Does the Age of Cochlear Implantation have Long-term Effects on CDT Scores?

A study submitted in partial fulfilment of the requirements
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Margaret H. Dutton B.A. (Ed) Hons,
PGDip Education Studies (Hearing Impairment)

University of Hertfordshire
Hatfield
Hertfordshire

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Statement of Originality

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I am grateful to the assistance of the Audiology and Speech and Language Therapy Departments at Mary Hare School and the parents that gave permission for their children's data to be analysed, without which I would not have been able to complete this research project. I thank Tracy James for her guidance and support with this project.

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1. Abstract

This study was a non-experimental retrospective analysis evaluating Continuous Discourse Tracking (CDT) scores in 56 children with at least one cochlear implant. The project was a cross-sectional study and investigated the long term effects of early (at or before 36 months) and late (post 36 months) cochlear implantation on CDT assessments of students attending an auditory/oral school for the deaf in England. The effect of the time since cochlear implantation on CDT scores was explored, as previous research by Donoghue et al (2000) ceased monitoring at 60 months post implantation and scores had not yet plateaued. This research investigated whether the CDT scores continued to progress beyond 60 months.

Results showed that early implantation did have a statistically significant impact on CDT scores, whilst the data for the time since implantation was inconclusive largely due to the fact that there was a large spread of data after 60 months post implantation. Mean CDT scores for bilateral, bimodal and unilaterally aided children were compared which produced unexpected results. The variables and population factors that may have influenced the CDT scores within this study were explored.

2. Introduction

At the time of writing it is nearly sixty years since Djourno and Eyries first began direct stimulation of the auditory nerve in Paris, (Raine, 2013). Subsequently, the technology and the number of people with cochlear implants has grown drastically. In the latest figures for the year ending 31st March 2016 published by the British Cochlear Implant group (BCIG) 1287 people received new implants and there was a maintained population of over 14000 individuals in the UK. As cochlear implant technology advances have been made and different makes and models produced, each manufacturer has claimed that their products provide the best outcomes for patients (Advanced Bionics, 2017a, Cochlear, 2016 and MED-EL, 2016). The new technology has been accompanied by a great deal of research, not only involving the actual surgical implantation and the technology, but also the progress of individuals post implant, giving rise to a picture of normative expectations. The expected outcomes of implanted children today are far greater than were ever thought possible. (Archbold, 2010).

Speech tracking has been a speech test that has been in use for nearly forty years since De Filippo and Scott first published an article about the procedure in 1978. It involves the subject listening to phrases of text and repeating them over a measured time period and calculating the average words per minute score. The procedure has had a variety of names including Speech tracking, Connected Discourse Tracking and Continuous Discourse Tracking, both referred to as CDT. It has frequently been used as part of a battery of tests in research involving cochlear implant outcomes (Holmes et al, 1987, Osberger et al, 1991, Hinderink et al, 1995, O'Donoghue et al, 1998, Nikolopoulos et al, 1999, Tait et al, 2000, O'Donoghue et al, 2000, Lonka et al, 2004 and Nikolopoulos et al, 2006). CDT scores have been used for a variety of reasons, one example included tracking the progress of five individuals CDT scores over a ten week period to evaluate a cochlear implant (Levitt et al, 1986). In 1999, Thomas and Cheshire investigated the impact of the aetiology, specifically

meningitic and non-meningitic causes of deafness, on implanted individuals using speech testing including CDT scores.

The age of diagnosis and subsequent aiding has decreased drastically over time to a few weeks of age, especially with the national Newborn Hearing Screening Protocol (NHSP, 2010). Diagnosis age and the subsequent aiding has been researched by many including Yoshinaga-Itano et al (1998) who investigated the effect the age at which children were issued with hearing aids had on the children's language development. They found that the earlier the children received their aids, the better their language scores were compared to those who received their aids later.

As the number of individuals receiving cochlear implantation increased, Nikolopoulos et al (1999) investigated how the age of implantation impacted on language development and included CDT as part of their battery of testing. They found that increasing age of implantation had a negative correlation to the combined speech test outcomes for the individuals three and four years post implantation and thus concluded from their research based on 126 children, that prelingually deaf children should receive implants as early as possible to maximise the health gains from cochlear implantation. Nikolopoulos et al (2006) conducted a longitudinal study of post-meningitic and congenitally deaf children using CDT results. Unfortunately, they ceased to collect data after 60 months post-implantation although the CDT scores had not plateaued. The researcher was unable to locate any research that investigated the impact of early and late implantation over sixty months post-implantation. As a result, cochlear implant outcomes, using CDT scores, over a longer period of time post-implantation became the focus of the research outlined in this study.

3. Literature Review

3.1. The History of Continuous Discourse Tracking

In 1978 De Filippo and Scott first documented the CDT procedure both as a way of communication training and also as an evaluation of a channel of communication. At this time they were comparing the use of a tactile device with and without lip reading and wanted a measurable task that simulated communication, rather than repeating syllables or single words. The test involved the tester speaking short phrases from a text and the subject repeating back the phrases, showing a structured form of interaction. The number of words from the text that were repeated over a given time span was used to calculate the average score of words per minute (wpm).

Di Filippo and Scott (1978) acknowledged variables that could affect the individual's score and the validity of comparisons, such as the text material, which must be similar in terms of language complexity and vocabulary. The subject's rate and clarity of speech production was also identified as having a great impact on their score. Their research was based on two individuals being tested for approximately ten minutes, four times per day for a total of twenty-one hours of testing. The sample size was extremely small, which raises queries regarding the validity of generalising their findings. Despite the frequency and longevity of testing the average wpm scores were still increasing, suggesting that the individuals had not reached their maximum ability and score.

During their testing Di Filippo and Scott investigated how familiarity with the tester impacted on the CDT score. Initially the introduction of a new tester decreased the average wpm but the scores quickly rose as the subject became more familiar with the tester. Di Filippo and Scott (1978) went on to suggest that CDT could be used for training and suggested degrading the signal quality or changing the level of the language of the text to create a challenge. They also suggested that the procedure may be used to develop the subject's

speech to ensure that the tester understood not only the content of the speech but also to copy the tester's intonation.

The test itself was easy to administer and needed no specialist equipment and it quickly became a popular measure, often as part of a battery of tests that included single words and sentences (Plant 2005). The test was used to investigate a range of areas, including the progress of individuals over time (Plant 2004), different equipment (Hopkinson 1986) and aetiology of deafness (Thomas and Cheshire, 1999). Unfortunately as there was no set procedure or protocol documented in the original article, researchers including Fenn and Smith (1987), Robins et al (1985) and Owens & Raggio (1987) all modified the test slightly, which changed the emphasis of the test and the scores calculated, thus meaning that direct comparisons were impossible. Fenn and Smith (1987) adapted the test by setting the number of repetition before being visually presented with the word, minimising the time spent on repair strategies. Robins et al (1985) adapted the test by using hierarchy of repair strategies; such as repetition, rephrasing or providing cues, meaning a greater time was spent when a repair strategy was required. Owens & Raggio (1987) placed the focus of the test on the subjects' use of a range of repair strategies.

Tye-Murray & Tyler (1988), whilst supporting speech tracking as part of rehabilitation training, were aware of the problems of it being used as a test and documented a critique of the procedure to ensure that all users were aware of the potential variables and the issues with comparing results from one study to another. Some of the tester variables had already been identified by Di Filippo and Scott (1978) in their original article, such as the subject's familiarity with the tester as they had noted that the tracking scores had dipped upon the introduction of the new tester and the intelligibility of the subject, however Tye-Murray and Tyler (1988) also detailed the variables associated with the subject, such as the day to day variability of the subject, the individual's attention levels, their level of language development, intellectual abilities including working memory and familiarity with the topic of the text. Schoepflin and Levitt (1991) further analysed the tracking procedure and investigated the interactions

between the talker and receiver, concluding that one of the long term objectives for CDT was to set rules for the procedure to minimise the variability.

Tye-Murray and Tyler (1988) and Schoepflin and Levitt (1991) raised concerns about the tester's ability to break the text into phrases, their use of facial and hand gestures and the clarity of their speech and lip patterns.

3.2. Repair Strategies

An issue that became evident from the adaptations of the procedure was how breakdowns in the repeating of speech were resolved; these are described as repair strategies. The end test score incorporates the time taken for the transmission time of the tester, the subject's response time and any time taken for a repair strategy. Some researchers set very clear procedures for repair strategies on the tester, such as repeating words twice before being given a written version of the word blockage (Fenn and Smith, 1987). Owens and Raggio (1987) however, placed the responsibility on the subject to select a repair strategy (for example, asking for the phrase to be repeated either wholly or partially). Each repair strategy requires a differing amount of time, ultimately having an effect on the final score achieved. It is therefore vitally important to know which procedure for repair strategy was used to ensure that comparisons can be made between tests conducted using the same methodology.

3.3. Text Difficulty

Hochberg et al (1989) investigated the impact of the text used in speech tracking tests and had found that the difficulty level of the text significantly affected tracking rates. They found that with easier texts using controlled vocabulary, the average CDT score was 62.9wpm, whilst when more difficult materials were used, such as adult detective novels, the average CDT score reduced to 29.5wpm. The selection of the text is therefore important, so as to ensure that the text is accessible and age appropriate particularly when the subjects are children.

3.4. Computerised CDT

Schoepflin and Levitt (1991) suggested developing a computerised version of the test to eliminate inter-tester differences, whilst also ensuring that a standard text is used. Spens et al (1992) acknowledged the advantages of speech tracking and the lack of a standardised approach. This led on to Gnosspelius and Spens (1992) developing a computer program at the Royal Institute of Technology (KTH), Sweden to conduct speech tracking. They tried to eliminate some of the variables previously identified, such as the variability of the tester, the text used and the familiarity of the subject with the talker. The original aim of developing the program was to minimise the time spent on repair strategies and to make the time uniform for each breakdown. In this way they incorporated Fenn and Smith's (1987) two repetitions before being presented with the written word protocol into their computer program. The success of the use of the computer program was unfortunately affected by the programing language used and the lack of compatibility with Microsoft software post Windows 98 (Plant 2004, 2005). The development of the computer program whilst removing some of the variables associated with the tester also meant that the face validity, which was a main advantage of the original test, was removed. The KTH computer program has since been modified to increase its compatibility with modern computers by the Rehabilitation Engineering Research Center on Hearing Enhancement at Gallaudet University and used by Bernstein et al, (2012) in their rehabilitation research. They found that the computer program was more '*structured, systematic, and efficient approach to training' (*p35) than the traditional method of using a human as the tester in the procedure. Interestingly, the research showed that at the end of the period of training, the individuals' scores were continuing to improve and had not yet plateaued, suggesting an area for future research to investigate when the rate of improvement begins to saturate.

3.5. Developing a standardised approach for use with children

Plant (2004) has been involved in CDT research for over twenty years and has been a strong advocate believing it:

> "*to be the single most valuable contribution made to communication training in the latter part of the twentieth century*" (p1).

Plant was a key person of the team working in Sweden with developing the KTH computerised version of speech tracking (Spens et al 1992) and its subsequent adaptation at Gallaudet University (Bernstein et al, 2012). He worked with Archbold and the Ear Foundation to develop a set of speech tracking materials aimed at children called 'KID TRAX' (Plant & Archbold, 2003). The production of 'KID TRAX' meant that there was guidance for professionals on conducting the training/test and there were standardised text materials which were child friendly.

St Thomas' Paediatric Cochlear Implant Team have used CDT to monitor their patients' progress at their annual review appointments for a number of years, using an adapted version of Mr Grumpy by Roger Hargreaves (Crofts, 2016). The Senior Teacher of the Deaf employed at the time reported that they would expect a normal hearing child to score 100 wpm and a good cochlear implant user to score 70 wpm. These figures were not based on official normative data researched in the department but on the team's experience of implanted children since the centre opened in 1995 (Crofts, 2016, Guy's and St Thomas' Hospital, 2017). CDT has also been used by Nottingham and Oxford Implant teams as part of their monitoring (Archbold, 2017, Clements, 2017)

Professionals recognised that together with the ease of administering and scoring the test, CDT gave a picture of the fluency of speech tracking in everyday communication and had high face validity as it relied on the interaction between the tester and subject. From the researcher's teaching experience in an auditory/oral school for the deaf and in mainstream classrooms, the skill of tracking a teacher's speech is essential for children to be able to learn.

3.6. Age of Cochlear Implantation

The introduction of New Born Hearing Screening in Wales, Scotland and England, in 2004, 2005 and 2006 respectively (Raine 2013) meant that children were diagnosed at a much earlier age and could therefore be referred to implant teams much sooner. The National Institute for Health and Care Excellence (NICE) guidelines introduced in 2009, although very strict have also meant that children in the UK have had free access to the cochlear implant program from the first few months of life, generally reducing the age of implantation and the time delay of language development that previous generations unfortunately suffered.

Ramsden and Graham (1995) wrote that at that time, the 'current ideal time' for implantation was two years. They noted that after the age of seven years, the plasticity of the auditory pathways lessons rapidly. Kirk et al (2002a) investigated how early implantation affected communication, particularly oral language and found that those children implanted before three years had significantly faster rates of language development. Kirk et al (2002b)'s research indicated that the children in their study that were implanted before two years not only had significantly faster rates of receptive language development, but also superior expressive language levels.

Sharma et al (2002) researched the effect that the age of implantation has on the cortical auditory pathways. Their research was based on the time delay or latency between a sound occurring and the brain responding. Key to their research was that the time delay was attributed to the time taken for the signal travelling across a synoptic junction in the auditory nerve and that the number of synoptic junctions was a function of age and was an index of the maturity of the cortical auditory pathway. Thus the longer the time delay, the more synoptic junctions, and the more mature the auditory pathway. Their findings showed that children implanted prior to three and a half years showed normal latencies, similar to those of hearing children, whilst those implanted after 7 years had abnormal reduced latencies, indicating that there were less synoptic junctions and that the cortical auditory pathway was not as mature. Sharma et al (2009) refined their theories and noted the very variable results recorded for

children implanted between 3½ and 7 years of age. The data therefore suggests that the critical period for implantation is about 3½ years and after the age of 7, the plasticity of the auditory pathways is reduced. One hundred and four deaf children participated in this research project along with one hundred and thirty-six hearing children and young people, meaning that this research had a large sample size from which to draw its conclusions.

Nikolopoulos, O'Donoghue and Archbold, who worked together at the Nottingham Cochlear Implant Centre, have published a number of articles detailing their research findings related to cochlear implantation, often using CDT as part of their research. In 1999, they looked at age of implantation using the data from one hundred and twenty six children who were all less than seven years old when they received their implants. These children were monitored for four years post implantation and the analysis of their data meant that Nikolopoulos et al concluded that implantation should occur as early as possible to maximise the gains from the cochlear implant. O'Donoghue et al (2000) conducted a longitudinal study and documented how they used CDT scores to indicate speech perception, again providing more evidence that early implantation was essential the development of listening to speech. Nikolopoulos et al (2006) used data they had collected to make a longitudinal study of the speech perception of congenitally deaf and post-meningitic children, again using CDT. The highest average CDT scores achieved in these pieces of research at five years post implantation were approximately 45 wpm, which is roughly two thirds of the rate that is currently expected for good implant users by St Thomas' Implant Team (Crofts 2016). It is important to note that this research is historical and reflects the technology of the implants of the time, which for some individuals was in the late 1980s and early 1990s. Since then developments have been made to both the internal implants and external processors used by individuals. With new advancements, expectations have increased and individuals are now expected to achieve higher scores.

3.7. Summary

In summary, advances in cochlear implantation have changed dramatically over time and so to have the language expectations of children receiving these implants. The NHSP has enabled a greater proportion of congenital deafness to be identified earlier together with subsequent early implantation. CDT testing has been used for monitoring implanted children and to compare those implanted early and late for a period of time, but no studies have been published that have investigated the long term impact of early or late implantation and CDT scores. The lack of research in the long term impact led to this research project.

4. Research Design

4.1. Objective

The objective of this study was to investigate whether there was a causal relationship between the age of implantation and CDT assessment scores in a population of children who attended an auditory/oral school for the deaf.

This project was designed on a non-experimental retrospective analysis evaluating CDT scores against the age of implantation and the time post-implantation for each subject. The project was a cross-sectional study; that is each subject was assessed once using the CDT test between January 2016 and November 2016.

The advantages of this approach were that the data had already been collected and was collected at a precise time. The disadvantages of this approach meant that the researcher was not present for each test and so could not be absolutely certain of the conditions, procedure or style used during the testing. The data provided a snap shot picture of that subject on that particular day in terms of their CDT score and was not repeated to check that it was a true reflection of the individual's ability. By taking the one score, it was not possible to see the progress a child has made over a period of time.

4.2. Rationale for Study

Nikolopoulos et al (1999) used CDT assessments as part of their battery of assessments in their longitudinal study and concluded that children should receive their implants as early as possible to maximise their language outcomes. O'Donoghue et al (2000) also found that the age of implantation was a covariate on CDT scores. Their research unfortunately ceased tracking the children's performance sixty months post-implantation although the individuals' CDT scores were still increasing. Investigating the impact of age of implantation on CDT scores over a longer period of time was identified as an area of further research. This project allowed the analysis of CDT over a longer

period of time, enabling the researcher to investigate whether the impact of early or late implantation has a long term effect on individuals.

A second area that was investigated using the collected data was the time post implantation and whether this had an impact on the individual's CDT scores. O'Donoghue et al (2000) and Nikolopoulos et al (2006)'s research included collecting CDT scores annually until five year post implantation. At this point, all the children's CDT scores were still increasing and so no maximum plateau score had been reached. The subjects in this study were grouped into those that had been implanted for sixty months or less and those that had been implanted for more than sixty months based on O'Donoghue's et al (2000) and Nikolopoulos et al (2006)'s research to investigate if there was any difference in the CDT scores of these two subgroups.

4.2.1. Hypotheses

The main null hypothesis for this research project was:

H_{MO}: The age of implantation has no resultant effect on children's CDT scores.

This was tested against the main alternative hypothesis:

H_{MA}: The age of implantation does have a resultant effect on children's CDT score, in that children who are implanted early score higher on the CDT assessment than children who are implanted late.

The second null hypothesis for this research project was:

H_{SO}: The time post implantation has no resultant effect on children's CDT scores.

This was tested against the second alternative hypothesis:

H_{SA}: The time post implantation does have a resultant effect on children's CDT score, in that children who have been implanted for longer score higher on the CDT assessment than children who have been implanted for a shorter time.

4.2.2. Definitions

For the purposes of this study, early implantation was defined as 36 months of age or earlier and late as post 36 months.

These values have been chosen based on the literature research. Ramsden & Graham (1995) reported that at that time the ideal time for implantation was two years of age. Sharma et al (2002, 2009) found that after three and half years the plasticity of the brain was reduced and the outcomes of implanted children became more variable and ultimately reduced. Similarly Kirk et al (2002a) found that there were significantly faster rates of language development when children were implanted before three years of age.

The subgroups for the time post implantation (60 months) were based on O'Donoghue et al (2000)'s research where they ceased to track children five years post implantation.

4.2.3. Study population

The children in the study group were not a representative sample of the general UK population of deaf children, as these children specifically attend a non-maintained auditory/oral special school for the deaf as their needs were greater than could be met by their local mainstream school. The school promotes its use of the auditory/oral approach, being taught in small groups by teachers of the deaf in acoustically treated classrooms (Mary Hare, 2016). One could theorise that the children who attend the school are practised listeners and so would score highly on the test. By restricting the study group sample to this particular school, ensured that there was a consistent current educational placement and the CDT test was conducted in a reasonably consistent way.

4.3. The Continuous Discourse Tracking Assessment

The head of the Speech Therapy Department was interviewed to investigate the precise procedure used for CDT assessments (Clements, 2017). The tests were conducted using the KTH tracking procedure as documented by Plant & Archbold (2003). The therapists and children were given instructions about the assessment (Appendix 2). They were asked to repeat short phrases from a

given text over the period of two minutes. The length of phrase was adjusted to the individual by the therapist conducting the text, who was familiar with the child. If a child became stuck, then the word was repeated twice before the word was orally given to the child. At the end of two minutes the number of words repeated was totalled, minus any words that were given. The total number of words was divided by two to give a CDT score of words per minute (wpm).

4.3.1. Variables

As this project was dealing with CDT assessments that had already been carried out, it was only possible to consider the variables retrospectively as the actual assessments were not observed.

- Independent variable
  The age of implantation (and time since implantation)

- Dependent variable
  CDT score

- Controlled variables
  - The CDT test procedure
    Two repetitions repair strategy used and tested by audition alone where possible (Clements, 2017)

Due to the retrospective nature of this study it was not possible to control all the variables concerned with the test, they were taken into account to inform the analysis and minimised as much as possible.

- The tester
  The Speech Therapists at the school conducted Continuous Discourse Tracking tests as part of their annual battery of testing to monitor progress (Clements, 2017). All the therapists were experienced with deaf children and had under gone annual CDT

training to ensure consistency when conducting the test. This involved videoing each other to give peer feedback to improve consistency. The tests were conducted by the child's usual therapist and so was a familiar speaker. The initials of the tester were recorded to enable the total number of testers to be calculated. In total nine different therapists conducted the CDT assessments. Despite the training and peer feedback it was not possible to ensure the same testing style was used by the tester because the researcher did not observe the assessments.

- The texts

  The secondary aged children all used the same text, which was an adapted version of the text that was used by Oxford Implant Centre (Appendix 3) The only adaptation being that it had been lengthened, maintaining the same level of language complexity by the Head of the school's Speech Therapy Department (Clements, 2017). The level of language complexity was maintained by checking the text using the Flesch Reading Ease and Flesch-Kincaid Grade Level language assessments in Microsoft Word. The therapists used the computer program developed by Gallaudet University's Rehabilitation Engineering Research Center on Hearing Enhancement (Bernstein et al 2012) to score the test. The verbal text was presented by the therapist and the child's response was recorded on the computer. When there was a breakdown, the therapist repeated the word twice before presenting a written version of the word on the computer screen. This word was then removed from the calculation of the CDT score.

  The primary aged pupils used a different text (Appendix 4) or one of the texts from Kid Trax (Plant & Archbold, 2003). The text was presented verbally and the child's response marked against a copy of the text. When there was a breakdown, the word was repeated twice before a written version of the word was given.

This was then recorded as a given word and not included in the CDT score.

- Listening environment

  All the testing was conducted in quiet, well-lit rooms within the Speech Therapy Department. The therapists recorded on the result sheet whether the pupils had access to lip patterns or whether an acoustic screen was used to remove visual cues. Using an acoustic screen enabled the sound of the speaker's voice to pass through, whilst preventing visual access to the speaker's lip patterns. Plant and Archbold (2003) demonstrated how an acoustic screen provided the subject with a better sound signal than if a piece of card or a hand was used to cover the visual cues from lip patterns.

- Level of hearing loss

  As this research focuses on children with cochlear implants, those children with moderate hearing losses were excluded as they would not have qualified for a cochlear implant according to the NICE Guidelines (2009). The children who were aided by a cochlear implant and a hearing aid were described as bimodal. Their audiologists must have felt that there was some residual hearing in that ear which would be maximised by the fitting of a hearing aid.

- <u>Uncontrollable variables</u>
  - Aetiology of deafness

    This data was collected, the children had a range of aetiology of deafness which can have a varying impact on their ability to hear and process speech. Certain causes of deafness, such as Auditory Neuropathy Spectrum Disorder, are known to be linked to fluctuating levels of hearing. The main reason for collecting this data was to look at spurious results to see if there was a possible reason due to the individual's cause of deafness.

- Unilateral, bimodal or bilateral implants

  This data was collected and used to analyse the average CDT scores of each sub-group. It would be reasonable to presume that the number of implants and hearing aids would have an impact on the individuals' access to sound and therefore their ability to follow speech in conversation. To remove this as a variable from the study group, one particular sub-group's data would need to be analysed separately. If bilateral implants were chosen as a sub-group, then it would have to be divided further into smaller sub-groups of simultaneous and sequential implants.

  No audiological testing of the hearing aid ear, such as otoscopy or tympanometry was completed to ensure that the child's access to sound using their hearing aid was optimal on the day of the CDT test.

- Ability to access sound prior to implantation

  Some children have no effective access to sound until implantation and so their period of being able to listen begins at the date of switch on. Many children do have some access to sound prior to implantation through using hearing aids, or may have had a progressive hearing loss and so may have had normal hearing for some period time during their lives. There was no clear data regarding this and so for this research project, the date of switch on was used as a crude measure for the start of the subjects' listening.

- The make and model of cochlear implant and processor

  This data was not collected for this research project. It is not certain whether the make and model of implant and processor would have had an impact on the CDT scores, but each manufacturer professes that their products give the best access to sound. To eliminate this variable, all the participants in the

research project would need to use the same internal implant and external processor. With the relatively small sample size, to discard a large proportion of the participants due to the make and model of their cochlear implant, would leave an extremely small study group. Drawing a conclusion on such a small group of children would not be statistically feasible.

- Primary mode of communication

  This data was not collected for this research project, although all the children attend the auditory/oral school for the deaf and so they must have some proficiency in spoken English. O'Donoghue et al (2000) found that mode of communication did have an impact on CDT scores; those children that use oral communication scored higher than those that used more visual modes of communication.

- Additional special needs

  During the data collection, the intelligence and any known additional needs of individuals was not collected. Students at the school for the deaf are assessed prior to being offered a place at the school to ensure that their needs can be met. The school specialises in providing education for hearing impaired children, but children with other additional needs to deafness are part of the school population. These needs include visual impairment, physical disabilities and mild additional needs (Good Schools Guide, 2017a, 2017b).

  Watson (1991) noted how intelligence has an impact on sensory tasks. From my experience of the schools' pupil population, there are very few, if any, children who have a severe or profound learning disability and so the intelligence of the children in the study group was not collected. The researcher did not find any research that focussed on investigating the impact a mild learning difficulty may have on auditory or speech testing.

Specific additional needs of the children may or may not have an impact on the individual's CDT scores. For example, an individual having a visual impairment or a physical disability, one would not expect their CDT score to be affected by their additional need. An additional need such as specific language impairment or a problem with speech production could however have a detrimental effect on their CDT score. From the researcher's personal experience, not all children who potentially have a specific language impairment necessarily have a confirmation of a specific language impairment. Even if those that have a definite diagnosis of a specific language impairment were excluded from the research study group, there would still be a number of children who potentially have a specific language impairment included in the results and so this may be an inaccurate method of grouping the study group.

- Reliability of results

  The test was only conducted once over two minutes and so the result provided a snapshot of that individual on a single particular day. Di Filippo and Scott's original research in 1978 included repeating the CDT test multiple times to calculate an average score. Their research was conducted with adults and it is generally accepted that children have a shorter attention span. Plant & Archbold (2003) in fact recommend conducting an assessment over five minutes but make the point that this may not be possible with younger children. They also made the point that due to the high level of concentration required for this assessment, any testing longer than this could result in a reduction in performance. The details about each child's level of attention were not recorded and so it is not possible to comment whether the CDT score was the best possible score for the individual or whether lower scores were in fact due to a lack of focus and attention on that particular day.

- Other data was not included as it was not readily available, this included previous mode of communication, length of time using auditory/oral communication, length of time attending an educational placement using auditory/oral communication, intelligence level and parental involvement in rehabilitation.

5. Methodology

5.1. Subjects

All the children that attend a particular aural school for the deaf in the UK and have at least one cochlear implant were invited to take part in this research project. The school offers places to pupils who are moderately, severely or profoundly deaf; if the school feels that their needs can be met by an auditory/oral school (Mary Hare, 2016). Due to the research being based on children with a least one cochlear implant, bilaterally moderately deaf children were excluded from this study. The school included children with some additional needs above and beyond their deafness. In total there were 158 children that had at least one cochlear implant and were invited to take part in the research project (Arnold, 2017, Gilbert 2017).

The permission form, participant information sheet and letter were sent home to the parents of children who have at least one cochlear implant (Appendix 1). The range of participants was dependent upon the number of returned written parental permission giving access to the school's Audiology and CDT data for their child.

Sixty parents out of one hundred and fifty eight (38.0%) parents returned the permission form, consenting for their child's data to be included in this research project.

This research project used data that is kept by the Speech and Language Therapy and Audiology Departments of the school for the deaf. The children, who were aged between 8 and 18 years of age, were pupils at the aural school for the deaf during the academic year 2016 and 2017 and have at least one cochlear implant.

5.2. Data collection

Once parental permission for the child's data to be included in this research project was received, their data was collected from the school's Speech

Therapy and Audiology Departments. Each individual was then allocated a pupil identification number, enabling the data to be anonymised from this point onwards. The data was compiled using a spreadsheet between January and March 2017.

The date of implantation, referred to in this research project was actually the day of switch-on, as until this date the cochlear implant was not activated. Switch-on usually takes place approximately a month after the implantation surgery to allow for recovery from the surgery (NDCS, 2015, Advanced Bionics, 2017b). The date of switch on was taken from either reports from the children's cochlear implant team reports or from the school's Audiology Summary Information Sheet that parents are requested to complete. Similarly the child's aetiology of deafness was abstracted from the cochlear implant centre reports or from the School's Audiology Summary Information Sheet.

The CDT Data was collected from the Speech Therapy Department's files together with whether the child used lip patterns and the initials of the therapist who conducted the test. The assessments were conducted between January and November 2016.

By using the date of switch-on and the child's date of birth, the age in months when each child received their implant was calculated. Similarly by using the date of the CDT test and the date of switch-on, the length of time since implantation was calculated in months.

Sixty children's parents gave their permission for their child's data to be included in the research project. Of those sixty, it was found that four children had required access to lip patterns when conducting the CDT assessment. The data of these four children was excluded from the final study group and subsequent data analysis to ensure that all the participants had used audition alone to complete the assessment.

5.3. Recording Results

The pupils' results were recorded using an Excel spreadsheet (Table 1) with the headings below. A full set of the data can be found in Appendix 5. The data was stored in accordance with the data protection procedures of the University of Hertfordshire. All material was kept on a computer with security password or within a locked cupboard. The data transferred was anonymised.

pupil ID	date of birth	no. of CIs	no. of HA	aetiology	date of implantation	date of CDT score	CDT Score	CDT Tester	access to lip patterns
									✓ or X

Table 1 Excel spreadsheet for data collection

5.4. Data Analysis Methodology

All data analysis was carried out using the database and formulas for data on Microsoft Excel.

The data was sorted using the age of implantation from youngest to oldest and then grouped into twelve month groupings. The mean, range, mode and median of the age of implantation were calculated.

The CDT scores were sorted from lowest to highest and grouped into those that scored less than 50, 50-59, 60-69 and so on. The mean, range, mode and median of the scores were calculated. The CDT scores were compared to the expected scores for CI users, as used by Oxford and St Thomas' Cochlear Implant Centres.

Using Kirk et al's (2002a) previous research findings, the data was divided into two sub groups, according to age of implantation at or before 36m as early and post 36m as late age of implantation. The mean, range, mode and median CDT scores were calculated for each sub-group.

The data was sorted according to time since implantation, from shortest to longest and then grouped into twelve month groupings. The mean, range, mode and median of the time since implantation were calculated. Using

O'Donoghue et al (2000)'s 60 month cut off, the data was sorted from the shortest time since implantation to the longest and then grouped into two subgroups; those implanted for 60 months or less and those implanted for over 60 months. The mean, range, mode and median CDT scores were calculated for each subgroup.

The age of implantation and associated CDT scores were plotted using a scatter graph to see if there was any correlation. Similarly the time since implantation and associated CDT scores were plotted using a scatter graph to see if there was any correlation.

The data was sorted using the aetiology of deafness.

The data was also sorted by the type and number of personal aid: unilateral cochlear implant, one cochlear implant and one hearing aid and bilateral implants. The mean, median and mode of the CDT scores for each subgroup were calculated.

Using the null hypothesis, the expected and actual results of the early and late implantation CDT scores were compared using the chi squared statistical test, to investigate whether the results were statistically significantly different or whether the differences could be due to pure chance. Similarly the results for the CDT scores of the two subgroups of time since implantation were also statistically tested using the chi squared test to see if there was a statistically significant difference.

6. Results and Data Analysis

6.1. Age at Implantation

The total number of participants in this study was fifty six and the statistical results of the age of implantation data as a whole are shown in Table 2.

	Mean	Range		Median	Modal range	Standard Deviation
		Lowest	Highest			
Age at implantation (in months)	49	13	170	35	25-36	35.63

Table 2 Statistical results of the age of implantation

From the data in Table 2, the range of the age of implantation varies from just over one year to just over fourteen years of age, with the average at just over four years of age. Figure 1 clearly shows that most children were implanted between two to three years (25 and 36 months). The majority of children were implanted by four years of age (48 months).

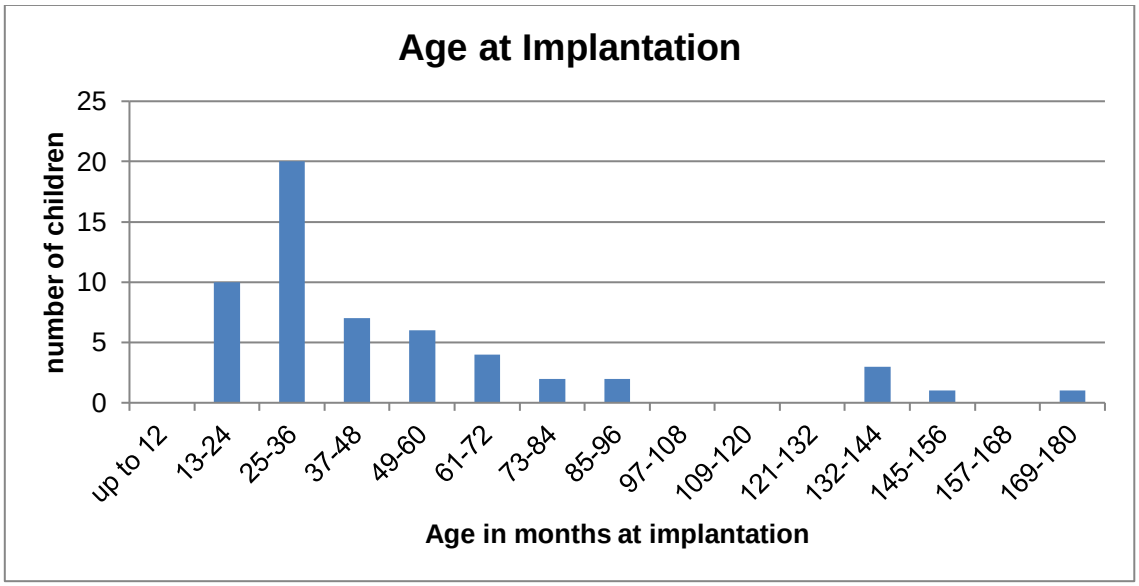

Figure 1 Age at Implantation

6.2. Time since Implantation

The statistical results of the time since implantation data as a whole are shown in Table 3.

	Mean	Range		Median	Modal range	Standard Deviation
		Lowest	Highest			
Time since implantation (in months)	110	3	191	118	133-144	42.81

Table 3 Statistical results for the time since implantation

From the data in Table 3, the average time since implant is approximately nine years, with the range form 3 months to 16 years. Figure 2 shows that most children had been implanted for between 11 and 12 years. The majority of children had been implanted for more than 60 months (5 years) and very few children had been implanted for less than 60 months

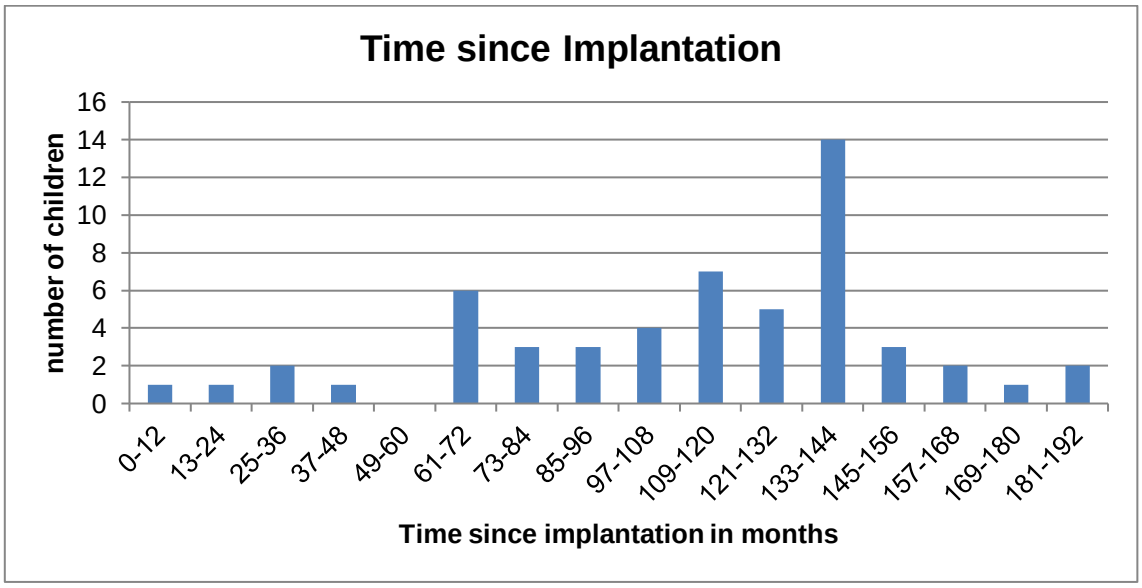

Figure 2 Time since Implantation

6.3. CDT Scores

The statistical results of the time since implantation data as a whole are shown in Table 4.

	Mean	Range		Median	Modal range	Standard Deviation
		Lowest	Highest			
CDT Score (wpm)	70.3	17	124	75	80-89	21.72

Table 4 Statistical results of the CDT scores

From the data in Table 4, the average CDT score was 70.3 wpm and most children's CDT scores were in the 80-89 wpm range. The mean and median are both less than the modal range, indicating that the distribution is not a normal distribution, but is more weighted to below the modal range, as can be seen in Figure 3. The number of children that scored above the modal range dropped rapidly.

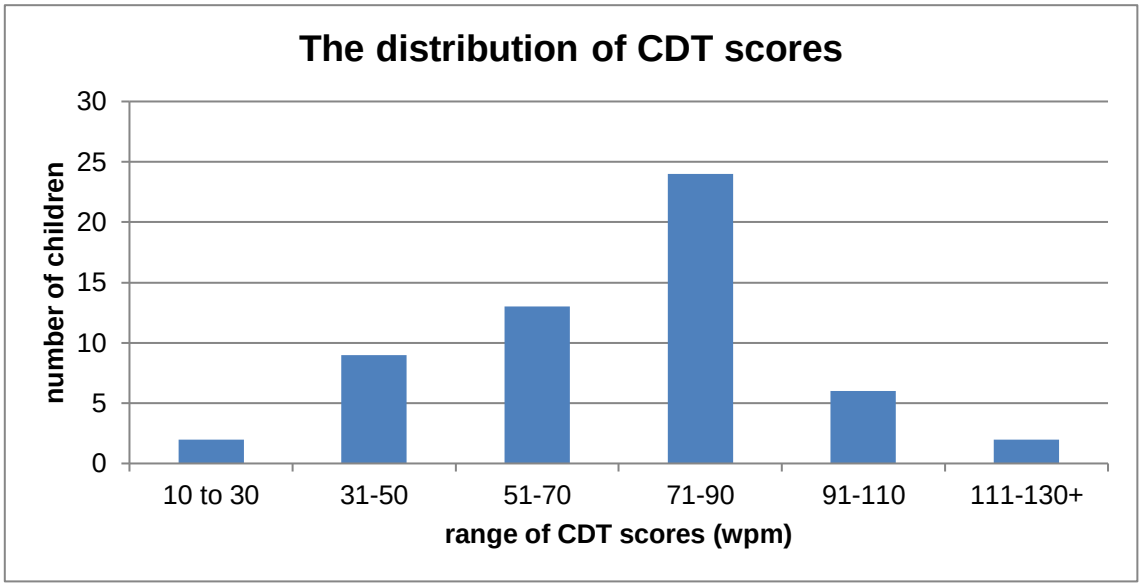

Figure 3 The distribution of CDT scores

6.4. Age of Implantation and CDT scores

The statistical results of the age at implantation and accompanying CDT scores data are shown in Table 5.

Age at implantation	36 months or before	After 36 months	Overall
Number of children	30	26	56
Average CDT score (wpm)	75.2	64.7	70.3
CDT Range (wpm)	28-124	17-101	17-124
Median (wpm)	80	65.8	

Table 5 Age of Implantation data

The numbers of children in the sub groups of children implanted before and after 36 months were approximately equal. The children implanted at 36 months or before achieved a higher average CDT score than those implanted after 36 months.

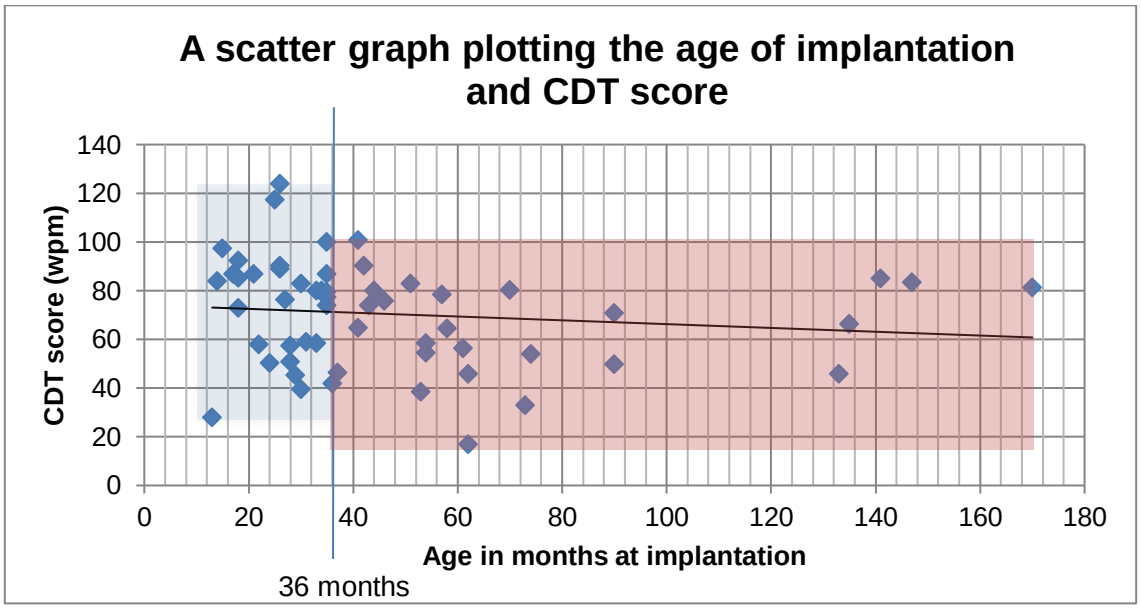

Figure 4 A scatter graph plotting the age of implantation and CDT score

The data for each individual's age of implantation and CDT score was plotted on a scatter graph (Figure 4). The division between early and late implantation has been identified on the graph and the shaded rectangles show cover the data for the two relevant groups: blue – implanted at or before 36 months and pink – implanted after 36 months.

The range of the CDT scores for those implanted prior to 36 months of age was 28 to 124 wpm, however the range for those implanted after 36 months of age was 17 to 101 wpm. The mean CDT scores have a difference of 10.5 wpm between the early and late groups of implanted children.

The correlation for the results on the scatter graph was -0.13, showing that there was a weak negative correlation of the CDT score with an increasing age of implantation.

The actual results were compared to the expected results using the null hypothesis that there was no difference in the CDT score between early and late implantation using a χ^2test (Table 6).

Age at implantation	Number of children	CDT Score total		Difference	Difference^2	Difference^2 / Expected value
		Actual	Expected			
36 months or before	30	30x75.2= 2256	30x70.3= 2109	147	21609	10.2
After 36 months	26	26x64.7= 1669.2	26x70.3= 1827.8	158.6	25154	13.8
Total	56					24.0

$\chi^2 =$ 24.0

Table 6 Chi Squared test results for the age of implantation

There was one degree of freedom and so using a χ^2 table a value of 24.0 means $p \leq 0.05$ and so was statistically significant. This indicates that the null hypothesis was rejected and children implanted at or before 36 months were more likely to achieve a higher CDT score than those implanted after 36 months.

6.5. Time since Implantation and CDT scores

The statistical results of the time since implantation and accompanying CDT scores data are shown in Table 7.

Time since implantation	60 months or less	More than 60 months	Overall
Number of children	6	50	56
Average CDT score	65.9	70.8	70.3
Range	33-85	17-124	
Median	74	75	

Table 7 Time since implantation data

The numbers of children in the sub groups of time since implantation were very unequal, with the majority of children having been implanted for longer than 60 months. The children implanted for longer than 60 months achieved a higher average CDT score than those implanted for 60 months or less.

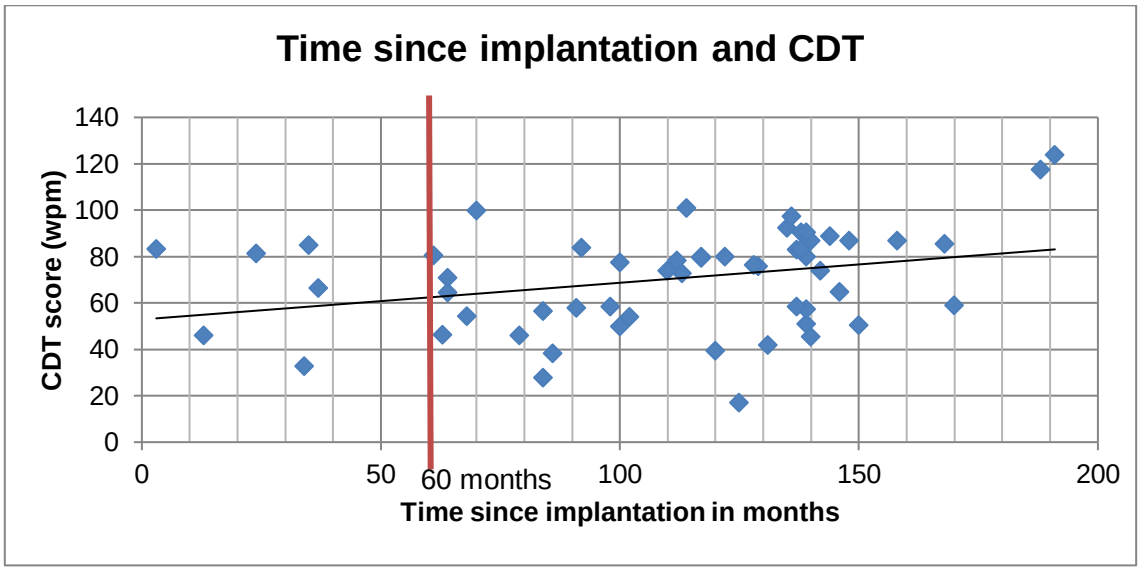

Figure 5 A scatter graph plotting the time since implantation and CDT score

The data for each individual's time since implantation and CDT score was plotted on a scatter graph (Figure 5). The division between those that had been implanted for 60 months or less and those that had been implanted for longer was identified on the graph. The range of the CDT scores for those that had been implanted for 60 months or less was 33 to 85 wpm, and the range for those implanted for longer than 60 months was 17 to 124 wpm. The mean CDT scores have a difference of 4.9 wpm between the two groups of children. The

correlation for the results on the scatter graph was 0.31 and showed that there was a weak to moderate positive correlation of the CDT score with the increasing length of time since implantation.

The actual results were compared to the expected results using the null hypothesis that there was no difference in the CDT score between early and late implantation using a χ^2test (Table 8).

Time since implantation	No. of children	CDT Score total		Difference	Difference^2	$\frac{\text{Difference}^2}{\text{Expected value}}$
		Actual	Expected			
60 months or less	6	6x65.9= 395.4	6x70.3= 421.8	26.4	696.96	1.652
More than 60 months	50	50x70.8 = 3540	50x70.3= 3515	25	625	0.178
Total	56					1.830

$\chi^2 =$ 1.830

Table 8 Chi Squared test results for the time since implantation

There was one degree of freedom and so using a χ^2 table a value of 1.830 means $p > 0.05$ and so was not statistically significant. This indicates that the null hypothesis cannot be rejected. Based on the data of the children in this research project the average CDT scores for those children implanted less than or more than 60 months was not significantly different. Care does need to be taken as there was a small proportion of children (11% or 6 individuals) that had been implanted for less than 60 months.

6.6. Aetiology of Deafness

Once the data was sorted according to the child's cause of deafness, there were extremely low numbers in each group, some only having an individual child (Figure 6). The graph shows how prevalent having an unknown aetiology of deafness continues to be, despite all the development in identifying causes of deafness. The most common causes of deafness after Unknown were ANSD and Connexin 26.

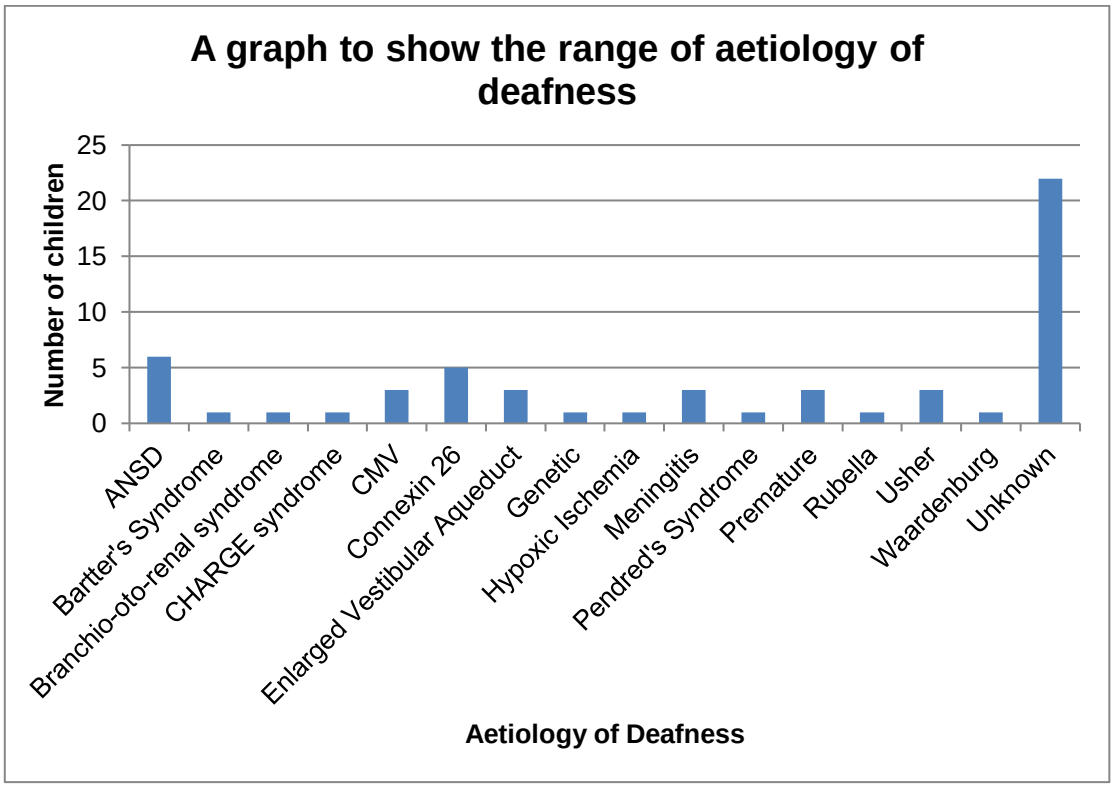

Figure 6 The range of aetiology of deafness

6.7. Type and number of Personal Aids

Table 9 shows the data for the CDT scores when the children were grouped according to the type and number of their personal aids.

Type of Aid	Bilateral 2 Cochlear Implants (2CI)	Bimodal 1 Cochlear Implant and 1 Hearing Aid (1CI and 1 HA)	Unilateral 1 Cochlear Implant (1CI)
Number of children	47	6	3
Average CDT score (wpm)	70.8	63.8	74.8
Range	17-124	39.5-101	57.5-87
Median	76	57.5	80

Table 9 Type and number of personal aids data

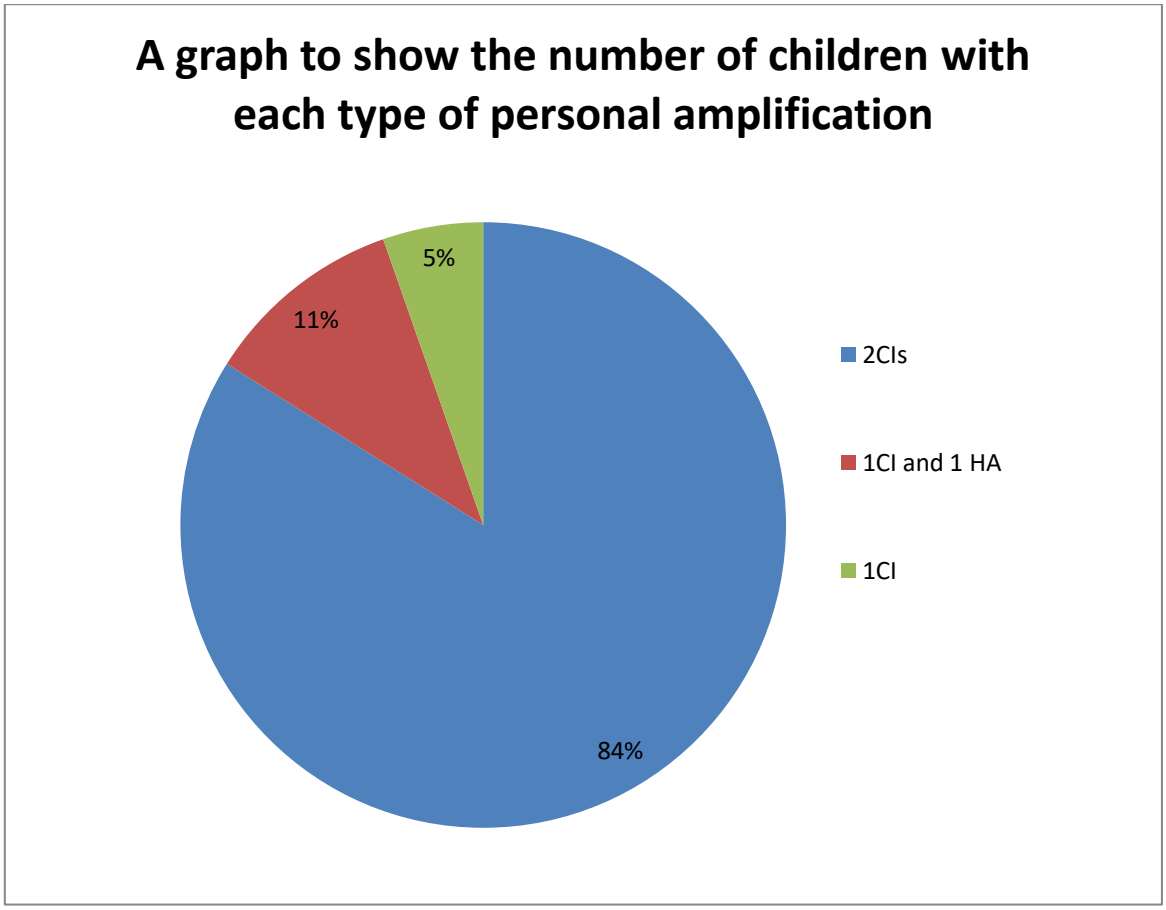

Figure 7 The number of children with each type of personal amplification

Figure 7 shows that the majority of children in this research project had bilateral cochlear implants, a small number were bimodal, having both an implant and a hearing aid. An even smaller number were unilaterally implanted. It was

important to consider the size of these subgroups when comparing the average CDT scores in Figure 8.

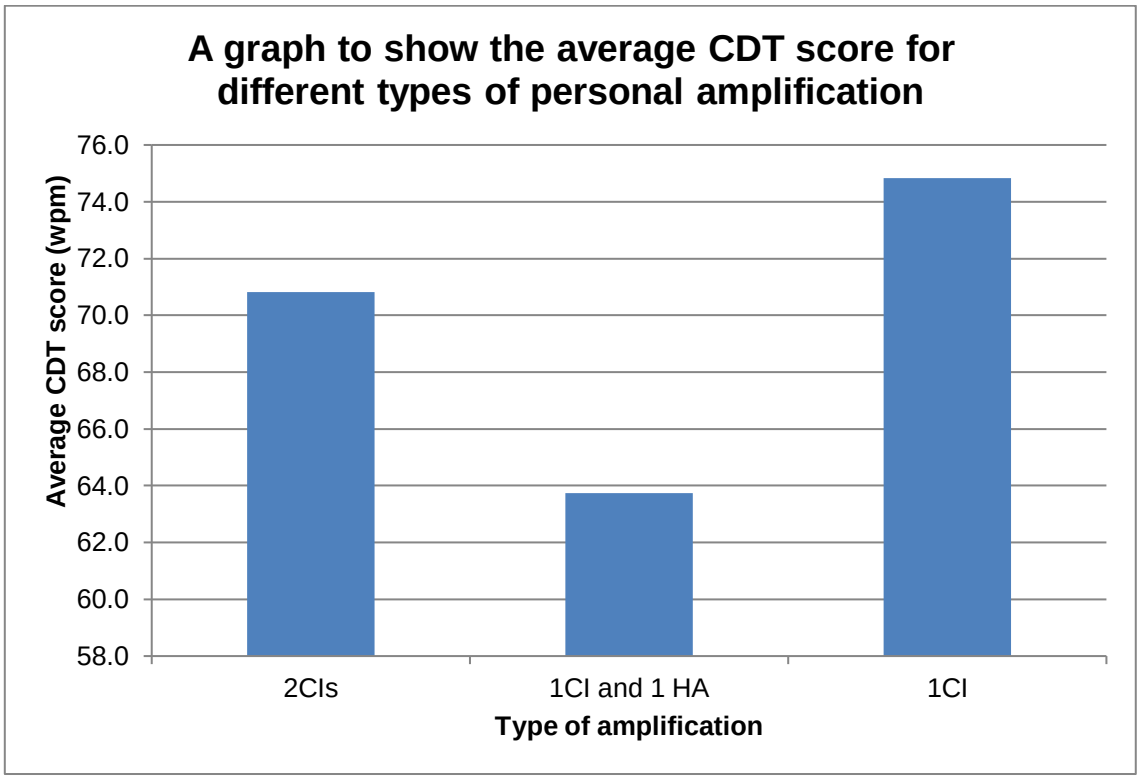

Figure 8 The average CDT score for different types of personal amplification

From the results, unilaterally implanted children achieved the highest CDT scores and bimodal children scored the lowest for this sample of children.

7. Discussion and Conclusion

7.1. Summary of Results

From the analysis of the results, there was a statistically significant difference in the CDT scores of those children implanted at or before thirty-six months of age compared to those implanted after thirty-six months of age.

The analysis of the CDT scores pre and post sixty months after implantation did not show any statistically significant difference between the two groups, but there was a weak to moderate positive correlation of increasing CDT score with age since implantation.

7.2. Discussion of Results

7.2.1. Age at Implantation

The median value of the age at implantation was thirty-five months (Table 2); this showed that at least half the children in the study group were implanted before thirty-six months. The benefit of the NHSP is clear to see from the results, as these younger children would not have been diagnosed so early in the past, resulting in a delay to their hearing being aided and impacting further on their receptive and expressive language development.

7.2.2. Time since Implantation

The majority of children had been using their implants for longer than sixty months (Figure 2) and so were above the upper monitored post-implantation time limits that O'Donoghue et al's (2000) and Nikolopoulos et al's (2006) research used. There were only six children who had been implanted for less than sixty months. Their time since implantation was 3 months, 13 months, 24 months, 34 months, 35 months and 37 months respectively. Only one child was at the very early stages of rehabilitation following implantation, although this child's CDT score was 83.5 wpm. As all the children in the study were of statutory school age, it was expected that there would be very few children that had been implanted for less than

sixty months due to early diagnosis and implantation following the NHSP. Five of the children who had been implanted for less than sixty months were implanted after twelve years of age. It was not clear why these children received their implants at such a late age. Even when these children's aetiology of deafness was considered, it was not clear if they had had a progressive hearing loss and their hearing level had deteriorated. There may have been a range of reasons why these particular children received implants at this late age, including parental and personal preference, dissatisfaction with previous personal aids or funding for the procedure. Three of these five children scored above 80 wpm on their CDT assessment so it appeared that they had quickly adapted to their new implants. Care needs to be taken with drawing conclusions from these results due to the particularly small number of individuals in the sub-group and that the study group was not representative of the implanted deaf population as a whole because all of the children attended an auditory/oral school for the deaf where there is a strong emphasis on developing speaking and listening skills.

7.2.3. CDT Scores

St Thomas' Implant Team use a CDT score of 70 wpm for a good cochlear implant user (Crofts, 2016), whereas Oxford Implant Team expect an average CI user to score 80 wpm (Clements 2016). The modal range for this research project was 80-90 wpm (Table 4), which was slightly above the expectations of the Oxford Team.

The mean (70.3 wpm) and modal range (80-90 wpm) for this study (Table 4) were well in excess of O'Donoghue et al's (2000) research where the mean CDT score of the forty children in the study at five years post-implantation was 44.8 wpm. O'Donoghue et al's study group included a range of aetiology, ages at implantation and modes of communication. One factor that may have decreased the mean for this study was that over half the children had used total

communication before implantation and so there had not been a strong focus on oral communication.

The modal range for this project's data (80-90 wpm) was much closer to Archbold's unpublished data for hearing five year olds of 95-105 wpm (Archbold, 2017). One cannot be certain to the reasons for these improved results and higher expectations, although advancements in technological developments may well have contributed.

Due to the CDT data being collected on one particular day and not being over a period of time, it was not possible to identify if the children were continuing to improve their scores or if they had achieved their maximum potential and their score had plateaued.

7.2.4. Age at implantation and CDT scores

Figure 4 illustrates how those children implanted before thirty-six months are more likely to achieve higher CDT scores than those implanted later. Some children implanted after thirty-six months do still achieve slightly above 80 wpm, but the majority score below this level. The χ^2test (Table 6) disproved the H_{MO} hypothesis that the age of implantation has no resultant effect on children's CDT scores. It showed that there was a statistically significant difference in the CDT scores between the early and late implanted sub groups and thus supported the H_{MA} hypothesis that the age of implantation does have a resultant effect on children's CDT score, in that children who are implanted early score higher on the CDT assessment than children who are implanted late. The results of this research supported Nikolopoulos et al (1999) and O'Donoghue et al (2000)'s research findings that early implantation provides the best possible outcomes. Early implantation does not necessarily guarantee that a child will achieve a high CDT score as there were still a number that were not achieving 60 wpm.

The number of active electrodes, the length of time the child has been using verbal communication or whether the child has a specific language impairment are just some factors that could have contributed to these lower than expected CDT scores for early implanted children. These variables cannot be confirmed because this data was not collected as part of this research project.

7.2.5. Time since Implantation and CDT Scores

The majority of children had been implanted for longer than sixty months with very few implanted for sixty months or less and so it was difficult to compare these subgroups. It was interesting to note that three of the children implanted for less than sixty months achieved greater than 80 wpm and had quickly adapted to their new implants.

The scatter graph (Figure 5) showed the positive correlation of 0.31 when the time since implantation and the CDT scores were compared. This indicated a weak to moderate positive linear relationship between the results. The relationship was not very significant and so the time since implantation was certainly not strong enough to be used as a predictor of the CDT assessments. The linear relationship indicated that the CDT scores continue to improve with time post implantation, however at some point the scores would plateau due to the maximum number of words a person can speak per minute. As O'Donoghue et al's (2000) research noted further investigation is needed to clarify the average time post implantation where CDT scores plateau.

The χ^2test results (Table 8) showed that there was no statistical difference between the two sub groups of children implanted for more or less than 60 months and so the second null hypothesis,

H_{SO} (the time post implantation has no resultant effect on children's CDT scores), was not disproved by the data in this project.

7.2.6. Aetiology of Deafness

The cause of deafness data was collected to see if it was a contributing factor for spurious CDT results. In this study, ANSD was the most common diagnosed cause of deafness (Figure 6).

Of the six children diagnosed with ANSD, the CDT scores ranged from 33 to 90.5 wpm, with half of these scoring above 70 wpm. A diagnosis of ANSD for these children did not therefore necessarily mean a lower CDT score. As its name suggests ANSD is a spectrum disorder with a variation of aetiology along the auditory system and therefore individuals with this diagnosis have variable outcomes with regards to the success of implantation. Rance et al (2002) and Teagle et al (2010) researched the outcomes for children with ANSD and found that 50% of their study group benefitted from being aided, but that outcomes were variable. This study reflects these research findings.

7.2.7. Type and Number of Personal Aids

The proportion of children with bilateral cochlear implants was very high and reflected the NICE (2009) guidelines that offer bilateral implants to children with severe to profound deafness.

The average CDT scores for the type and number of personal aid sub groups was unexpected (Figure 8). The researcher expected the bilateral sub group to have the highest mean CDT score, followed by the bimodal sub group and finally the unilaterally implanted group. Litovsky et al's (2006)'s and Ching et al's (2007) research found that bilaterally implanted children have the best access to sound and speech. It is important to remember that the CDT test was conducted in a quiet environment in close proximity

and so the individuals did not need to try to locate sound or focus on the speech signal rather than background noise. Neumann & Svirsky (2013) and Armstrong et al (1997) found that bimodal individuals scored better in speech testing listening than those that were unilaterally implanted when the speech testing was conducted in noise.

It is important to remember that the bimodal and unilateral sub groups had very small numbers. Of the three children that were unilaterally implanted, two had Connexin 26 as their aetiology and the other was unknown. All three children were implanted prior to forty-eight months of age and had all been using their implants for over ten years.

The CDT scores of the bimodal children ranged between 39.5 and 101 wpm. There was a range of aetiology including Connexin 26, Enlarged Vestibular Aqueduct, CMV and unknown. Their age of implantation varied between just over two years of age to approximately eleven years. The child, who had been implanted at approximately eleven years of age had only been implanted for thirteen months and achieved a CDT score of 46 wpm, it was highly likely that this child was still adapting to their new implant. From the data collected it was not possible to say why these children's CDT scores were so low in comparison to both the unilaterally and bilaterally implanted children, but it would be interesting to look at these specific children in more detail, for example their mode of communication in their previous educational placement to see if this had had an impact on the emphasis placed on their listening skills or if there were any other compounding variables.

The mean CDT score for bilateral implanted children was comparable to St Thomas' expected score for a good cochlear implant user and slightly below the level expected by Oxford's Auditory Implant Team. The results of this research did not reflect

Litovsky et al's (2006) findings that bilateral implants were more beneficial than unilateral implants. Although the bilaterally implanted sub-group contained a large number, the group also contained children implanted both early and late, whilst the unilaterally implanted group only contained children that had been implanted before 36 months of age. When the unilaterally implanted mean CDT score (74.8 wpm) was compared to the mean of the bilateral children who had been implanted early (77.7 wpm), it did reflect Litovsky et al's (2006) research and showed that on the whole the early bilaterally implanted children achieved better outcomes than those that were unilaterally implanted.

7.3. Limitations

7.3.1. Study group

It was important to note the small size of the sample of pupils for this research project. The number of subjects involved meant that individual scores had a high impact on the results causing a greater shift than an individual in a larger sample size.

Only the data of 38.0% of the total possible number of implanted individuals that attend the school was included due to participation in the research project being reliant on parental permission. It was impossible to say whether the study group was a true representation of the implanted children that attend the school, without comparing the sample to the data of all the implanted children that attend the school. The study group was certainly not a representative sample of the deaf population of the UK, due to the individuals all attending one particular auditory/oral school for the deaf. Deaf children are taught in a range of educational placements including mainstream schools and use a variety of modes of communication such as sign supported English and British Sign Language. The pupils at this special school for the deaf were taught using an auditory/oral mode of communication.

To gain a better understanding of the impact of age of implantation on CDT scores, it would have been better to have a larger sample drawn from a range of educational placements.

7.3.2. Type of personal amplification

No data was collected regarding the individuals' cochlear implants or processors. To minimise the type of personal amplification variable, then the sample group would all need to use the same internal and external equipment.

Detailed information about each individual's personal aids was not collected as part of this research project. When the average CDT scores for different types of aids was analysed, the data produced an unexpected anomaly, in that the average CDT scores for bilateral or unilateral implants with and without hearing aids did not reflect the expected results as suggested by previous research by Litovsky et al (2006) and Ching et al (2007). This may be due to the small number of subjects being unilaterally implanted and either using one or no hearing aid.

Due to not having the detailed information about the children's hearing aids, it was impossible to know how the hearing aids were programmed, for example providing a wide audiological range or a narrow range to complement the cochlear implant. As this was unknown, it was impossible to know if this contributed another set of variables to the sample group.

As the detailed information regarding the implants was not collected, the number of active electrodes compared to the total number of possible active electrodes was unknown. Each manufacturer uses a different maximum number of electrodes, for example Advanced Bionics uses 16, whilst Cochlear uses 22 and MED-EL uses 12 (Cochlear 2012). Evidence suggests that having more active electrodes, can lead to better speech perception, however recent research has been conducted

investigating the dual stimulation of adjacent electrodes to enable intermediate pitches to be perceived (Donaldson & Kreft, 2005).

Although each make and model of implant has a different maximum numbers of electrodes, invariably for some children not all electrodes are active and so are not optimally aided. A small proportion of inactive electrodes would not have a great impact on the individual's ability to access sound; however having a larger proportion, such as 50% would have a greater impact. In fact some of the subjects that were excluded from the sample due to their needing access to lip patterns during the CDT test may have had a high proportion of inactive electrodes. Incorporating collecting more precise information regarding the individuals' personal aids would be beneficial for future research, so that these variables can be considered when analysing the results.

7.3.3. Aetiology

Although this data was collected and analysed, due to the small sample and the wide range of causes of deafness, no clear conclusion can be made. By recording the aetiology, it was possible to look more closely at spurious results to see if aetiology was a compounding variable.

7.3.4. Pre implantation

The data for age at implantation recorded the date of switch on for the individuals' implant or implants. No data was collected regarding the date of diagnosis and the subsequent aiding between diagnosis and implantation and whether this was effective or whether the child suffered from auditory deprivation. Similarly data regarding the child's level of hearing loss pre-implantation was not recorded to investigate whether this was a stable or progressive hearing loss.

7.3.5. Implantation

This data for bilateral implanted subjects did not record whether they received implants simultaneously or sequentially. Chadha et al (2011) investigated speech detection in noise for children with simultaneous and

sequential cochlear implants and found that simultaneously implanted children achieved better results than those implanted sequentially.

7.3.6. Post implantation

Data was not collected regarding the child's aided threshold levels and so it is not possible to comment on the effectiveness of the children's aids and how this may have contributed to their CDT scores. It is important to remember that threshold levels show the subject's ability to detect sound at different frequencies, whereas speech tests, such as the CDT test, requires the subjects not only to detect but also to discriminate sounds and reproduce what they have heard.

Data was not collected regarding the preferred mode of communication, nor whether their favoured mode had changed over time since implantation. The data did not include whether the educational placement reflected the individuals' preferred mode of communication or if the communication mode of the child's educational placement had changed over time. The school where the children attended used an auditory/oral communication approach and so one would expect the subjects to be used to listening, however some children have BSL as their first language and others are known to transfer from a more sign rich environment to the auditory environment of this particular school. Listening is a skill and so one would expect those that regularly use their auditory skills would achieve a higher CDT score and those that have relied on sign would not score as highly. This would be an interesting area for future research.

Moeller (2000) found that those children, whose parents who were involved in family interventions, supporting the parents' interactions with their deaf child, achieved higher language outcomes than those children from families who were not so actively involved. The research was measured over a relatively short period of time, comparing the children's language at 5 years of age. It would be interesting to investigate if these

positive language outcomes had a longer lasting effect into children's secondary education.

7.3.7. Additional needs

The data collection did not include whether a child had any other additional needs such as an auditory processing problem or an expressive language problem (for example a stammer) either of which would have a negative impact on the average CDT score. There will of course always be children who have one or either of these issues, but who just haven't been officially diagnosed. It would be difficult to try and exclude any children who have not got a confirmed diagnosis. If a true representative sample of the deaf population was required then children with these additional needs should be included, however to make the data for the hypothesis as precise as possible by minimising the variables, then these groups should be excluded. Similarly, using Watson's (1991) research findings concerning intelligence and the impact this has on sensory testing, it would be helpful to include this type of data to refine the study group to include those individuals with intelligence above a particular level.

7.3.8. CDT

There are many variables associated with the CDT test that have already been identified in the Research Design. While accounted for as much as possible when designing this study, it was still possible that such variables could have affected the CDT scores (see research design for more detail.

Over time, since Di Filippo and Scott (1978) first published their article regarding CDT and Tye-Murray and Tyler (1988)'s critique of the procedure, the need for a prescriptive procedure has been recognised. Plant's work at KTH in Sweden and the Gallaudet tried to ensure a more rigid procedure was followed and similarly his work with Archbold and the publication KID TRAX in (2003) also tried to ensure a clear procedure for testing was used. Despite this, there is still no one clear procedure or text to be used for testing. Due to the idiosyncrasies of each place of testing, it is extremely difficult to compare results. Even within this one school,

despite the Head of the Speech Therapy Department trying to ensure consistency, nine individuals completed the tests and two different texts were used.

7.4. Recommendations

This research project showed that early cochlear implantation (at or before thirty-six months) enabled children to have a greater chance of achieving a higher CDT score. It provided support to the NICE (2009) guidelines and Archbold's (2010) research pertaining to the benefits of early diagnosis and subsequent early implantation. Repeating the research with a larger population from a wider range of educational placements would be beneficial, as would collecting data regarding the children's personal aids, additional needs and previous mode of communication. Statistical tests on larger samples produce more accurate averages as outlying results have a smaller impact on the mean. The collection of additional data would enable these variables to be considered during analysis of the results.

As the results of the statistical testing for the secondary hypothesis were not conclusive, further longitudinal research looking at how children's CDT scores progress over time would be beneficial. This research could then be used to see if the previous 60 month monitoring used by O'Donoghue et al (2000) and Nikolopoulos et al (2006), which the researcher used as the cut off for this study, is in fact an appropriate length of time and whether an earlier or later point would be more suitable for dividing the sub groups.

7.5. Further Study

The main aspect that restricted this research project was the sample size and so repeating this study with a larger group of children would enable the validity of the conclusions to be checked. Ideally a national study would give a more representation view of the deaf children's population of the UK.

Whilst enlarging the sample size, it would also be possible to refine subgroups within the study to remove potential variables such as receptive and expressive language difficulties, low cognition levels, participation in early family

interventions or implant and processor variations before comparing CDT scores to see if these variables do in fact have an impact on the individuals' scores.

This was a cross sectional study, looking at the individuals' scores at one point in the school year. As the school conducts this test annually, it would be interesting to track the progress of individuals over time. By conducting a longitudinal study, it would be possible to investigate the impact of an auditory/oral educational placement.

Since the NHSP was nationalised in 2006, congenital deafness has been identified much earlier and accompanied by aiding, reducing the period of auditory deprivation. Due to the age range of the sample group in this study, the children straddle the time before and after the NHSP was nationalised. With the passage of time, it would be interesting to see if the mean age of implantation reduces further.

Pimperton et al (2016) found that early diagnosis due to the NHSP and subsequent aiding had a positive impact on children's language skills and reading skills. It would be beneficial to gather data to calculate CDT norms for the both the cochlear implanted population now that NHSP is established.

There has been a large amount of research into the outcomes of cochlear implantation using CDT scores. At present there are no published norms or expected CDT scores for children that use bilateral hearing aids and so this is an area that would benefit from further study.

Throughout all the research involving CDT, no study group demonstrated a score that plateaued. Levitt et al (1986) and Plant et al's (2015) research with hearing impaired adults was still demonstrating progress after eight to ten weeks of auditory training. O'Donoghue et al (2000)'s research with cochlear implanted children was still showing improvements sixty months post implantation. As the school tests CDT each year it would be relatively easy to analyse the year on year results to see if some or all of the children continued to improve or if there was a maximum score for each individual.

Analysing the CDT scores in terms of year on year progress in relation to the mode of communication at the child's previous school would be easy to research. This would enable the impact of an auditory/oral educational placement to be measured in terms of the children's tracking of speech.

7.6. Conclusion

The results of this study demonstrated that early cochlear implantation (before 36 months) enabled children to generally achieve higher outcomes on the CDT test than those implanted after 36 months, supporting the main hypothesis. The impact of the time since implantation was not significant for the CDT data in this study.

This research project began as a small, simple investigation, but it has produced more questions pertaining to the impact of different variables not only involved with the actual CDT test but in relation to the participants of the study group and how a child's progress can be affected by a wide range of aspects. It has therefore suggested a range of areas for future study.

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9. Appendices

9.1. Appendix 1 Ethics forms

Letter to parents

Dear Parent

I am writing to you to request your permission to access your child's Continuous Discourse Tracking (CDT) Assessment carried out during Speech and Language sessions at Mary Hare Schools, together with their date of birth, date of cochlear implantation and their aetiology of deafness, held by Mary Hare Audiology Department.
My name is Maggie Dutton and I was previously employed as a Teacher of the Deaf at Mary Hare Primary School. I am currently studying for the MSc in Educational Audiology. For my dissertation I am studying whether the age at cochlear implantation has an impact on the score of the CDT assessment that the Speech and Language Therapists conduct each year at Mary Hare Schools. Please see the accompanying information sheet, which provides more details concerning my research.
I would be grateful if you would give your parental consent, by completing the permission form and returning it to K Clements by Thursday 5th January.
Thanking you in anticipation,

Mrs Maggie Dutton

Participant Information Sheet

UNIVERSITY OF HERTFORDSHIRE

ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS

FORM EC6: PARTICIPANT INFORMATION SHEET

Analysis of Continuous Discourse Tracking Data with regard to age of cochlear implantation

Introduction

You are being invited to take part in a study. Before you decide whether to do so, it is important that you understand the research that is being done and what your involvement will include. Please take the time to read the following information carefully and discuss it with others if you wish. Do not hesitate to ask us anything that is not clear or for any further information you would like to help you make your decision. Please do take your time to decide whether or not you wish to take part. The University's regulations governing the conduct of studies involving human participants can be accessed via this link:http://sitem.herts.ac.uk/secreg/upr/RE01.htm

Thank you for reading this.

What is the purpose of this study?

Continuous Discourse Tracking (CDT) is an assessment that was designed by De Filippo & Scott (1978) and has been used to track progress of cochlear implanted patients by several implant teams. The assessment is completed by the Speech and Language Therapists for all children at Mary Hare Schools each academic year. This study intends to use the data collected and research the impact of the age of cochlear implantation has on CDT scores.

I would like your consent to use the CDT data that Mary Hare has recorded related to your child, together with the age of your child at cochlear implantation. This data will be used for the main body of my dissertation with the University of Hertfordshire

Do I have to take part?

It is completely up to you whether or not you decide to grant permission for me to use the data relating to your child's CDT and age at implantation data.

If you decide to grant permission you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to allow me to use the data does not mean that you can't change your mind. You are free to withdraw your permission at any stage without giving a reason.

How long will my part in the study take?

Mary Hare Schools already has this data and so your child will not need to complete any further activities for this study.

What will happen to me if I take part?
Your child's data will be anonymised, analysed and reported on to provide an insight into the impact the age of cochlear implantation has on CDT scores.

What are the possible disadvantages, risks or side effects of taking part?
No risks.

What are the possible benefits of taking part?
My research project findings will be shared with Mary Hare staff and other professionals.

How will my taking part in this study be kept confidential?
All data will be anonymised before being used in the dissertation.

What will happen to the data collected within this study?
The data will be anonymised and stored in accordance with the data protection procedures of the University of Hertfordshire. All material will be kept on a computer with security password or within a locked cupboard. Any data transferred will be made anonymous.

Who has reviewed this study?
This study has been reviewed by: The University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority

Who can I contact if I have any questions?
If you would like further information or would like to discuss any details personally, please get in touch with me, in writing, by phone or by email:

Maggie Dutton
Teacher in Charge of the Hearing Resource Base
Westwood Farm Schools
Fullbrook Crescent
Tilehurst
READING
RG31 6RY
Tel: 0118 9425182
mdutton@westwoodfarmschools.w-berks.sch.uk

Supervisor:
Tracy James
t.james@training.maryhare.org.uk

Although we hope it is not the case, if you have any complaints or concerns about any aspect of the way you have been approached or treated during the course of this study, please write to the University's Secretary and Registrar.
Thank you very much for reading this information and giving consideration to taking part in this study.

Permission Form

UNIVERSITY OF HERTFORDSHIRE
ETHICS COMMITTEE FOR STUDIES INVOLVING THE USE OF HUMAN PARTICIPANTS

FORM EC3
CONSENT FORM FOR STUDIES INVOLVING HUMAN PARTICIPANTS

I, the undersigned *[please give your name here*, *in BLOCK CAPITALS]*

……..…
of [*please give contact details here, sufficient to enable the investigator to get in touch with you, such as a postal or email address]*

…..…….…
here by freely agree to take part in the study entitled

Analysis of Continuous Discourse Tracking Data with regard to age of cochlear implantation

1 I confirm that I have been given a Participant Information Sheet (a copy of which is attached to this form) giving particulars of the study, including its aim(s), the names and contact details of key people and, as appropriate, the risks and potential benefits, and any plans for follow-up studies that might involve further approaches to participants. I have been given details of my involvement in the study.

2 I have been assured that I am free to withdraw my permission at any stage without disadvantage or having to give a reason.

3 I have been told how information relating to my child (data previously obtained) will be handled: how it will be kept secure, who will have access to it, and how it will be used.

4 I have been told that I may at some time in the future be contacted again in connection with this or another study.

Signature of participant……..…Date……..

Signature of (principal)
investigator……Date……

Name of (principal) investigator *MARGARET DUTTON*

9.2. Appendix 2 Instructions for CDT

Instructions for Therapists

Continuous discourse tracking test guidelines for children completing the test through AUDITION ALONE

1. Read the introduction to the child. A modified language version is provided for children with lower language abilities.

2. Carry out the test over 2 minutes

3. Use the acoustic hoop at all times.

4. Use your clinical judgement to read out the text at an appropriate pace for the child (You can speak faster than normal conversational pace for pupils who can manage this). Clinical judgement of auditory memory abilities must also be used to determine how much text will be read at any one time. If the child makes an error, repeat the word or part of the text that they did not say correctly. A second repetition can be provided if necessary. After this, drop your hoop and repeat for a third time with clear lip patterns. (Circle any words that require lip patterns for the pupil to repeat correctly)

5. If the child cannot process the word even with lip patterns then cross through the word(s) they have missed and continue with the test. When scoring the test at the end, do not count any words which have been crossed through.

Instructions for pupils

Introduction for delivering continuous discourse tracking assessment through audition alone.

Introduction

We're going to do a test of your listening now. I'm going to read a story to you a few words at a time then I want you to repeat what I say as quickly as you can. I'm going to cover my lips with this hoop so you must listen carefully. If you don't understand something I say then I will repeat it for you. If you still don't understand I will repeat it again. After that I will put the hoop down and say it again so you can see my lips.

You only have to listen to me for two minutes and then we'll stop. It's a race to see how many words you can repeat back to me so go as fast as you can!

Let's have a practice. Remember to repeat what I say.

"I think speech therapy is fantastic! (Insert therapist's name) is the best speech therapist in the world!"

Well done! Ok, let's do the real test now. I'll say, "Three, two, one, go!" And then we'll begin. Ready?

9.3. Appendix 3 Secondary CDT Text

CDT text tracking assessment: Secondary school
(Timed over 2 minutes)

Date: **Name:**

John wakes up at six o'clock on weekday mornings. He goes downstairs and makes a pot of tea. While the (20) kettle boils he lets his dog out into the garden and feeds his cat. He has a shower and eats (20) breakfast. John always has the same breakfast in the morning to save time. He has 2 slices of toast and (20) marmalade. He eats this while he takes his dog for a walk in the field at the bottom of his garden. (21) Total=81

John leaves his house at seven o'clock to catch his train. In the summer he walks to the station, but (20) he drives in the winter as it is often wet and dark. He catches the 7.20 train to the town (20) where he works and then has a short walk to his office at the bank. He buys a cup of (20) coffee as he walks to his office. He drinks his coffee while he answers his emails (16). Total=76

His first appointment is at nine with his manager. John then meets with customers throughout the morning to help them (20) invest their money wisely. He really enjoys this part of his job, although sometimes customers can be rude (18). Total=38

John stops for lunch at 1 o'clock. He usually has a sandwich at his desk. On quiet days he takes (20) his lunch outside to eat in the park across the road from his office. John leaves work at five o'clock (20) and catches the train home. (5) Total=45

John goes to the gym on Mondays and Wednesdays. He jogs with his dog on the other evenings. John plays (20) rugby in the winter and has rugby practice on Friday nights. The team usually goes out for supper after rugby practice. (21) Total=41

Total number of words: /2= _____ words per minute

Flesch Reading Ease **86.9**

Flesch-Kincaid Grade Level **4.1**

9.4. Appendix 4 Primary CDT Text

CDT text tracking assessment: Primary school
(Timed over 2 minutes)

Date: **Name:**

In December there was lots of snow. It fell on (10) a Saturday. I was disappointed because there were no snow (10) days. I didn't miss any school. We had to stay (10) inside for four days which was very boring. I watched (10) a lot of TV and played games with my brother (10) and sister. Eventually we went for a drive to the (10) shop. The roads were very icy and it was dangerous but (10) we needed to buy some food. I made a big (10) snowman in the garden and decorated it with a hat (10), scarf and gloves. I hope it snows this term so (10) that I can miss some school! (6)

I really enjoy going sledding when it snows. (8) My brother Tom and I walk up a steep hill (10) close to where we live and then take turns to (10) sledge down the hill (4). Tom is always a bit nervous at first because when (10) he was younger he fell off and hurt his arm (10) but after a few goes we feel more confident and (10) laugh and shout all the way down the hill until (10) we land up in the ice cold snow at the bottom (11). It is so much fun! (5)

Total = 194 words

Total number of words: /2= _____ words per minute

Flesch Reading Ease **90.7**

Flesch-Kincaid Grade Level **4.0**

9.5. Appendix 5 Raw Data

Data Collected

pupil ID	no. of CIs	no. of HA	Aetiology	Age at implantation in months	Time since implantation in months	CDT Score	Tester	lip patterns
1	2	0	Connexin 26	25	188	117.5	A	X
2	2	0	Branchio-oto-renal syndrome	31	170	59	B	X
3	2	0	ANSD	170	24	81.5	C	X
4	2	0	Unknown	90	100	50	B	X
5	2	0	Unknown	62	125	17	C	X
6	2	0	Usher	41	146	65	A	X
7	2	0	Meningitis	18	168	85.5	C	X
8	2	0	Bartter's syndrome	35	148	87	D	X
9	1	0	Connexin 26	21	158	87	C	X
10	2	0	Unknown	35	142	74	B	X
11	2	0	Unknown	141	35	85	B	X
12	2	0	Meningitis	30	138	83	C	X
13	2	0	Unknown	51	137	83	C	X
14	2	0	Connexin 26	46	129	76	A	X
15	2	0	Premature	74	102	54	E	X
16	2	0	Meningitis	24	150	50.5	E	X
17	2	0	ANSD	135	37	66.5	C	X
18	2	0	Waardenburg	33	139	80	D	X
19	2	0	Unknown	33	137	58.5	A	X
20	2	0	CHARGE Syndrome	26	144	89	F	X
21	2	0	Unknown	26	191	124	B	X
22	2	0	ANSD	57	112	78.5	E	X
23	2	0	Usher	29	140	45.5	A	X
24	1	1	Enlarged Vestibular Aqueduct	28	139	51	C	X
25	1	0	Connexin 26	28	139	57.5	C	X
26	1	0	Unknown	44	122	80	E	X
27	2	0	Rubella	26	139	90.5	F	X
28	2	0	Auditory Neuropathy	42	138	90.5	F	X
29	2	0	Unknown	17	140	87	A	X
30	2	0	Unknown	147	3	83.5	F	X
31	2	0	Usher	27	128	76.5	C	X
32	1	1	Premature	41	114	101	A	X

pupil ID	no. of CIs	no. of HA	Aetiology	Age at implantation in months	Time since implantation in months	CDT Score	Tester	lip patterns
33	2	0	Unknown	43	110	74	G	X
34	2	0	Unknown	18	135	92.5	D	X
35	2	0	Unknown	54	98	58.5	C	X
36	2	0	CMV	15	136	97.5	G	X
37	2	0	Enlarged Vestibular Aqueduct	34	117	80	D	X
38	2	0	Unknown	35	117	79.5	G	X
39	1	1	Connexin 26	30	120	39.5	D	X
40	2	0	Premature	62	79	46	H	X
41	2	0	Unknown	61	84	56.5	G	X
42	1	1	Genetic	133	13	46	F	X
43	2	0	Pendred's Syndrome	36	131	42	B	X
44	2	0	Unknown	90	64	71	F	X
45	2	0	Unknown	35	100	77.5	I	X
46	2	0	Unknown	53	86	38.5	B	X
47	1	1	Unknown	70	61	80.5	B	X
48	2	0	Unknown	18	113	73	I	X
49	1	1	CMV	58	64	64.5	H	X
50	2	0	Unknown	54	68	54.5	H	X
51	2	0	Unknown	22	91	58	I	X
52	2	0	ANSD	37	63	46.5	I	X
53	2	0	ANSD	73	34	33	H	X
54	2	0	Hypoxic Ischemia	14	92	84	H	X
55	2	0	Enlarged Vestibular Aqueduct	35	70	100	D	X
56	2	0	CMV	13	84	28	H	X