# Standardization of the Time Compressed Sentence Test

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## Abstract

**The Time Compressed Sentence Test (TCST) was developed to identify and quantify disorders of auditory processing in children. The test consists of sentences that were time compressed at 0, 40, and 60%. Standardization data was obtained from 13 beta site examiners in 7 states. One-hundred sixty three normally hearing and typically developing children between the ages of 6 and 11 years were administered the test. Statistical analysis of the first 117 children tested found significant differences between the 40% and 60% time compression conditions and for subjects by age. There were also significant differences between right and left ear scores. The implication of these analyses is that is it necessary to interpret findings using tables of norms reported separately for each age and for right and left ears. Descriptive statistics were used to identify "cut-off" scores, and then converted to standard scores and percentiles**

### Introduction

Auditory processing can be simply defined as taking the received signal and locating, transforming, analyzing, clarifying, attending to and/or storing it so that it becomes functionally useful (Katz & Wilde, 1994). In the absence of hearing loss, some children have difficulty listening in the presence of competing noise, following verbal instructions, and interpreting speech that is distorted or presented at rapid rates. These children are considered to have an auditory processing disorder (Jerger & Musiek, 2000) .

In 1993 the American Speech-Language and Hearing Association (American Speech-Language Hearing Association, 1996) convened a task force to assess best practices regarding the definition, diagnosis, and treatment of children and adults presumed to have a central auditory processing disorder. According to the task force, "central auditory processes are the auditory system mechanisms and processes responsible for the following behavioral phenomena:"

- Sound localization and lateralization.
- Auditory discrimination.
- Auditory pattern recognition.
- Temporal aspects of audition, including
  - -temporal resolution
  - -temporal masking
  - -temporal integration
  - -temporal ordering.
- Auditory performance decrements with competing acoustic signals.
- Auditory performance decrements with degraded acoustic signals.

The ASHA panel concluded that CAPD can result from a, "dysfunction of processes dedicated to audition and also may include other factors such as a general dysfunction across modalities i.e. attention deficit disorders" (American Speech-Language Hearing Association, 1996). In addition, the panel stated that CAPD might coexist with other dysfunctions. According to the ASHA panel, the diagnosis of a central auditory processing disorder is accomplished using a variety of indices. Categories of behavioral auditory measures include "low-redundancy monaural speech (time compressed, filtered, interrupted, competing, etc)."

More recently the "Report of the Consensus Conference on the Diagnosis of Auditory Processing Disorders in School-Aged Children" (Jerger & Musiek, 2000) stated that promising tests for the identification of auditory processing disorders include measures of temporal resolution. The report also states that temporal processing [is] a key dimension of auditory, especially speech processing and "monotic assessment is essential to ensure that significant ear asymmetries are detected." The implication is that testing individual ears using sensitized speech tests consisting of degraded acoustic signals is important to identify differences in ear performance that lie outside the normal range.

### Time Compressed Speech and Assessment

There are different strategies utilized to degrade a speech signal, one of which is to alter the temporal aspects of acoustic signals. As the compression ratio of the speech signal increases, there is a degradation of recognition performance (Wilson, Preece, Salamon, Sperry, & Bornstein, 1994). Wilson found that compression ratios above 50% substantially affected speech perception. These findings are consistent with earlier findings that recognition performance is most affected by compression ratios above 60% (Beasley & Freeman, 1977). For example, Beasley et al. studied 60 children who were 4, 6, and 8 years of age using the Word by Picture Identification (WIPI) Test and the PB-K 50 tests that were time compressed by 0%, 30% and 60%. Results of their study suggest that as the time compression increases, intelligibility decreases with significant deterioration occurring at 60% time compression. The NU-6 time compressed monosyllable word lists produced by Beasley, Schwimmer and Rintlemann (Beasley & Freeman, 1977) had normative data for children only for sound field presentation. None of the tests referenced above have found extensive clinical use.

The effect of speaking rate on children has been studied for words (D.S. Beasley, Maki, & Orchik, 1976) and sentences (McCroskey, 1984) . Beasley's purpose was to stress the auditory system with accelerated speech and find the point of breakdown. McCroskey advanced the view that every auditory system has its temporal limit and individuals who show "verbal disabilities" (auditory processing disorders) will reach that limit at a lower time compression rate than normal children. For example, McCroskey and Thompson (McCroskey & Thompson, 1973) studied the effect of speech rate on children with reading disorders. As a group, the children with a reading disorder required longer time to receive, appreciate, and respond to relatively short sentences that contained easy vocabulary than children who read normally. The children with a reading disorder had particular difficulty with time-compressed sentences. In spite of the promise of this early work on time-altered speech, no clinically useful time compressed sentence test is available at the time of this writing.

Time compressed speech can be utilized to assess patients with neurological deficits. Earlier, time compressed speech was used to detect neurological deficits that were undetectable utilizing only pure tone and word discrimination as an assessment of audition. Calearo, Antonelli, Bocca, and others from Milan, Italy were among the first to assess patients with cortical lesions using time compressed speech. Calearo and Antonelli (Calearo & Antonelli, 1973) report a series of experiments that found performance decrements in patients who were aging and patients with Parkinson's disease. In general, patients show reduced performance in the ear opposite a temporal lobe lesion. According to Calearo and Antonelli results of time-compressed speech in patients with central auditory pathway lesions are "wholly analogous" to those obtained with other acoustically degraded speech tests.

Techniques for assessing different temporal aspects of auditory perception include assessment of thresholds for brief tones, testing for temporal ordering and sequencing of tonal or click stimuli, gap detection thresholds, and discrimination of time compressed speech. All of these techniques find that disturbances in the temporal aspects of audition are related to cortical lesions. These findings are summarized in several references (Baran & Musiek, 1991; Olsen, 1991; Pinheiro & Musiek, 1985; Thompson & Abel, 1992). According to Grimes (Grimes, Mueller, & Williams, 1984) the presence of a peripheral hearing loss, even a mild high frequency sensorineural hearing loss, will depress test scores obtained using a time compressed speech measure.

In summary, results of research conducted over the years have established that time compressed speech including both monosyllables and sentences show reduced speech perception at increased compression rates. Speech perception is especially affected above 50% time compression. The tests show expected contralateral ear effects, with reduced performance opposite a hemispheric lesion. Recent interest in the development of degraded speech tests of auditory function for purposes of identifying auditory processing disorders has created a need for a standardized time compressed sentence test. The purpose of this paper is to report on the standardization of a new test of degraded speech, the Time Compressed Sentence Test (TCST).

## Method

### TCST Description and Subtests

*Description*

The TCST is made up of three subtests with 0%, 40% and 60% time compression. The test is presented at a most comfortable listening level or, if hearing is normal at 55 dBHL. The subtests are described below:

**Subtest 1** is a practice and preliminary screening list consisting of 10 sentences with zero time compression (a normal rate of speech). These sentences are used to assure that the child is able to repeat a sentence of the length used. Since all subjects in the normative database typically had 100% response to the practice items, there are no normative data for this subtest.

**Subtest 2** consists of two lists of ten sentences that are presented at 40% time compression. These sentences are presented to each ear separately.

**Subtest 3** consists of two lists of ten sentences that are presented at 60% time compression. These sentences are presented to each ear separately.

*Technical Specifications and Recording*

Test materials were adopted from the sentence tests from the Manchester University Test A developed by Watson (Watson, 1957) that were patterned after the earlier sentence test of Fry and Kerridge (Fry & Kerridge, 1939). The sentences were developed for testing the discrimination of hearing impaired children in Great Britain. The test items were slightly modified for word familiarity in the United States. The sentences are of equal difficulty and, according to Watson," each contains nouns and verbs of well-selected phonetic composition."

The sentences were recorded using a male speaker with a general American dialect in the studios of AUDiTEC™ of St. Louis, and digitized directly to hard disk. The sentences were edited for equivalent level, employing a standard VU meter on Cakewalk Pro Audio 9 software installed on a Compaq computer. Time compression was achieved by employing a plug-in available in the Cakewalk Pro Audio 9 software package. To obtain 40% compression one recording was required. To obtain 60% compression, two recordings of 50% and 10% were necessary since the software does not compress beyond 50%. Finally, interstimulus intervals were adjusted to 5 seconds. The TCST is 8 minutes long and takes less than 15 minutes to administer and score

*Selection and qualification of examiners*

Thirteen licensed audiologists in 7 states volunteered to participate in gathering normative data. Two were in private practice, 3 were in hospital settings, 4 were in university settings, and 4 were educational audiologists.

In return for their efforts, the external examiners received a Time Compressed Sentence Test CD, and a copy of the normative data and manual. All examiners were provided with a Beta CD, score forms, and instructions for administering the test. They were also provided criteria for subject selection, exclusion criteria and instructions for administration of the test. Each Beta site examiner was responsible for obtaining local IRB approval. This investigator obtained IRB approval at the University of Cincinnati and the Cincinnati Board of Education.

*Subjects*

The subjects included in the standardization study included 78 children between the ages of 6 and 11 years. Subjects were assigned to one of five groups by age from 6-0 to 6-11, 7-0 to 7-11, 8-0 to 8-11, 9-0 to 9-11, and 10-0 to 11-11 years. The total group of subjects in the normative database included 34 males and 44 females. The 78 children included: 57 who were Caucasian, 10 were Hispanic, 10 were African American, and 1 Native American. The number of subjects in each group is shown in Table 1. At the time of the testing, the audiologists administering the test filled out a questionnaire providing information on participating subjects. This information helped to categorize each child's diagnostic status.

**Table 1: Summary table of the number of males and females in each group on whom statistical testing was conducted and normative data developed (N=78).**

| Age | Male | Female | Caucasian | African American | Hispanic | Asian | Native American | Total |
|---|---|---|---|---|---|---|---|---|
| 6 | 8 | 8 | 14 | 2 | 0 | 0 | 0 | 16 |
| 7 | 5 | 7 | 10 | 0 | 2 | 0 | 0 | 12 |
| 8 | 2 | 8 | 7 | 3 | 0 | 0 | 0 | 10 |
| 9 | 8 | 10 | 12 | 1 | 5 | 0 | 0 | 18 |
| 10 to11 | 11 | 11 | 14 | 4 | 3 | 0 | 1 | 22 |
| | | | | | | | | |
| | 34 | 44 | 57 | 10 | 10 | 0 | 1 | 78 |

All children who were tested met the following criteria:

a. Hearing within normal limits (0-15 dBHL) at frequencies 500, 1000, 2000 and 4000 Hz.
b. Normal tympanometry with a notch shaped tympanogram and middle ear pressure between 0 and -200 daPa.
c. Normally achieving with subjects attending a regular classroom. No subject in the normative database had a diagnosis of ADD, language disorder, learning disability, or auditory processing disorder.
d. Possess the cognitive ability to understand the instructions and to repeat a sentence of 4 to 5 words.
e. Native English speaker.

Prior to experimental testing, children were administered a pure-tone hearing test and tympanometry.. A history was obtained to rule out a diagnosis of ADD, language disorder, learning disability, or auditory processing disorder. The children were also screened to determine that they possessed the cognitive ability to follow instructions and repeat the sentences. After pre-experimental testing, if children met the criteria for inclusion as a subject, experimental testing was initiated.

*Administration and Scoring: Test Procedure*

Prior to administering the TCST subjects were administered a pure tone threshold test and tympanometry. The TCST norms were obtained on subjects with normal hearing and tympanometry. There are no data currently available to interpret results obtained on subjects with either conductive or sensorineural hearing loss.

Examiners were instructed to administer the test at the subject's most comfortable listening level (MCL). If the MCL could not be determined the test was administered at 55 dB HL. The first 10 sentences were for practice, to assure that the child was able to repeat a sentence of the length used in the test. The practice sentences were administered binaurally, or with five sentences to each ear. The practice sentences were not scored. Then the examiners tested one ear for lists one and two at 40% and 60% time compression and opposite ear for lists three and four at 40% and 60% time compression. They were instructed to administer rotate the first ear tested between the right and left ear for alternating subjects.

The child was instructed to listen carefully, to repeat all of the words in the sentence, and to take a guess if they were not sure. Children who were unable to repeat the practice sentences were to be excluded from the study, but no child failed the practice sentences. During testing examiners were instructed not to pause the test between sentences to allow the child more time to respond. They were allowed to pause the test briefly between lists.

Beta site examiners did not score the test results. All score sheets were forwarded to the author who scored the findings. The results were scored as follows:

Each sentence is divided into three parts consisting of a subject, verb, and an object. These parts are divided by hash marks on the score form. Each part is scored separately giving the possibility of three errors per sentence. When the child missed one of the content words in the sentence it constituted an error. Errors in articles of speech such as "the" and "a" were not considered an error. The total number of errors was converted to a percent correct.

## Results

*Statistical Analysis*

Statistical analyses and normative data were based on 78 subjects. Although substantial additional data were obtained we limited the number of subjects to 78 in order to have an equal number at each age level of right ear tested first and left ear tested first.

Results of statistical analyses found that there was a significant difference between 40% and 60% time compression ($p < 0.001$) and age ($p < 0.001$) with a significant interaction between time compression and age ($p < 0.008$). There was no significant difference between the right and left ear scores at 40% time compression ($p < 0.87$) or 60% time compression ($p < 0.61$). There was also no significant Ears X Age interaction ($p < 0.123$). The implication of these analyses is that is it necessary to interpret findings using tables of norms reported separately for each age and condition of time compression.

**Table 2: Summary table of Descriptive Statistics of right ear vs. left ear grouped across time compression. The table includes the Mean and SD of performance by age for the right and left ears with equal numbers of subjects in each age group with right ear tested first and left ear tested first (N= 78).**

| Ear | Age | 40% TC % Correct | 40% TC SD % | 60% TC % Correct | 60% TC SD % | N |
|---|---|---|---|---|---|---|
| Right | 6 | 93.4 | 8.9 | 75.5 | 16.4 | 16 |
| | 7 | 96.7 | 4.2 | 86.5 | 8.9 | 12 |
| | 8 | 95.7 | 4.1 | 84.8 | 10.5 | 10 |
| | 9 | 95.6 | 4.4 | 81.5 | 12.2 | 18 |
| | 10 & 11 | 99.5 | 1.3 | 92.0 | 3.5 | 22 |
| | | | | | | |
| Left | 6 | 83.4 | 6.3 | 75.5 | 11.9 | 16 |
| | 7 | 96.7 | 3.7 | 85.7 | 9.5 | 12 |
| | 8 | 96.0 | 4.9 | 82.8 | 9.8 | 10 |
| | 9 | 97.4 | 3.0 | 81.1 | 8.6 | 18 |
| | 10 & 11 | 98.4 | 3.5 | 90.4 | 6.5 | 22 |

*Development of Norms and Interpretation of Results*

Descriptive statistics were calculated for the right ear and. the left ear across time compression for each age group. The percent correct along with the standard deviation and the number of subjects in each age group is presented in Table 2. In general the percent correct is greater and the standard deviation of responses is smaller with increasing age. The SD was substantially smaller for 40% time compression compared to 60% time compression.

Normative data for the TCST were developed for 1-year intervals from 6 years, 0 months, to 9 years, 11 months, and one combined age group for 10 and 11 year olds (10 years, 0 months, to 11 years, 11months). These data are presented in the *Examiners Manual* (Keith, 2002) . Cut-off scores are suggested for children who have borderline and abnormal auditory processing abilities for the TCST. The cut-off scores are based on >1.0 standard deviation that represents borderline performance and >1.5 SD that represents abnormal performance. This decision is based on the premise that -1 SD is the 16th percentile and -1.5 represents approximately the 7th percentile in a normal distribution. A more conservative cut-off score of -2 SD (the 3rd percentile of performance) would have greater test specificity with poorer test sensitivity. That is, using -2 SD as a cut-off results in a smaller chance of identifying a child as abnormal when that child is actually normal. However, the "down-side" of using -2 SD is that some children who are abnormal will be considered to fall in the "borderline" category. In the end the examiner needs to adopt a cut-off score (and a hit-miss rate) with which they are comfortable.

Percentile ranks for each age group were converted to normalized z scores and then to standard scores with a mean of 100 and a standard deviation of 15. Finally, TCST standard scores may be converted to a percentile rank using the tables presented in the *Examiners Manual* (Keith, 2002). The advantage of standard scores is that it is a scoring scale common to psychoeducational batteries. It enables examiners to directly compare relative rankings of performance across tests (e.g., standardized tests of auditory processing, language, and intelligence) standardized on the same populations and provides information about test-retest performance. Using standard scores, examiners can determine normal, borderline, and disordered performance by setting their own criteria.

*Interaural asymmetry*

A second aspect of test result interpretation includes evaluation of the right and left ear differences to ensure that abnormal ear asymmetries are identified (Jerger & Musiek, 2000). There is no "gold standard" for identifying ear asymmetries so this author suggests that differences of greater than two standard deviations will assure an appropriate test sensitivity and specificity. To that end tables are provided in the *Examiners Manual* (Keith, 2002) to determine whether a child's interaural performance is within normal limits.

**Discussion**

In summary, standardization of the Time Compressed Sentence Test (TCST) is presented. The results of the TCST standardization sample indicated that:

1. Raw scores of percent correct for each age group increased with age as the standard deviation decreased.
2. There was a significant difference between conditions of time compression with substantial greater number of errors for the 60% time compression compared to 40% time compression for each age group.
3. There was nosignificant difference between the right and left ear scores nor was there a significant ears by age interaction.
4. The raw scores were converted to z scores and percentiles for comparison to other standardized auditory, language, and intelligence tests.

The time compressed sentence test is a behavioral sensitized speech test delivered monaurally (one ear at a time) at a comfortable listening level. The test is designed to measure a child's response to meaningful sentences that are presented at 0%, 40%, and 60% time compression. At the time of this writing the only standardized time compressed test available utilizes monosyllable words. We believe that time compressed sentences are a more realistic stimuli since they represent typical speech more normally. For example, Calearo and Antonelli (1973) stated that "The use of meaningful sentences offers major advantages with respect to isolated words. . . . . Meaningful sentences approach in a more realistic way everyday speech since the influence of factors that might increase the intersubject variability such as intelligence, skill, vocabulary, and dialects is reduced." The purposes of the TCST include assisting in the diagnosis of an auditory processing disorder and describing the child's functional communication, specifically the child's ability to understand acoustically degraded or rapid rates of speech. Children with behaviors and histories consistent with an auditory processing disorder may benefit from administration of the Time Compressed Sentence Test. In addition, children who fail the TCST should be administered a Random Gap Detection Test (RGDT) to determine whether the poor performance is based on (a) a temporal processing disorder in which case the RGDT results would be abnormal or (b) because of a poor ability to perform on tasks of degraded speech. Finally, results of testing with this measure may yield insights into behaviors of children with slow reaction times and speed of auditory processing. The test can also be used as an adjunct to electrophysiologic and imaging studies in determining the site of lesion in the auditory system.

Persons using this test should note that while time compressed speech is altered in the time domain, it is not solely a test of temporal processing abilities as is the case with gap detection threshold tests. Time compressed speech tests, in the opinion of this author, are measures that fall in the category of "Auditory performance decrements with degraded acoustic signals" (American Speech-Language Hearing Association, 1996) although they may also identify children who have difficulty with auditory temporal resolution. Understanding of the sentences is based on the child's ability to interpret rapidly changing acoustic features where speech perception is based on mapping acoustic features into linguistic representations.

Implications for remediation

In a chapter on auditory processing disorders Keith and Fallis (1998) suggest an algorithm for remediation based on results of tests of auditory processing. That model is summarized below.

Remediation algorithm based on results of central auditory tests (Keith & Fallis, 1998)

| | |
|---|---|
| Disorder of temporal processing identified by reduced performance on gap-detection tests | Perceptual training (modify speaker rate, auditory discrimination, phoneme training, computer assisted remediation. |
| Disorder of auditory figure ground or other monaural degraded speech test including filtered words and time-compressed speech | Reduce noise in environment. Classroom management including preferential seating. Use of FM system or other assistive listening device |
| Disorders of binaural separation/maturation found on dichotic tests | Receptive and expressive language remediating usually provided by a speech-language pathologist |

The model suggests that children who have difficulty with low-redundancy speech including speech in the presence of background noise (with poor signal to-noise ratios), speech that is distorted in the frequency domain (filtered speech), or time altered speech (time compressed speech) require classroom management to compensate for their reduced listening skills.

Unproven but conventional approaches for adapting the classroom environment for children with auditory processing disorders are available in many resources. Our understanding of children who fail the TCST is that they have general difficulty with acoustically degraded speech, and will likely have problems in many listening situations. The test will not lead to "cook book" approaches to remediation. Nevertheless, some specific suggestions for children who fail the TCST include:

- Slow the rate of speech presented to the child to facilitate auditory perception
- Slowing the speech rate may give the auditory system an opportunity to perceive those features that have eluded the child during more rapid productions.
- Reduce background noise that masks available rapid acoustic transients in the speech signal.
- Present smaller "chunks" of information.

Finally, as with all central auditory assessment, the Time Compressed Sentence Test is to be used as a part of a test battery. No individual test is sufficient for the diagnosis of APD.

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