native American/Eskimo___ f. Hispanic/Latino___ g. Other ____

7. Father’s years of school completed __ 8. Mother’s years of school completed ___

9. Please √ your concern level about student’s listening skills: (a) none ___
(b) mild__(c) moderate___ (d) high____

10. Please √ where any of the following conditions or services have occurred for student:

a.____ Special Education m.____ NONE OF THESE

b.____ Learning Disability

c.____ Dyslexia (or Language Learning Disability____)

d.____ History of Speech-Language delay or therapy

e.____ Permanent Hearing Loss (aided___ unaided___ mild ___ mod___ severe __ one sided___)

f.____ Learning English as a 2nd Language after age 5

g.____ Attention Deficit Disorder/ADHD (taking medication__ no meds.__)

h.____ Frequent middle ear infections____ middle ear fluid____ surgery____

i.____ Jaundice Problem as newborn (mild__ mod.__ severe__)

j.____ Auditory Processing Disorder (C)APD)

k.____ Autism/Asperger Syndrome (PDD)

l.____ Developmental Delay (MR)

Tables

Table 1: Factor analysis loadings with oblimin rotation and Kaiser normalization. Values are shown only for loadings greater than 0.30.

	Question (Abbreviated)	Original Scale Allocation	Factor Analysis Results		
			AP	Lang	ATT
3	Listens attentively in noisy group or classroom	AP, ATT	0.84		***
4	Hears your words accurately when attentive (quiet)	AP		0.50*	
5	Hears your words accurately when attentive (noise)	AP	0.86		
9	Understands speakers in echo noise	AP	0.68		
10	Listens accurately to competing speakers	AP	0.78		
11	Listens accurately while doing something else	AP	0.62		
12	Listens accurately without visual cues	AP	0.87		

13	Listens accurately while doing a related visual task	AP	0.71		
15	Avoids distractions when listening	AP	0.55		0.32**
18	Listens long periods without fatigue or fidgets	AP	0.61		0.52**
21	Hears speakers' words accurately from behind	AP	0.82		
22	Does not say 'what' when conversing in quiet	AP	0.78		
23	Does not say 'what' when conversing in noise	AP	0.70		
27	Answers questions promptly (in noise)	AP	0.75		
28	Readily follows sequential oral directions	AP, Lang	***	0.51	
32	Understands fast talking or foreign speakers	AP	0.55		
33	Understands soft spoken, high voiced speakers	AP	0.62		
34	Listens accurately on phone	AP	0.69		

35	Hears speakers words accurately when 8 ft. away	AP	0.49		
36	Discriminates accurately between similar sounding words	AP	0.60		
37	Understands instructions ok when attentive (noise)	AP	0.84		
39	Can spell correctly with phonics	AP	-0.30	0.90*	
40	Can read new words phonetically	AP	-0.31	0.83*	0.32*
43	Remembers spoken directions.	AP	0.62		
44	Can learn as well through auditory as through visual channel	AP	0.40	0.33**	
45	Readily follows musical pitch and rhythm patterns	AP		0.61*	
46	Varies speaking voice expressively	AP		0.64*	
47	Notes speakers' keyword emphases and other voice cues	AP		0.67*	
51	Does not need 'extra' noise controls at school and home	AP	0.38		
52	Does not need speakers to talk more distinctly	AP		0.63*	-0.31*

6	Listens carefully to important information	ATT	0.43*		0.38
14	Avoids distractions when working at desk	ATT	0.58*		0.57
17	Can study without fatigue or fidgeting	ATT	0.35**		0.66
20	Concentrates readily on low interest but important tasks	ATT	0.60*		0.33
24	Attends to details – avoids careless errors when studying	ATT	0.38**		0.53
29	Readily organizes tasks	ATT			0.54
31	Not forgetful	ATT	0.44*		0.31
7	Understands spoken instructions (quiet)	Lang	0.61*		
16	Understands written instructions	Lang		0.41	0.45*
19	Explains things fairly easily during conversations	Lang		0.52	
25	Understands and uses longer sentences	Lang		0.70	
26	Answers questions promptly	Lang	0.66*		

	(quiet)				
30	Understands slang expressions	Lang		0.51	
38	Uses new words correctly	Lang		0.71	
41	Reads stories at an ok rate (for age)	Lang		0.89	
48	Understands speakers without needing simpler words	Lang		0.87	
50	Speaks fluently, without many pauses or ‘ahs’	Lang		0.60	-0.33**
2	Pays attention to speakers in quiet classrooms	Off Scale Comparisons	0.56		
8	Understands spoken instruction (noise)	Off Scale Comparisons	0.89		

Note: * indicates the scale a factor is assigned to instead of the original scale.

** indicates the scale a factor is assigned to in addition to the original scale.

*** indicates the scale a factor was originally assigned to but was not assigned to by the factor analysis.

Table 2: Group scale score means and standard deviations for younger and older groups.

Group		Scale Score Mean (and SD)		
		AP	ATT	Lang
NC	Younger (*N* = 104)	82 (16)	76 (21)	90 (12)
	Older (*N* = 94)	87 (14)	82 (18)	92 (13)
ADHD	Younger (*N* = 22)	52 (18)	26 (17)	64 (21)
	Older (*N* = 18)	50 (20)	32 (18)	63 (22)
APD	Younger (*N* = 10)	38 (14)	59 (19)	66 (15)
	Older (*N* = 10)	43 (22)	53 (19)	59 (16)
LD	Younger (*N* = 6)	25 (2)	31 (23)	34 (13)
	Older (*N* = 4)	28 (13)	26 (10)	32 (12)

Table 3: Regression model *p*-values assessing the effect of each explanatory variable on each scoring scale.

Variable	df	*p*-value		
		AP	ATT	Lang
Group	3	< 0.001*	< 0.001*	< 0.001*
Age	1	0.007*	0.004*	0.01*
Gender	1	0.71	0.25	0.95
Race	3	0.18	0.21	0.39
Rater Education Level	1	0.13	0.05	0.002*

Note: * indicates significance at the $p < 0.05$ level.

Table 4: Normal and clinical inter-group comparisons for each scoring scale.

	AP		ATT		Lang	
g_1 *vs.* g_2	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value	Estimate (95% CI)	*p*-value
NC vs. ADHD	-31.2 (-43.2, -20.3)	< 0.001*	-57.6 (-67.9, -44.6)	< 0.001*	-17.9 (-28.6, -10.1)	< 0.001*
NC vs. APD	-43.5 (-58.9, -27.7)	< 0.001*	-25.5 (-44.7 ,-8.9)	< 0.001*	-19.9 (-35.6, -9.3)	< 0.001*
NC vs. LD	-59.3 (-75.1, -38.2)	< 0.001*	-58.1 (-74.4, -33.2)	< 0.001*	-50.8 (-73.8, -26.5)	< 0.001*
ADHD vs. APD	-12.2 (-28.4, 6.5)	0.33	31.8 (9.4, 51.4)	< 0.001*	-2.8 (-24.6, 15.9)	0.99
ADHD vs. LD	-26.7 (-40.7,-5.0)	0.01*	-0.5 (-16.7, 26.3)	1.00	-35.2 (-51.9, -9.0)	0.004*
APD vs. LD	-14.0 (-27.9, 9.3)	0.35	-31.4 (-47.1, -2.7)	0.03*	-32.8 (-51.7, -3.5)	0.02*

Note: * indicates significance at the $p < 0.05$ level.

Table 5: Age group percentile ranks for each scoring scale.

Percentile	Score (%)							
	Younger Group (7-10 years)				Older Group (11-17 years)			
	AP	ATT	Lang	TAP	AP	ATT	Lang	TAP
90	97	97	100	96	98	100	100	98
80	95	94	98	93	97	97	100	97
75	94	91	98	93	97	97	100	96
70	93	91	98	92	96	97	100	96
60	91	87	98	90	94	94	98	93
50	88	81	95	87	93	88	98	91
40	82	75	93	82	91	84	98	89
30	76	72	90	76	84	77	91	84
25	74	67	86	75	81	72	89	80
20	71	61*	82	71	78	69*	89	76
15	68*	50*	79*	71*	72*	60*	82*	72*
10	54*	42**	71*	55*	62*	53*	77*	63*
5	42**	30**	60*	45*	51**	46**	58*	53**
3	40**	25**	45**	38**	50**	33**	44**	49**
1	32**	20**	33**	32**	43**	28**	39**	44**

Note: * indicates moderate clinical risk

** indicates high clinical risk

Table 6: Key listening challenges for APD versus ADHD group on the AP scale and ATT scale as suggested by single item comparisons with all of the items on that scale. (Note, lower mean score values indicates greater difficulty with item).

	APD Group		ADHD Group	
	Item	Mean Score*	Item	Mean Score**
AP scale	36. Differentiating similar sounding words.	0.89	49. Listening accurately without louder volumes.	0.83
	5. Hearing words accurately in noise.	1.16	18. Not tiring easily when listening.	1.17
	52. Understanding unclear speakers.	1.21	43. Remembering detailed directions.	1.32
	21. Understanding speakers from behind.	1.21	3. Listening attentively in noisy conditions.	1.41
	44. Learning as well verbally as visually.	1.21	15. Staying focussed when listening.	1.47
	23. Not needing repeats when conversing in noise.	1.26		
ATT scale	29. Staying organized.	1.53	29. Staying organised.	0.78
	3. Listening attentively in noisy conditions.	1.74	20. Concentrating on low interest tasks.	0.85
	17. Studying long periods without fatigue/fidgeting.	1.89	24. Avoiding careless errors.	0.85
			31. Not being forgetful.	0.93

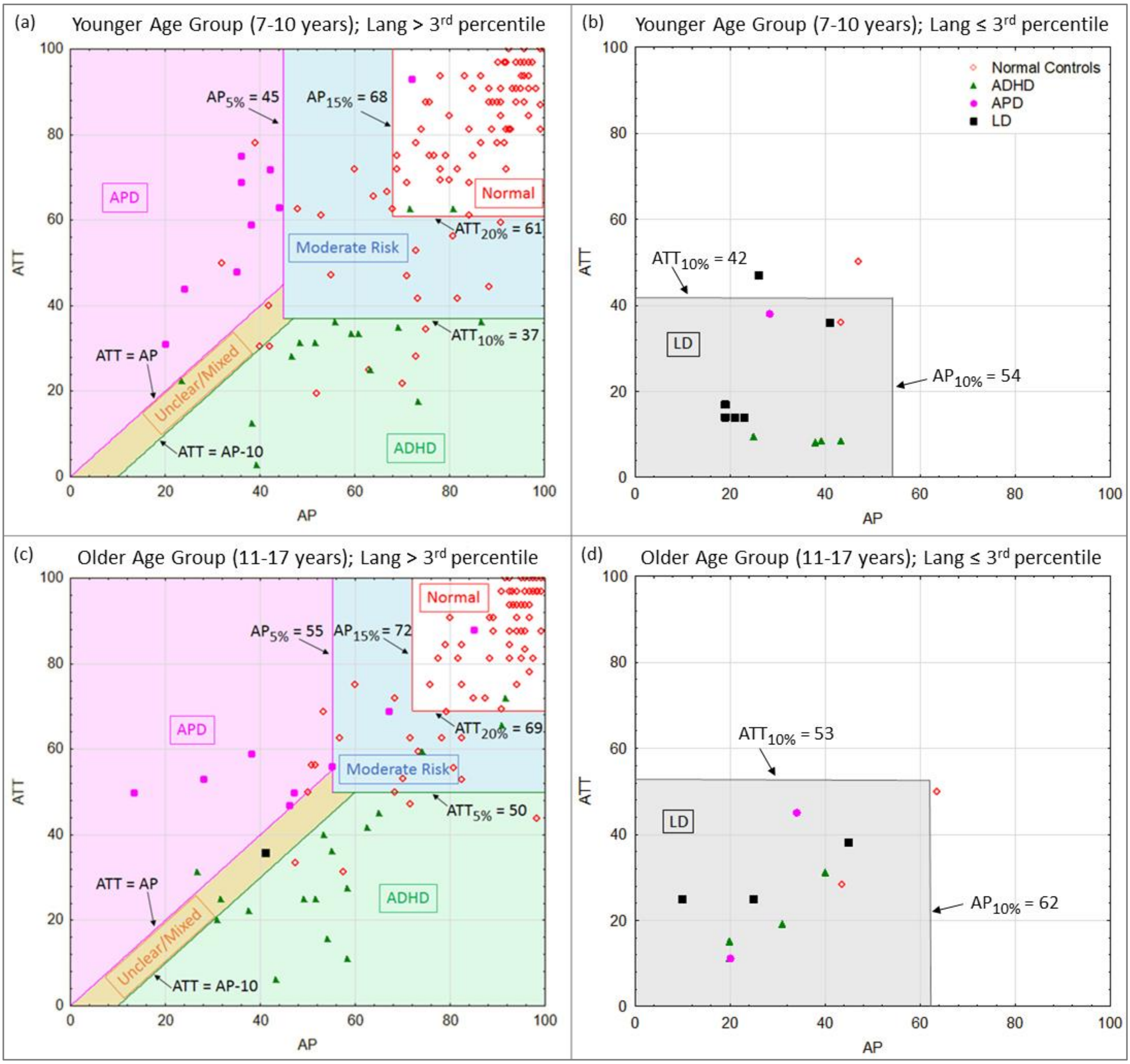
Note: * APD Group scores for all AP scale items: *Mean* = 1.8; *SD* = 1.4

APD Group scores for all ATT scale items: *Mean* = 2.1; *SD* = 1.5

** ADHD Group scores for all AP scale items: *Mean* = 2.1; *SD* = 1.4

ADHD Group scores for all ATT scale items: *Mean* = 1.2; *SD* = 1.3

Figure 1


(a) Younger Age Group (7-10 years); Lang > 3rd percentile
APD
Moderate Risk
Normal
ADHD
Unclear/Mixed
AP5% = 45
AP15% = 68
ATT20% = 61
ATT10% = 37
ATT = AP
ATT = AP-10
ATT
AP
(b) Younger Age Group (7-10 years); Lang ≤ 3rd percentile
Normal Controls
ADHD
APD
LD
ATT10% = 42
AP10% = 54
(c) Older Age Group (11-17 years); Lang > 3rd percentile
AP5% = 55
AP15% = 72
ATT20% = 69
ATT5% = 50
(d) Older Age Group (11-17 years); Lang ≤ 3rd percentile
ATT10% = 53
AP10% = 62

Figures Captions

Figure 1: Attention scale scores as a function of auditory processing scale scores for younger and older age groups who have language scores above the third percentile (graphs (a) and (c)) and who have language scores below the third percentile (graphs (b) and (d)). Shading differentiates the regions for which each of APD, ADHD, LD, unclear/mixed, and normal would be considered the most likely condition (colours shown on online version).