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# Investigating the interaction between dichotic deficits and cognitive abilities using the Dichotic Digits difference Test (DDdT)

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**Abstract**

**Background**: The Dichotic Digits difference Test (DDdT) was developed in order to investigate the relationship between dichotic processing and cognitive abilities and, through the use of differential test scores, to provide professionals with a clinical tool that could aid in differentiation of clients with genuine dichotic deficits from those where cognitive disorders are impacting on test performance. The DDdT consists of four subtests: dichotic free recall (FR), dichotic directed left (DLE) and right ear (DRE), and diotic. Scores for six conditions are calculated (Free Recall LE, RE and total, as well as the DLE, DRE and diotic). Scores for four difference measures are also calculated: Dichotic advantage, Right Ear Advantage (REA) FR; REA Directed and Attention Advantage.

**Purpose:** To investigate the role of cognitive abilities on DDdT test performance.

**Research Design:** Correlational analysis between the various DDdT conditions and difference measures, as well as between dichotic, diotic and cognitive factors (memory, intelligence and attention).

**Study Sample:** Fifty non-clinical children (7, 0 (yrs, mths) to 12, 1, mean 9, 2) and ten clinical children with a diagnosed memory or dichotic deficit (7, 0 (yrs, mths) to 15, 0, mean 9, 5) took part in the study.

**Data Collection and Analysis:** Pearson product moment correlations were utilized to determine the strength of relationships between DDdT conditions as well as between these scores on these conditions and performance on the various cognitive assessment tools, which included the number memory forward (NMF) and reversed (NMR) subtests of the Test of Auditory Processing Skills – Third Edition (TAPS-3), IVA+Plus continuous performance test (CPT) and the Test of Non-Verbal Intelligence-4 (TONI-4). Parent and participant questionnaires were also administered.

**Results:** Diotic performance was significantly correlated with performance on all the free recall DDdT conditions ($r = 0.6$ to $0.8$; $p < 0.00001$). Further, significant correlations were found between the FR LE and total conditions and all the cognitive measures - attention, memory and IQ - with r ranging from 0.3 to 0.4 ($p < 0.05$ to $0.01$). Right ear performance was not significantly correlated to any cognitive measure, except for FR RE and NMF ($r = 0.35$; $p = 0.006$). The DDdT dichotic advantage measure was investigated in a subset of clinical children and found to aid in differentiating true dichotic from spurious results.

**Conclusions:** As found in the normative data study, the high correlation between dichotic and diotic performance by the clinical and non-clinical participants suggests that factors other than dichotic performance play a substantial role in a child's ability to perform a dichotic listening task. Indeed, 61% of the variance in FR total scores for the children in this study was accounted for by factors that do not involve the perception of dichotic stimuli. This view is supported by the correlations between measures of attention and memory and dichotic scores. This result has wide-spread implications in respect to interpretation of CAPD test results and further investigation of the use of the DDdT in a clinical population is warranted.

**Key Words:** Dichotic, diotic, free recall, directed; impulsivity; sustained attention; central auditory processing disorder

**Abbreviations:** CAPD = Central Auditory Processing Disorder; CPT = continuous performance test; DDdT = Dichotic Digits difference Test; DLE = directed left ear; DRE = directed right ear; FR = free recall; LIFE = Listening Inventory for Education; NAL = National Acoustic Laboratories; NMF = number memory forward; NMR = number memory reversed; REA = right ear advantage; TAPS-3 = Test of Auditory Processing Skills – Third Edition; TONI-4 = Test of Non-Verbal Intelligence-4

## INTRODUCTION

Paper 1 of this two part investigation into the development and evaluation of the Dichotic Digits difference Test (DDdT; Cameron et al, 2013) reported on collection of normative and retest reliability data. In the introduction to that paper, research was discussed whereby significant correlations were shown between dichotic performance and cognitive ability (DeBonis 2015; Ahmmed et al, 2014; Maerlender, 2010; Tomlin et al, 2015), and that the right ear advantage (REA) effects that are described as a hallmark of dichotic testing cannot be explained on the basis of hypothetical conduction properties of specific auditory pathways, but instead in terms of dynamic processes, including those in which individuals deliberately direct their attention in different ways (Hiscock and Kinsbourne, 2011; Westerhausen and Hugdahl, 2008).

The previous paper on the development of the DDdT showed that in a typically-developing population, performance on the free recall LE, RE and total DDdT conditions was highly correlated with diotic performance (r ranging from 0.5 to 0.7, $p < 0.0001$). As the memory load and response criteria are identical for the dichotic free recall and diotic DDdT conditions, it was concluded that factors other than dichotic performance play a substantial role in a child's ability to perform dichotic listening tasks. The aim of the present study was investigate the correlations between DDdT condition scores in a population of clinical and non-clinical children; to compare those results to that seen in the previous normative data study; to investigate correlations between performance on DDdT conditions and cognitive abilities; and to examine the use of the DDdT dichotic difference score as a method of differentiating children with true dichotic deficits from those who obtain low scores on a dichotic test for other reasons.

## METHOD

Approval for the study was granted from the Australian Hearing Human Research Ethics Committee and the Catholic Schools Office, Diocese of Broken Bay.

### Participants

A total of 60 participants took part in the cognitive correlation study. All participants in the DDdT cognitive study spoke English as their first language, had no diagnosed attention disorder, and had normal hearing, defined as equal to or better than 20 dB HL at all octave frequencies between 250 Hz and 8000 Hz. There were 50 children (non-clinical group) aged 7, 0 (yrs, mths) to 12, 1 (mean 9, 3) who were recruited from a Catholic primary school in New South Wales, Australia. The school had an average Index of Community Socio-Educational Advantage value similar to the national average. There were 21 males and 29 females.

There were also ten children (clinical group) aged 6, 3 (yrs, mths) to 15, 0 (mean 9, 5), of which five were male and five were female. The clinical sample were recruited from ten Australian Hearing centres offering a CAPD service (Cameron et al, in press). The Australian Hearing CAPD service specifically targets children experiencing listening deficits in noisy environments. Clients from the CAPD service were accepted into the DDdT study if they had a scaled score of 6 or less (corresponding to a z-score of -1.33 or less) on either the number memory forward (NMF) or reverse (NMR) subtests of the Test of Auditory Processing – Third Edition (TAPS-3; Martin and Brownell R, 2005) or were below the normal range (by more than 2 SD) on the Dichotic Digits Test (Wilson and Strouse, 1998) compared to published normative data (Singer et al, 1998). Three of the clinical group were accepted into the study because of low memory scores, while the remaining seven had dichotic (LE or RE free recall) deficits.

## Procedure

The ten clinical children were assessed in a sound-attenuated booth at the National Acoustic Laboratories. Testing took approximately two hours to complete. Pure tone audiometric screening was performed using a Maico MA 53 clinical audiometer with circumaural Sennheiser HDA 200 audiometric headphones. The fifty non-clinical children were assessed in a quiet room on the school grounds. Sound levels in the school testing rooms were measured between 45-50 dBA using a Q1362 digital sound level meter. Pure tone audiometric screening was performed using an Interacoustics Audio Traveller A222 portable audiometer with Telephonics TDH 39P audiometric headphones in H7A Peltor cups. The DDdT (as described in paper 1, and summarized below) as well as the following assessment tools were administered. The TAPS-3 was re-administered to the 10 participants in the clinical group who had been referred from Australian Hearing.

### *DDdT*

The DDdT was administered with the use of a laptop computer and Senheisser HD215 headphones. Sound levels were calibrated prior to each appointment, using the procedure described in paper 1 (Cameron et al, submitted). The four subtests were presented in the order free recall (FR), directed left ear (DLE), directed right ear (DRE) and diotic. Five practice trials and twenty scored trials were presented in each subtest and the participants' task varied depending on the subtest. Each trial consisted of four randomly selected digits presented as temporally overlapped pairs. The four subtests were presented, as described below, resulting in six conditions, and four advantage measures, which are scored as percent correct:

a) Dichotic Free Recall (FR LE, FR RE and FR Total): a set of two numbers were presented to the left ear (e.g. 8, 6) at the same time as two *different* numbers were presented to the right ear (e.g. 1, 3). The digits presented first to each ear overlapped in time, as did the digits presented second to each ear. Participants were asked to repeat back all four numbers in any order (e.g. 6, 8, 1, 3). The LE and RE were scored separately. The average of the LE and RE scores – referred to as FR Total - was also calculated.

b) Dichotic directed LE (DLE): Presentation of stimuli was as per Dichotic FR described above. However participants were asked to repeat back only the digit pair heard in the left ear (e.g. 8, 6), in any order.

c) Dichotic directed RE (DRE): As for DLE, however participants were asked to repeat back only the digit pair heard in the right ear (e.g. 1, 3), in any order.

d) Diotic: A series of four numbers were presented to *both* ears (e.g. 8, 1, 6, 3). Two digits overlapped exactly in time (e.g, 8, 1), followed by the other two overlapping digits (6, 3). Participants were asked to repeat back all four digits in any order.

***TAPS-3 NMF***

The number memory forward (NMF) subtest of the TAPS-3 is a measure of verbal short term memory. Digit sequences of increasing length were presented live-voice by the researcher. The digits were presented at a rate of one digit per second. The client was tasked with repeating the digits back in the order they were heard. In accordance with the TAPS-3 instructions, if the digits were repeated in the correct order, without any additional digits inserted, a score of 2 was recorded. If an error was made in the order that the digits were repeated then the item was scored as 1. If any digits were omitted or inserted during repetition then a score of 0 was recorded. Testing was discontinued once three consecutive 0 point responses had been recorded. Results are reported as scaled scores.

### *TAPS-3 NMR*

The number memory reversed (NMR) subtest of the TAPS-3 is a measure of verbal working memory. Digit sequences of increasing length were presented live-voice by the researcher, at a rate of one digit per second. The client was tasked with repeating the digits back to the audiologist in the reversed order. Scoring for the NMR is based on the same rules as used for the NMF, as discussed above.

### *IVA+Plus*

The IVA+Plus Integrated Visual and Auditory Continuous Performance Test (CPT; Sandford, 2012) is an automated computer based test of auditory and visual sustained attention. During the test the participant was presented with 32 practice trials and 500 scored trials of visual and auditory numerals (1 and 2). The participant was tasked with pressing the mouse button whenever a 1 was presented and instructed not to respond to 2. During the test the frequency of the numbers (1 and 2) varied so that both prudence (a measure of impulsivity) and vigilance (a measure of inattention) could be assessed. Quotient scores for prudence and vigilance were automatically calculated by the software. Average performance is said to be in the standard quotient score range of 90 to 109. Quotient scores of 60 and below represent extreme impairment. A quotient score was not calculated when the program detected performance (e.g. continually pressing the response button) suggested responses were invalid. In this instance a quotient score of 40 (four standard deviations below the mean) was adopted to allow for meaningful analysis of correlations. Only the scores for the auditory stimuli were analyzed for the purposes of this study.

***TONI-4***

The Test of Non-Verbal Intelligence-4 (TONI-4; Johnsen et al, 2010). Participants were presented with an image of an incomplete pattern (test item) in a stimulus book. The examiner asked the child which, of a series of possible images (response items) at the bottom on the page, would best complete the target pattern. The child responded by pointing. The examiner sat beside the participant with the stimulus book placed directly in front of the participant during testing. Six training items were presented. Children aged six to nine years commenced at item 1, children aged ten and over commenced at item 20 in accordance with standard test administration outlined in the TONI-4 manual. If the participant selected the correct response image the test item is scored as 1. If the participant's response did not match a score of 0 is recorded. Testing continues until three incorrect responses were recorded from five consecutive test items. The TONI-4 index score has a distribution with a mean of 100 and standard deviation of 15.

***LIFE***

The Listening Inventory of Education – Student Appraisal of Listening Difficulty questionnaire (LIFE; Anderson and Smaldino, 1998). Fifteen real-life listening situations (such as listening to a teacher in a noisy classroom) were described to the child verbally by the examiner and reinforced using pictures cards. The child was asked to rate his or her level of listening difficulty in the situation depicted on the stimulus card by pointing to a face on a response card. There were three levels of listening difficulty, ranging from always easy to always difficult. Picture cards one to ten depict classroom listening situations, with a maximum score of 100 points possible (0 given for always difficult to 10 given for always easy). Cards 11 to 15 depict additional listening situations, with a maximum of 100 points possible (0 given for always difficult to 20 given for always easy).

***Fishers Auditory Checklist***

The Fisher's Auditory Checklist (Fisher, 2008) is a questionnaire comprising a 25-item checklist of auditory behaviours which may be affected when children have difficulty listening in noisy environments. For example, item 4 reads: Does not listen carefully to directions - often necessary to repeat instructions. Each participant's parent was requested to complete the checklist prior to the research appointment by placing a check mark before each item that was considered to be a concern. A four percent credit is given for each item that is *not* checked**.**



## RESULTS

Statistical Analysis was performed using Statistica Version 10. DDdT data was arcsine transformed prior to analysis.

**Group results**

Group means and standard deviations for the 50 non-clinical and 10 clinical children are provided in Table 1 for all DDdT conditions and difference scores, as well for the various cognitive assessment tools and the two listening difficulty rating scales.

**Table 1. Average means and SDs for each DDdT condition and advantage measure for the 50 non-clinical and 10 clinical children who took part in the cognitive correlation study. DDdT conditions are reported as z-scores. The CPT tests of prudence and vigilance are reported as quotients, number memory forward (NMF) and reversed (NMR) as standard scores, and the TONI-4 as an index score.**

| | *Combined (n=60)* | | *Non-clinical (n=50)* | | *Clinical (n=10)* | |
|---|---|---|---|---|---|---|
| Condition | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* |
| FR LE | -0.13 | 1.00 | 0.00 | 0.86 | -0.77 | 1.42 |
| FR RE | -0.18 | 0.94 | -0.11 | 0.95 | -0.56 | 0.86 |
| FR Total | -0.15 | 1.07 | -0.00 | 1.02 | -0.89 | 1.03 |
| DLE | -0.30 | 1.02 | -0.17 | 0.89 | -0.92 | 1.38 |
| DRE | -0.24 | 1.08 | -0.20 | 1.14 | -0.44 | 0.75 |
| Diotic | 0.05 | 0.96 | 0.23 | 0.94 | -0.82 | 0.41 |
| Dichotic Adv | -0.21 | 0.85 | -0.24 | 0.77 | -0.05 | 1.22 |
| FR REA | -0.02 | 0.92 | -0.08 | 0.77 | 0.28 | 1.47 |
| Directed REA | 0.02 | 0.99 | -0.05 | 1.02 | 0.36 | 0.78 |
| Attention Adv | -0.29 | 1.09 | -0.32 | 1.08 | -0.16 | 1.22 |
| CPT Prudence | 79.97 | 23.37 | 79.77 | 23.79 | 80.9 | 21.3 |
| CPT Vigilance | 77.7 | 28.57 | 77.67 | 29.0 | 78.1 | 27.7 |
| NMR | 9.65 | 2.28 | 9.88 | 2.32 | 8.50 | 1.72 |
| NMR | 9.63 | 2.34 | 9.98 | 2.25 | 7.90 | 2.13 |
| TONI-4 | 101.1 | 10.3 | 100.8 | 10.7 | 102.9 | 8.70 |
| LIFE | 94.5 | 28.4 | 88.9 | 25.9 | 122.5 | 24.1 |
| Fisher's | 84.3 | 20.2 | 91.6 | 10.9 | 48.0 | 16.0 |

**DDdT Correlations**

Pearson product-moment correlation analysis were used to analyse whether correlations existed between scores on the various measures derived from the DDdT for the 60 children in the cognitive study. Results for the combined non-clinical and clinical groups are provided in Table 2.

**Table 2. Pearson product-moment correlation coefficient (r), analyzed from the arcsine transformed z scores on the various DDdT conditions for the 60 children in the cognitive correlations study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | FR LE | FR RE | FR Total | DLE | DRE | Diotic |
|---|---|---|---|---|---|---|
| FR LE | 1.00 | 0.46 *** | 0.90 *** | 0.61*** | 0.23 | 0.67 *** |
| FR RE | | 1.00 | 0.79 *** | 0.16 | 0.43 ** | 0.63 *** |
| FR Total | | | 1.00 | 0.51*** | 0.37 ** | 0.78 *** |
| DLE | | | | 1.00 | 0.36 ** | 0.42 ** |
| DRE | | | | | 1.00 | 0.31* |
| Diotic | | | | | | 1.00 |

The correlation between the diotic condition and the various free recall conditions were highly significant. FR LE ($r = 0.67$, $p < 0.00001$); FR RE ($r = 0.63$, $p < 0.00001$) and FR Total ($r = 0.78$, $p < 0.00001$). Figure 1 shows the correlation between FR Total and Diotic z-scores for the children in cognitive and the clinical groups. It is noted that the correlation co-efficient for the ten children in the clinical group alone was 0.52, which although high was not significant (p = 0.12). The lack of significance is due to the sample size rather than any difference between the groups.

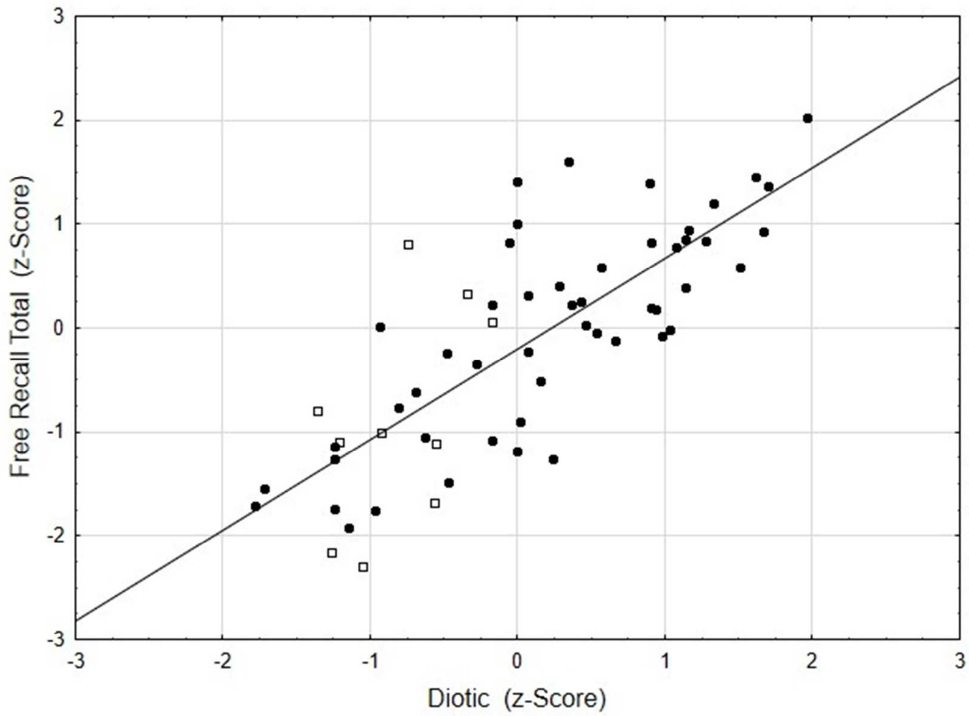



**Figure 1.** Scatterplot of the DDdT Free Recall Total z-scores compared to the diotic z scores for the 50 children in the non-clinical group (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

**Correlations Between Cognitive Measures and Listening Ratings**

Pearson product-moment correlations were used to analyse whether scores on the various cognitive assessment tools and the two listening difficulty rating scales were correlated, as shown in Table 3. Significant correlations occurred between the two measures of attention - prudence and vigilance. Also, the two measures of memory - NMF and NMR – were significantly correlated. Non-verbal intelligence, as measured by the TONI-4, was significantly correlated with both impulsivity (prudence) and working memory (NMR).

**Table 3. Pearson product-moment correlation coefficient (r) between the various cognitive assessment tools and listening ratings scales, for the 60 children cognitive correlation study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | CTP Prudence | CTP Vigilance | NMF | NMR | TONI-4 | LIFE | Fisher's |
|---|---|---|---|---|---|---|---|
| CTP Prudence | 1.00 | 0.54 *** | 0.18 | 0.22 | 0.28 * | 0.12 | -0.08 |
| CTP Vigilance | | 1.00 | 0.15 | 0.09 | 0.17 | 0.07 | 0.04 |
| NMF | | | 1.00 | 0.56 *** | 0.16 | -0.09 | 0.19 |
| NMR | | | | 1.00 | 0.31 * | -0.20 | 0.33 * |
| TONI-4 | | | | | 1.00 | 0.18 | -0.10 |
| LIFE | | | | | | 1.00 | -0.33 * |
| Fisher's | | | | | | | 1.00 |

The two ratings of listening difficulty - LIFE and Fishers- with ratings of 94 (28) and 84 (20) respectively, were *negatively* correlated. This was due to parents of the 10 children in the clinical group rating their children as poorer at auditory processing on the Fisher's than the children rated themselves on the LIFE (Figure 2).

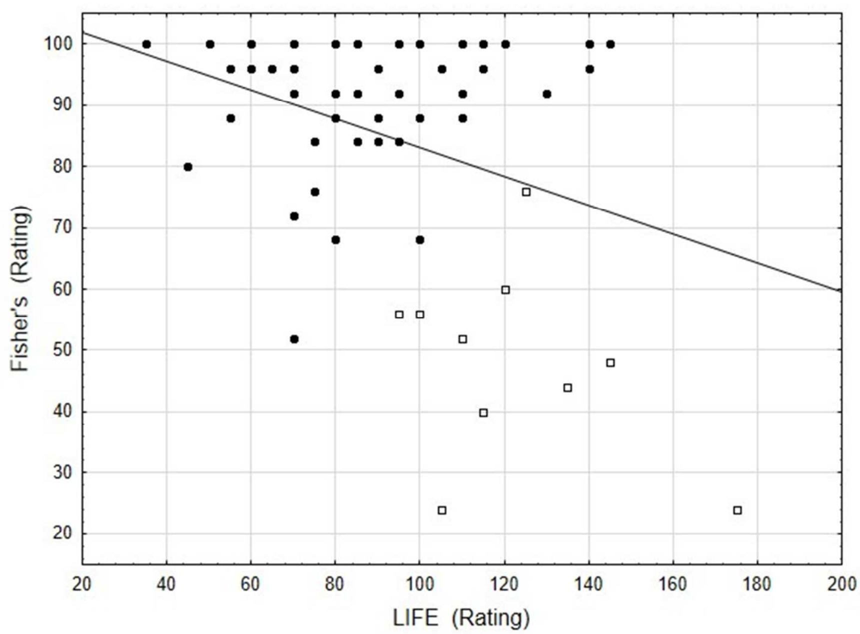



**Figure 2.** Scatterplot of the LIFE compared to Fisher's Checklist ratings for the 50 children in the non-clinical group (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.



**Cognitive Correlations with DDdT Conditions**

Pearson product-moment correlation analysis were used to analyse whether correlations existed between scores on the various measures derived from the DDdT, scores on the cognitive measures, and scores on the measures of listening difficulty in real life. As shown in Table 4, these reveal significant correlations between the DDdT Free Recall LE and Total conditions and all of the cognitive measures (impulsivity, inattention, short term and working memory and non-verbal intelligence). A similar pattern was also reflected in the Diotic condition correlations. Only the CTP Vigilance correlation was non-significant, although significance was nearly reached ($p = 0.058$). Figures 3 and 4 show the relationship between TAPS-3 NMF and NMR respectively and the Free Recall Total and Diotic DDdT conditions.

Right ear performance was not significantly correlated to cognitive function in either the free recall or directed DDdT conditions. The only exception was Free Recall RE and the TAPS-3 NMF measure of short term memory (r = 0.35, p = 0.006).

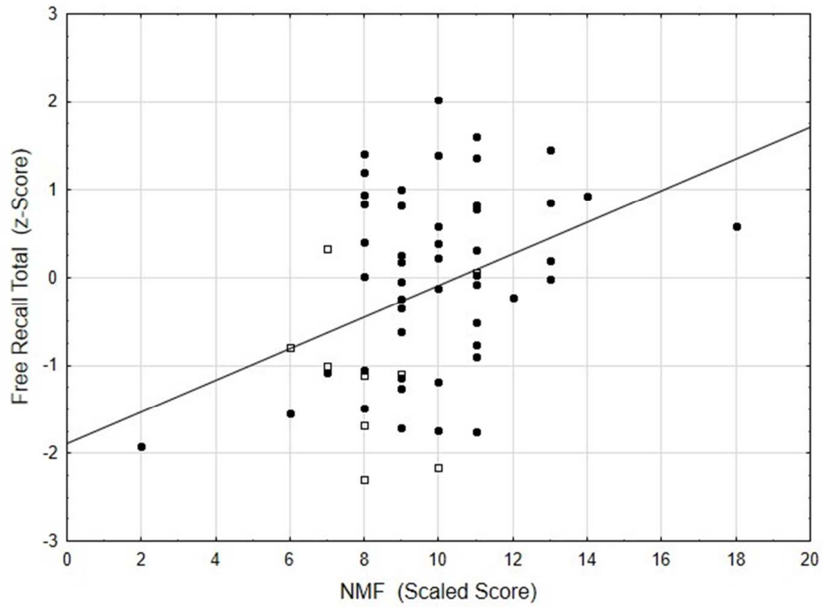
Finally, in respect to the real life listening difficulty ratings, there was a significant correlation between the Fisher's checklist completed by the participant's parent and the DDdT FR Total (r = 0.28, p = 0.033) and Diotic (r = 0.31, p = 0.015). Children of parents who reported poorer auditory processing skills for their children also scored more poorly on the dichotic and diotic DDdT measures.



**Table 4. Pearson product-moment correlation coefficient (r), analyzed from the arcsine transformed z scores on the DDdT conditions and difference measures and the cognitive assessment tools and listening ratings scales, for the 60 children cognitive correlation study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | CTP Prudence | CTP Vigilance | NMF | NMR | TONI-4 | LIFE | Fisher's |
|---|---|---|---|---|---|---|---|
| FR LE | 0.37 ** | 0.28 * | 0.29 * | 0.37 ** | 0.28 * | -0.04 | 0.25 |
| FR RE | 0.22 | 0.16 | 0.35 ** | 0.23 | 0.17 | -0.08 | 0.19 |
| FR Total | 0.36 ** | 0.27 * | 0.38 ** | 0.38 ** | 0.27 * | -0.08 | 0.28 * |
| DLE | 0.37 ** | 0.10 | 0.30 * | 0.27 * | 0.26 * | 0.09 | 0.17 |
| DRE | 0.15 | 0.11 | 0.19 | -0.08 | 0.10 | -0.07 | 0.01 |
| Diotic | 0.35 ** | 0.25 | 0.46 *** | 0.52 *** | 0.24 | -0.21 | 0.31 * |
| Diotic Adv | 0.13 | 0.13 | -0.09 | -0.19 | 0.09 | 0.12 | -0.02 |
| FR REA | -0.16 | -0.11 | -0.03 | -0.22 | -0.13 | -0.06 | -0.10 |
| Directed REA | -0.18 | 0.01 | -0.05 | -0.29 * | -0.12 | -0.13 | -0.14 |
| Attention Adv | -0.07 | -0.17 | -0.02 | -0.18 | -0.05 | 0.11 | -0.13 |

(a)




(b)

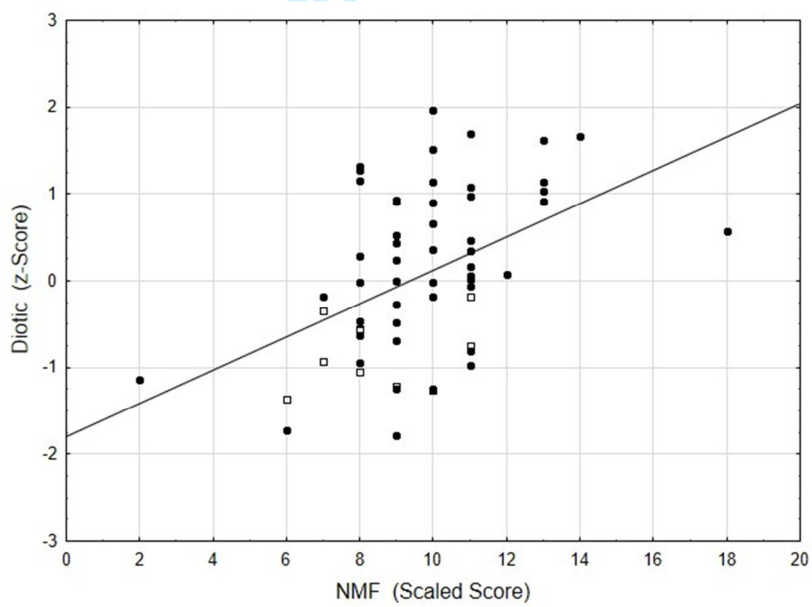
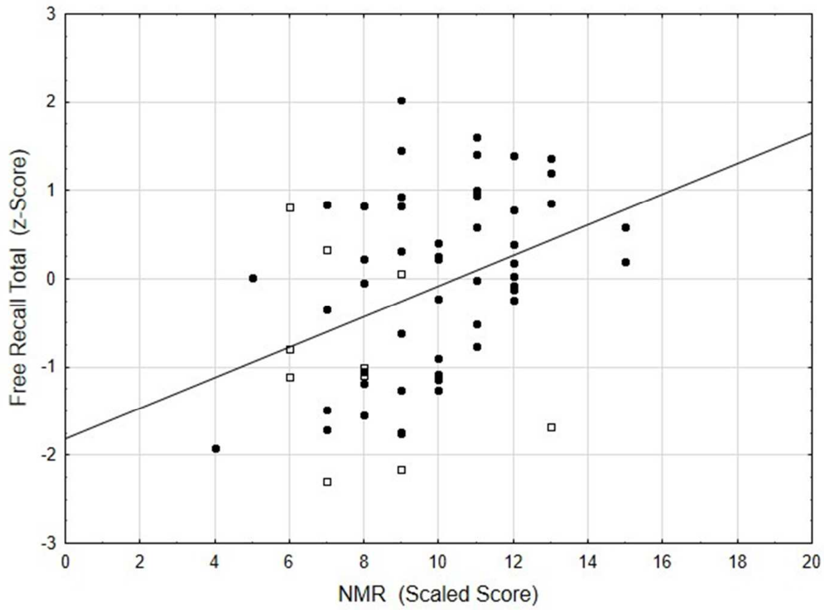



**Figure 3.** Scatterplot of the (a) DDdT Free Recall Total and (b) Diotic z-scores compared to the TAPS-3 NMF condition for the 50 children in the non-clinical (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

(a)




(b)

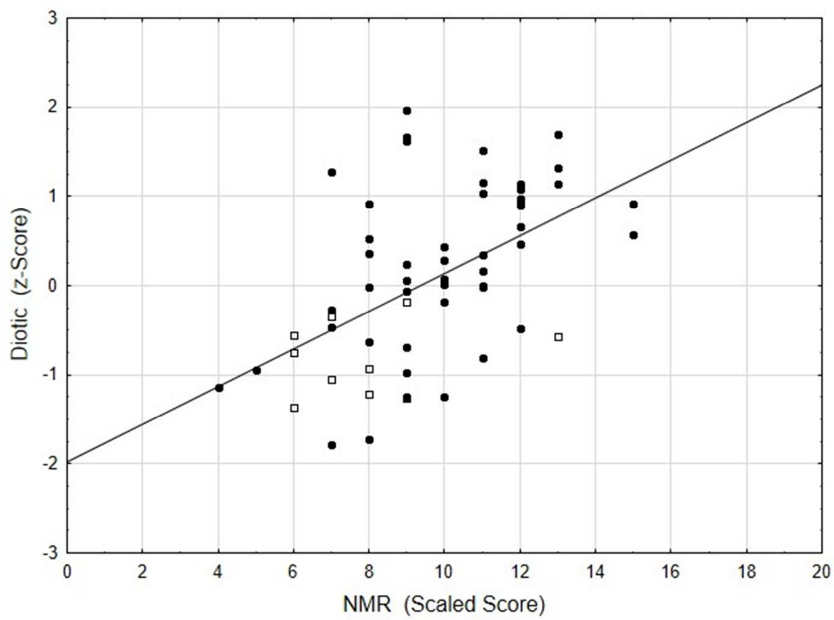



**Figure 4.** Scatterplot of the (a) DDdT Free Recall Total and (b) Diotic z-scores compared to the TAPS-3 NMR condition for the 50 children in the non-clinical (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

## DISCUSSION

This study investigated the relationship between the various conditions of the DDdT and between the DDdT and a number of cognitive assessment tools and real-life listening ratings scales. Fifty non-clinical and ten clinical children took part. The high correlation ($r = 0.78$, $p < 0.00001$) between performance by the children on the diotic condition and the FR total condition is striking. This means that 61% of the variance in the FR total scores is accounted for by factors that do not involve the perception of dichotic stimuli. Table 1 shows that the standard deviation of FR total scores is 1.07, which is a variance of 1.14. The variance accounted for by diotic perception is therefore 0.69 (i.e. 61% of 1.14). As Table 5 in paper 1 on the normative data study shows, a variance of 0.25 is attributable to random measurement error. This leaves only a variance of 0.20, or 17% of the total variance in RF total scores that could potentially be accounted for by true differences in dichotic perception. Of course, if a group with more aberrant dichotic perception due purely to true dichotic deficits were to be included, this figure would increase.

Given the small number of clinical cases included in this study, it would be speculative to draw any conclusions at this stage, but some comments seem appropriate. First, as shown in Table 1, although all the average dichotic z-scores are low for the 10 children in the clinical group (range -0.44 for DRE to -0.89 for FR total), so too is the average z-score for the diotic condition (-0.82). Consequently the mean dichotic advantage z-score is very close to zero (-0.05), indicating that, as a group, the clinical children are just as able to take advantage of dichotic cues as typically-developing children.

Second, of the seven children initially tested in the clinic who were outside normal limits on the Dichotic Digits Test, every one of the seven had a higher right ear score when retested in the research lab on the DDdT a short time later, by an average of 20 percentage points. This may be due to learning from the previous testing experience, a different tester, or the position of the dichotic test within the test battery. Alternatively, it may just represent regression to the mean (because the inclusion criteria favoured including in the study children found in the clinic to have low dichotic test results). These factors must explicitly be considered in any work investigating the effect of remediation on poor dichotic listening ability.

Third, the potential value of the dichotic advantage measure can be illustrated with two examples. One of the clinical cases, a female aged seven years, seven months, included in the study due to deficits on the dichotic digits test (LE 60%, RE 30% correct). This child had a z-score on the DDdT of -0.76 for the free recall LE condition and close to -2.0 for both the free recall RE and the total conditions. In the diotic condition, her z-score was only -0.6. Consequently, it seems the child is having disproportionately more problems when there are dichotic cues than when there are not and her dichotic advantage z-score of -1.55, near the lower end of the normative population, reflects this. The dichotic advantage z-score makes it clear just how aberrant a child's ability to take advantage of dichotic cues is.

This child's results contrast with those of a male, aged ten years, five months. He was included in the study due to deficits on the dichotic digits test (LE 84% and RE 82.5%). On retest with the DDdT his free recall left ear z-score was -1.8 and his right ear z-score was +0.7. One might have suspected, without access to the diotic z-score (which was -1.3), that the child had a problem in dichotic perception in the left ear. However, the dichotic advantage z-score for this child was +0.3, showing that he had at least average (age-appropriate) ability to make use of dichotic cues. One would therefore look for other explanations, unrelated to dichotic listening ability, as to why the child performed badly on the dichotic test and why the child presumably was experiencing real life listening difficulties. Indeed, this child had a CTP vigilance (inattention) quotient score of 59, which is considered to represent an extreme impairment.

In respect to measures of real life listening ability, Table 3 reveals a disconcerting significant but negative correlation between the Fishers and Life scores for the clinical and non-clinical groups combined. The reason, however, is evident in Figure 2: the negative correlation is not present for either group alone, but rather, the clinical group shows a different relationship between the Fisher's and Life scores than occurs for the non-clinical group. Compared to the non-clinical group, either the parents of the clinical group are over-estimating the difficulties faced by the children, or the clinical children are underestimating their difficulties. Correlations between at least one of these report measures and any other variable might lead to spurious conclusions about an association if the correlations are based on a combination of children from a clinical group and children from some control population.

Based on the analyses conducted, it appears that dichotic performance is strongly associated ($r = 0.78$) with cognitive skills that are involved in perceiving and repeating simultaneously presented digits, even when there are not dichotic cues present. It is worth speculating on whether even a strongly asymmetric fail can be the result of cognitive deficits. Processing sounds input to the right ear seems intrinsically easier than sounds input to the left ear for most young children. However, the left ear pathways can produce high scores provided sufficient cognitive resources can be applied to the task. Low attention, memory or even IQ may prevent sufficient cognitive resources being applied, thereby having a bigger impact on left ear scores than right ear scores. How often this occurs versus a genuine dichotic deficit (i.e. one in which dichotic scores are low even when diotic perception is normal) is unclear and requires additional testing in a clinical population. To this end, future research will involve use of the DDdT in over 50 Australian Hearing centres who offer a CAPD service.

## CONCLUSION

It is anticipated that the DDdT dichotic advantage score will provide a useful indicator of true dichotic processing ability. In the meantime, care should be taken in interpreting traditional dichotic test results in the absence of indicators of cognitive performance, particularly in respect to measures of memory and attention.



## REFERENCES

Ahmmed AU, Ahmmed AA, Bath JR, Ferguson MA, Plack CJ, Moore DR. (2014) Assessment of children with suspected auditory processing disorder: A factor analysis study. *Ear Hear* 35(3): 295-305.

Anderson KL, Smaldino JJ. (1998) Listening Inventory For Education: An Efficacy Tool-Student Appraisal of Listening Difficulty. Tampa, FL: Educational Audiology Association.

Cameron S, Glyde H, Dillon H, Whitfield J, Seymour J. (Submitted) The Dichotic Digits difference Test (DDdT): Development, normative data and retest reliability studies. *J Acad Audiol*.

Cameron S, Glyde H, Seymour J, Dillon H. (2013) Dichotic Digits difference Test (DDdT) (Research Version) [Computer software]. Sydney, NSW: National Acoustic Laboratories.

Cameron S, Glyde H, Dillon H, King A, Gillies K. (in press) Results from a national central auditory processing disorder service: A "real world" assessment of diagnostic practices and remediation for CAPD. *Seminars in Hearing*.

DeBonis DA. (2015) It is time to rethink central auditory processing disorder protocols for school-aged children. *Am J Audiol* 24: 124-136.

Fisher LI. (2008) Fisher's auditory problems checklist. Tampa, FL: Educational Audiology Association.

Hiscock M, Kinsbourne M. (2011) Attention and the right-ear advantage: What is the connection? *Brain Cogn* 76: 263-275.

Johnsen SK, Brown L, Sherbenou RJ. (2010) Test of Non-Verbal Intelligence 4th ed. Austin, TX: pro-ed.

Maerlender A. (2010) Short-term memory and auditory processing disorders: Concurrent validity and clinic diagnostic markers. *Psychol Schools* 47(10): 975-984.

Martin N, Brownell R. (2005) Test of Auditory Processing Skills 3rd ed. Novato, CA: Academic Therapy Publications.

Sandford JA. (2012) IVA+Plus Integrated Visual and Auditory Continuous Performance Test [Computer software]. Richmond, VA: BrainTrain, Inc.

Singer J, Hurley RM, Preece JP. (1998) Effectiveness of central auditory processing tests with children. *Am J Audiol* 7(2): 73-84.

Tomlin D, Dillon H, Sharma M, Rance G. (2015) The impact of auditory processing and cognitive abilities in children. *Ear Hear*, doi: 10.1097/AUD.0000000000000172.

Westerhausen R, Hugdahl K. (2008) The corpus callosum in dichotic listening studies of hemispheric asymmetry: A review of clinical and experimental evidence. *Neurosci Biobehav Rev* 32: 1044-1054.

Wilson RH, Strouse A. (1998) Tonal & speech materials for auditory perceptual assessment (Disc 2.0) [CD]. Mountain Home, TN: VA Medical Centres.

## FIGURE CAPTIONS

**Figure 1.** Scatterplot of the DDdT Free Recall Total z-scores compared to the diotic z scores for the 50 children in the non-clinical (solid circles) and the 10 children in the clinical group (open squares). The solid and dashed lines represents least squares regression line for the cognitive and clinical groups respectively.

**Figure 2.** Scatterplot of the LIFE compared to Fisher's Checklist ratings for the 50 children in the non-clinical group (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

**Figure 3.** Scatterplot of the (a) DDdT Free Recall Total and (b) Diotic z-scores compared to the TAPS-3 NMF condition for the 50 children in the non-clinical group (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

**Figure 4.** Scatterplot of the (a) DDdT Free Recall Total and (b) Diotic z-scores compared to the TAPS-3 NMR condition for the 50 children in the non-clinical (solid circles) and the 10 children in the clinical group (open squares). The solid line represents least squares regression line.

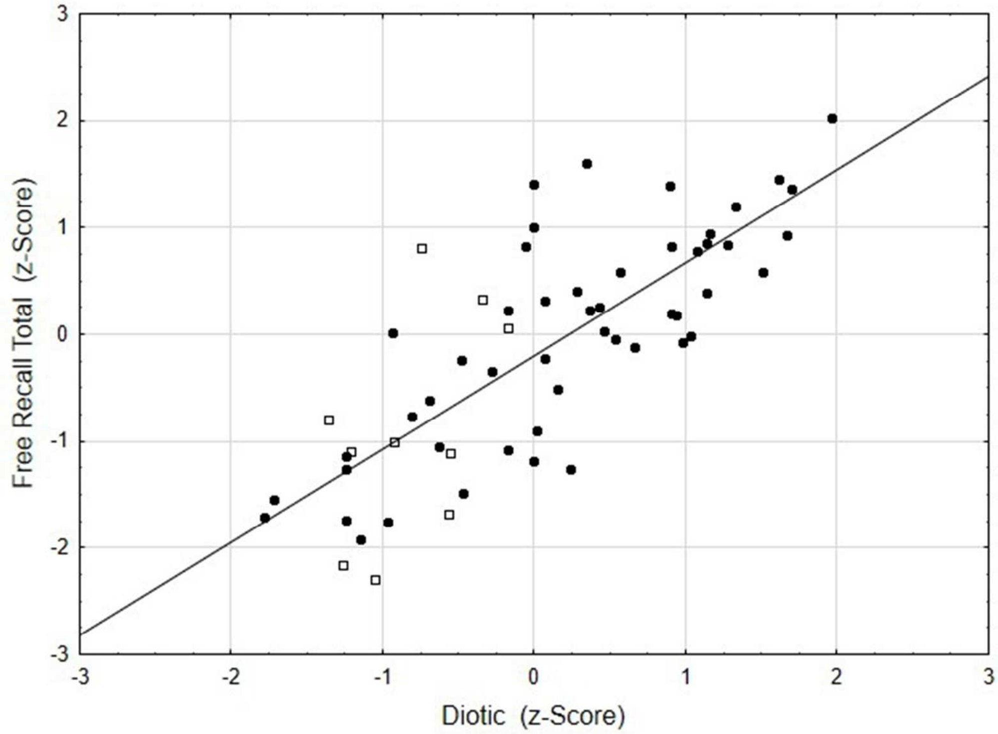



Figure 1
165x123mm (96 x 96 DPI)

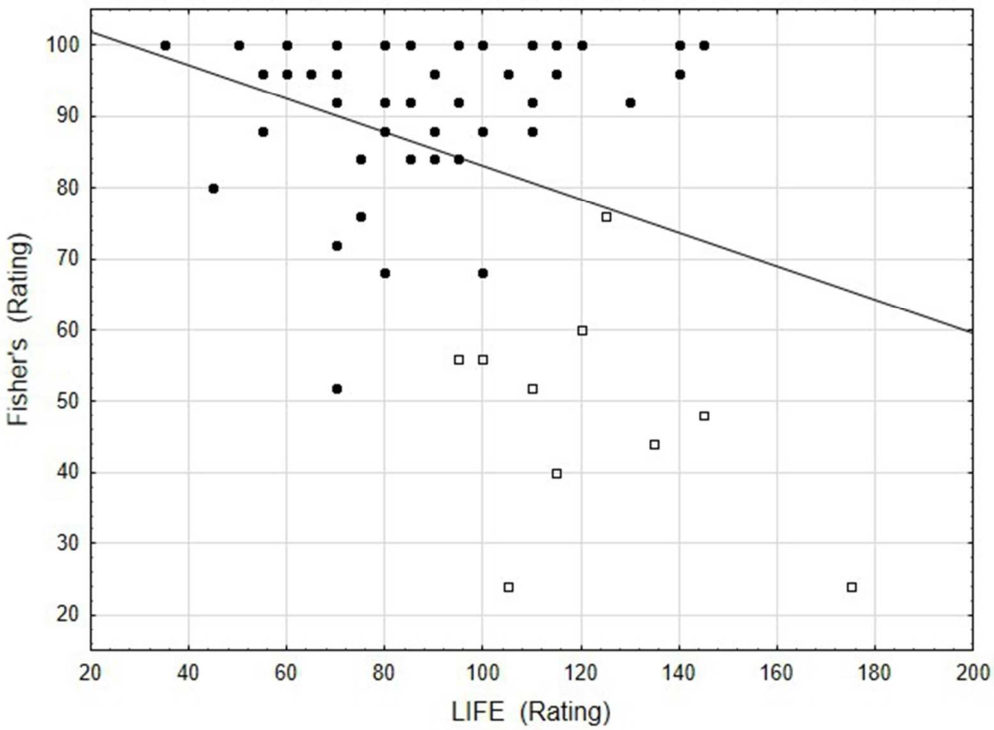



Figure 2
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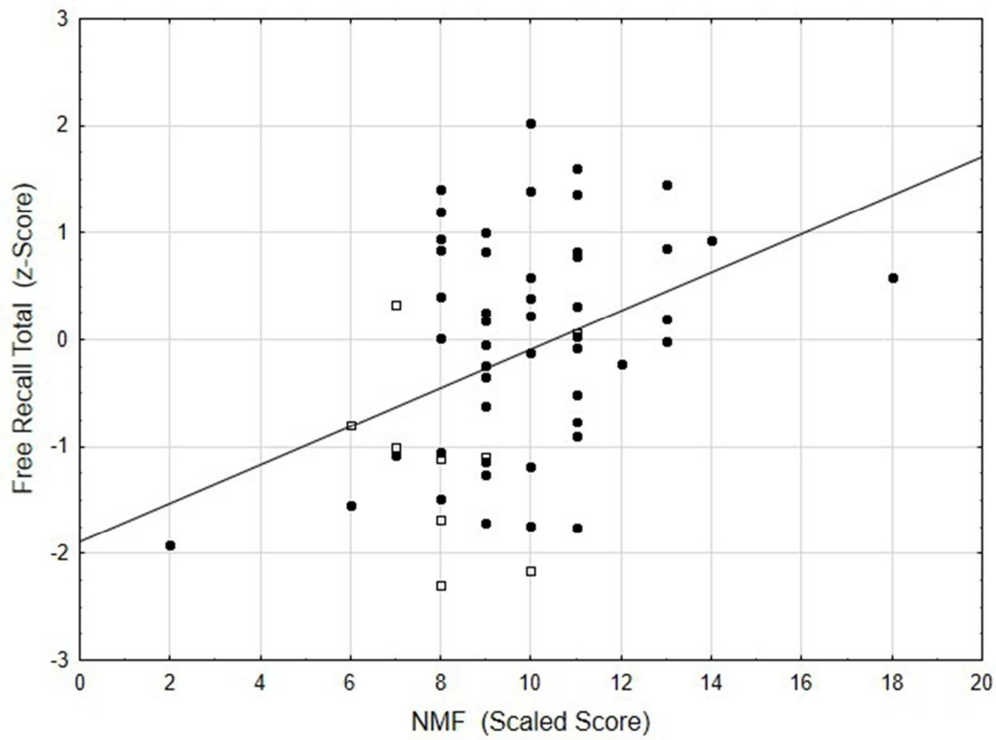


Figure 3a
165x123mm (96 x 96 DPI)

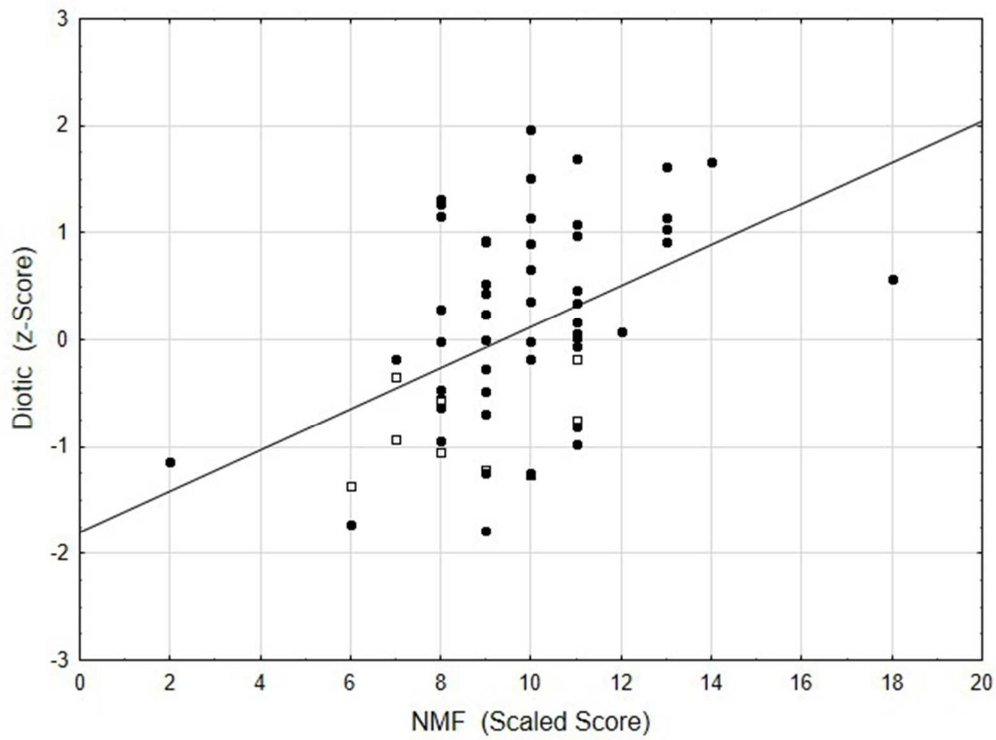


Figure 3b
165x123mm (96 x 96 DPI)

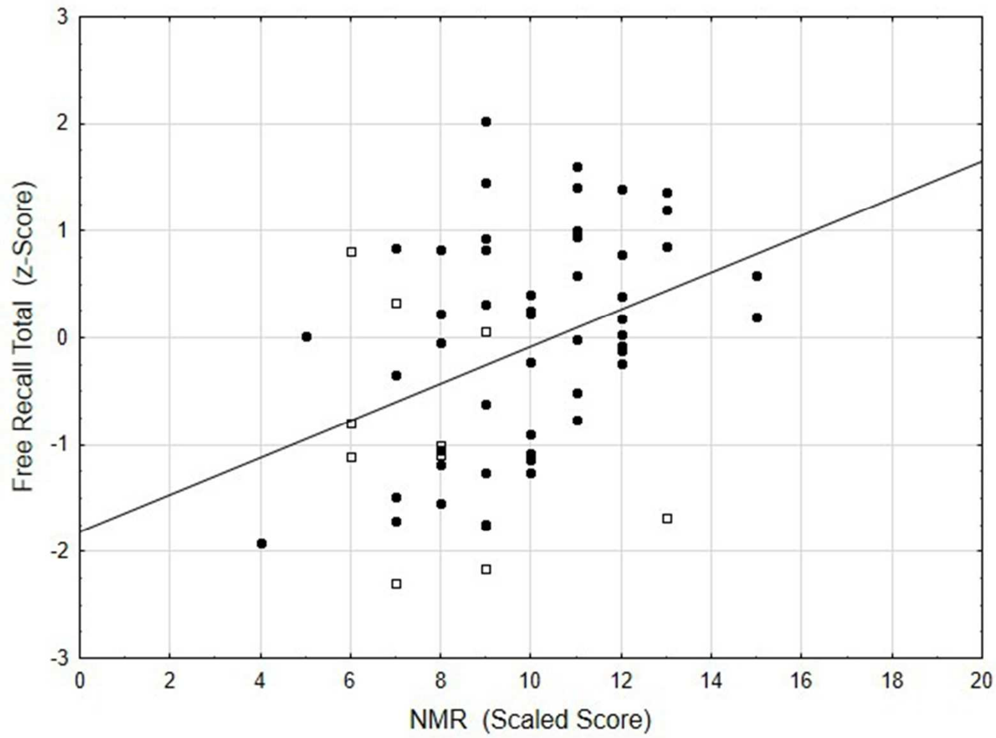


Figure 4a
165x123mm (96 x 96 DPI)

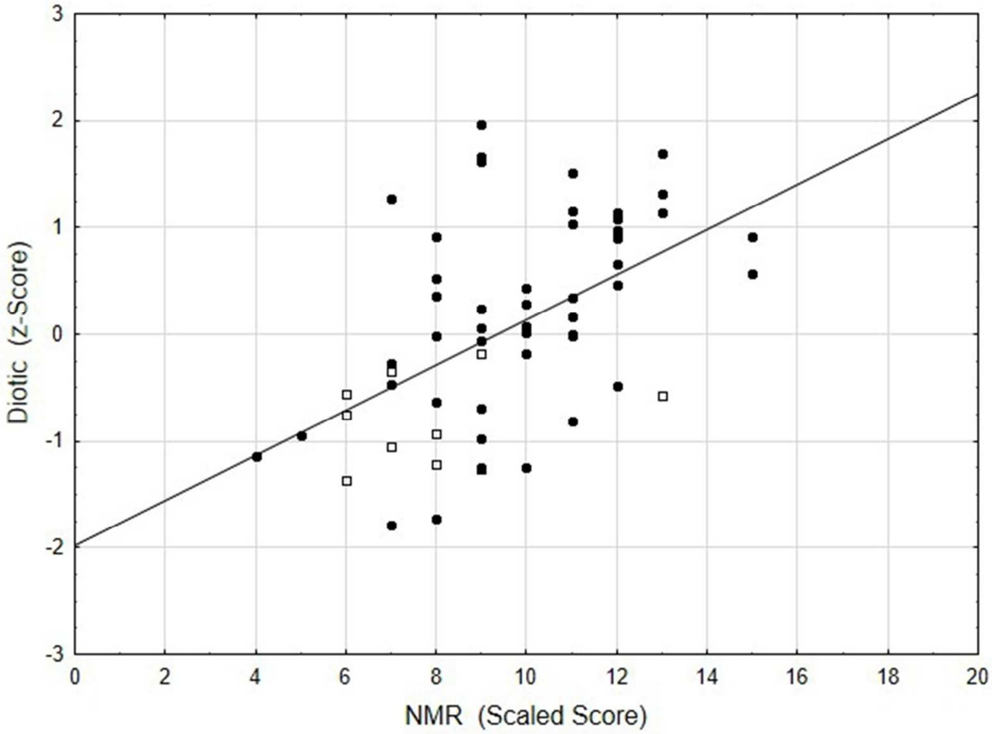


Figure 4b
165x123mm (96 x 96 DPI)

**Table 1. Average means and SDs for each DDdT condition and advantage measure for the 50 non-clinical and 10 clinical children who took part in the cognitive correlation study. DDdT conditions are reported as z-scores. The CPT tests of prudence and vigilance are reported as quotients, number memory forward (NMF) and reversed (NMR) as standard scores, and the TONI-4 as an index score.**

| | *Combined (n=60)* | | *Non-clinical (n=50)* | | *Clinical (n=10)* | |
|---|---|---|---|---|---|---|
| Condition | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* |
| FR LE | -0.13 | 1.00 | 0.00 | 0.86 | -0.77 | 1.42 |
| FR RE | -0.18 | 0.94 | -0.11 | 0.95 | -0.56 | 0.86 |
| FR Total | -0.15 | 1.07 | -0.00 | 1.02 | -0.89 | 1.03 |
| DLE | -0.30 | 1.02 | -0.17 | 0.89 | -0.92 | 1.38 |
| DRE | -0.24 | 1.08 | -0.20 | 1.14 | -0.44 | 0.75 |
| Diotic | 0.05 | 0.96 | 0.23 | 0.94 | -0.82 | 0.41 |
| Dichotic Adv | -0.21 | 0.85 | -0.24 | 0.77 | -0.05 | 1.22 |
| FR REA | -0.02 | 0.92 | -0.08 | 0.77 | 0.28 | 1.47 |
| Directed REA | 0.02 | 0.99 | -0.05 | 1.02 | 0.36 | 0.78 |
| Attention Adv | -0.29 | 1.09 | -0.32 | 1.08 | -0.16 | 1.22 |
| CPT Prudence | 79.97 | 23.37 | 79.77 | 23.79 | 80.9 | 21.3 |
| CPT Vigilance | 77.70 | 28.57 | 77.67 | 29.0 | 78.1 | 27.7 |
| NMR | 9.65 | 2.28 | 9.88 | 2.32 | 8.50 | 1.72 |
| NMR | 9.63 | 2.34 | 9.98 | 2.25 | 7.90 | 2.13 |
| TONI-4 | 101.1 | 10.3 | 100.8 | 10.7 | 102.9 | 8.70 |
| LIFE | 94.5 | 28.4 | 88.9 | 25.9 | 122.5 | 24.1 |
| Fisher's | 84.3 | 20.2 | 91.6 | 10.9 | 48.0 | 16.0 |

**Table 2. Pearson product-moment correlation coefficient (r), analyzed from the arcsine transformed z scores on the various DDdT conditions for the 60 children in the cognitive correlations study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | FR LE | FR RE | FR Total | DLE | DRE | Diotic |
|---|---|---|---|---|---|---|
| FR LE | 1.00 | 0.46 *** | 0.90 *** | 0.61*** | 0.23 | 0.67 *** |
| FR RE | | 1.00 | 0.79 *** | 0.16 | 0.43 ** | 0.63 *** |
| FR Total | | | 1.00 | 0.51*** | 0.37 ** | 0.78 *** |
| DLE | | | | 1.00 | 0.36 ** | 0.42 ** |
| DRE | | | | | 1.00 | 0.31* |
| Diotic | | | | | | 1.00 |

**Table 3. Pearson product-moment correlation coefficient (r) between the various cognitive assessment tools and listening ratings scales, for the 60 children cognitive correlation study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | CTP Prudence | CTP Vigilance | NMF | NMR | TONI-4 | LIFE | Fisher's |
|---|---|---|---|---|---|---|---|
| CTP Prudence | 1.00 | 0.54 *** | 0.18 | 0.22 | 0.28 * | 0.12 | -0.08 |
| CTP Vigilance | | 1.00 | 0.15 | 0.09 | 0.17 | 0.07 | 0.04 |
| NMF | | | 1.00 | 0.56 *** | 0.16 | -0.09 | 0.19 |
| NMR | | | | 1.00 | 0.31 * | -0.20 | 0.33 * |
| TONI-4 | | | | | 1.00 | 0.18 | -0.10 |
| LIFE | | | | | | 1.00 | -0.33 * |
| Fisher's | | | | | | | 1.00 |

**Table 4. Pearson product-moment correlation coefficient (r), analyzed from the arcsine transformed z scores on the DDdT conditions and difference measures and the cognitive assessment tools and listening ratings scales, for the 60 children cognitive correlation study. Significant correlations are marked with an asterisk (* < 0.05; ** < 0.01; *** <0.001).**

| Condition | CTP Prudence | CTP Vigilance | NMF | NMR | TONI-4 | LIFE | Fisher's |
|---|---|---|---|---|---|---|---|
| FR LE | 0.37 ** | 0.28 * | 0.29 * | 0.37 ** | 0.28 * | -0.04 | 0.25 |
| FR RE | 0.22 | 0.16 | 0.35 ** | 0.23 | 0.17 | -0.08 | 0.19 |
| FR Total | 0.36 ** | 0.27 * | 0.38 ** | 0.38 ** | 0.27 * | -0.08 | 0.28 * |
| DLE | 0.37 ** | 0.10 | 0.30 * | 0.27 * | 0.26 * | 0.09 | 0.17 |
| DRE | 0.15 | 0.11 | 0.19 | -0.08 | 0.10 | -0.07 | 0.01 |
| Diotic | 0.35 ** | 0.25 | 0.46 *** | 0.52 *** | 0.24 | -0.21 | 0.31 * |
| Diotic Adv | 0.13 | 0.13 | -0.09 | -0.19 | 0.09 | 0.12 | -0.02 |
| FR REA | -0.16 | -0.11 | -0.03 | -0.22 | -0.13 | -0.06 | -0.10 |
| Directed REA | -0.18 | 0.01 | -0.05 | -0.29 * | -0.12 | -0.13 | -0.14 |
| Attention Adv | -0.07 | -0.17 | -0.02 | -0.18 | -0.05 | 0.11 | -0.13 |