Problem-Solving Ability in Elementary School-Aged Children with Hearing Impairment

Donna Fisher Smiley, PhD
Arkansas Children's Hospital and Conway Public Schools, Conway, Arkansas

James W. Thelin, PhD
University of Tennessee, Knoxville, Tennessee

Dee M. Lance, PhD
University of Central Arkansas, Conway, Arkansas

Robert A. Muenchen, MS
University of Tennessee, Knoxville, Tennessee

The present study was conducted to evaluate the problem-solving ability of children with hearing impairment. The performance of a group of children with hearing impairment (HI Group) was compared to that of a group of children with normal hearing (NH Group). The participants were asked to solve two types of mathematical problems: those requiring computation alone and word problems requiring the use of both language and mathematical computation. The results of this study revealed that there were no significant differences between the HI Group and NH Group in the ability to solve mathematical equations involving the use of language and mathematical computation problems. Additionally, it was found that problem-solving ability was related to language ability, but not to hearing ability in the children with hearing impairment.

Introduction

In the United States educational system, a majority of children with hearing impairment who use an aural/oral mode of communication are mainstreamed into conventional schools rather than receiving their education in special schools for the deaf or hearing impaired. As a part of the assessment of educational abilities and needs in the mainstream, these children are evaluated using standardized measures of intelligence, language ability, and academic achievement. Special intervention is provided when achievement or abilities are found to be below expectations on these standardized measures. Existing standardized measures provide a description of specific abilities and disabilities of children with hearing impairment. However, in most cases, these measurements provide minimal information about how the impairment may affect the child's ability to learn, to apply knowledge, and to function in the school environment.

Successful functioning depends on the ability to solve a variety of problems to assist the individual in reaching diverse goals. New problem-solving skills are acquired at each stage of the developmental and educational process. In the present study, the interest was on the ability of children with hearing impairment to apply knowledge by solving problems that were relevant to the child and required the use of different processes than the tasks used on standardized intelligence and language tests. The primary issue was to determine if the cognitive function of children with hearing impairment differs from children with normal hearing on higher-level tasks that require or do not require the use of language.

Function and Disability

Over the past several decades, research has been conducted by individuals and the World Health Organization (WHO) on the description of function and dysfunction and on the methods for assessing functional outcomes for person with disabilities (Granger, 1984; Nagi, 1965,1991; Pope & Tarlov, 1991; WHO, 1980, 1997, 1999, 2000, 2001). To determine functional outcomes for a person with hearing impairment, the description of the disability begins with the specification of the disability in terms of hearing, but it extends to the effects of hearing impairment on all other aspects of functioning. For example, hearing impairment may affect the ability to measure intelligence, and it may also affect the acquisition of knowledge. It may affect the ability to acquire language, which in turn may affect any activity requiring the use of language. Thus, improvement of functional outcomes for children with hearing impairment depends on an understanding of the consequences of hearing impairment for a wide range of activities that are essential for functional adequacy.

The WHO (2001) developed the *International Classification of Functioning and Disability* (ICF), which is a general system for classifying and listing the consequences of all types of impairments. An individual's ability to function can be viewed from an individual perspective and from a societal perspective. The individual perspective involves the execution of a task or action by a person. The societal perspective is the involvement of a person in a life situation (WHO, 2001). The application of this system to hearing impairment reveals that the consequences of hearing impairment have the potential for pervasive effects on the functioning of an individual (Fisher & Thelin, 1999). The WHO model has many uses, but, in the present study, it was used to identify the aspects of function and dysfunction that were considered to be most important to children with hearing impairment.

In the WHO model (2001), the term "functioning" is used to describe the activity of and participation in fundamental life processes, such as learning, applying knowledge, communication, mobility, self-care, relationships, employment and social/ community life. Each process is composed of elements that provide a description of the multi-tiered nature of each process. For example, the process of applying knowledge includes focusing attention, thinking, reading, writing, calculating, and problem solving.

Problem Solving

Problem solving is the means by which previously acquired knowledge, skills and understanding are used to satisfy the demands of an unfamiliar situation (Krulick & Rudnick, 1988). Thornton (1995) proposed that the psychological processes necessary for problem solving are a part of a "baby's basic endowment" (p. 32). She also states that the processes used in problem solving depend on the information or knowledge base of the child. In other words, the richer the child's knowledge base, the easier it is for the child to figure out how to solve a problem.

Problem solving can be considered in the context of thinking as a whole. Several hierarchies and frameworks of thinking have been proposed (Anderson, 1983; Gardner, 1983; Johnson-Laird, 1983; Perkins, 1981). Marzano et al. (1988) proposed a framework in which thinking has four dimensions: metacognition, critical/ creative thinking, thinking processes and thinking skills. This framework, which has been diagrammed in Figure 1, illustrates that each successive dimension is embedded in the preceding dimension. Metacognition is the awareness and control over one's own thinking and includes commitment, attitudes, and attention. Critical thinking is reflective thinking that is focused on deciding what to believe or do. Creative thinking is the ability to form new combinations of ideas to fulfill a need. Thinking processes are macro-level operations involving the combination of thinking skills in predictable sequences. Examples of thinking processes are problem solving, concept formation and composing. Thinking skills are specific or micro-level operations, such as focusing, analyzing, integrating and evaluating. Thinking skills require the use of language and involve the application of knowledge. An individual cannot define a problem without having knowledge of the problem area or the language to label or describe the problem.

As there are frameworks for thinking, there have been several theories or models of problem solving proposed (Anderson, 1983; Edeh, 2007; Newell & Simon, 1972; Van Dijk and Kintsch, 1983; Wickelgren, 1974). Polya (1957) advanced a model for understanding problem solving that is widely accepted by educators. The elements of this model are the abilities to (1) understand the problem, (2) devise a plan, (3) carry out the plan and, (4) evaluate the solution. When proceeding through this problem-solving process, an individual must have a knowledge base to apply to the problem situation.

Problem Solving and Hearing Impairment

The acquisition and use of a knowledge base are dependent on language and thinking skills. Children with hearing impairment may have a diminished knowledge base and language impairment, due to decreased auditory input. In addition, the ability to apply knowledge may be affected by the presence of a language impairment in children with hearing impairment. For example, children with hearing impairment are less likely to "overhear" information. This reduction in incidental learning may result in negative consequences of knowledge acquisition (Carney & Moeller, 1998). To further compound the problem, a limited knowledge base may affect the acquisition of additional knowledge (Paul, 2007).

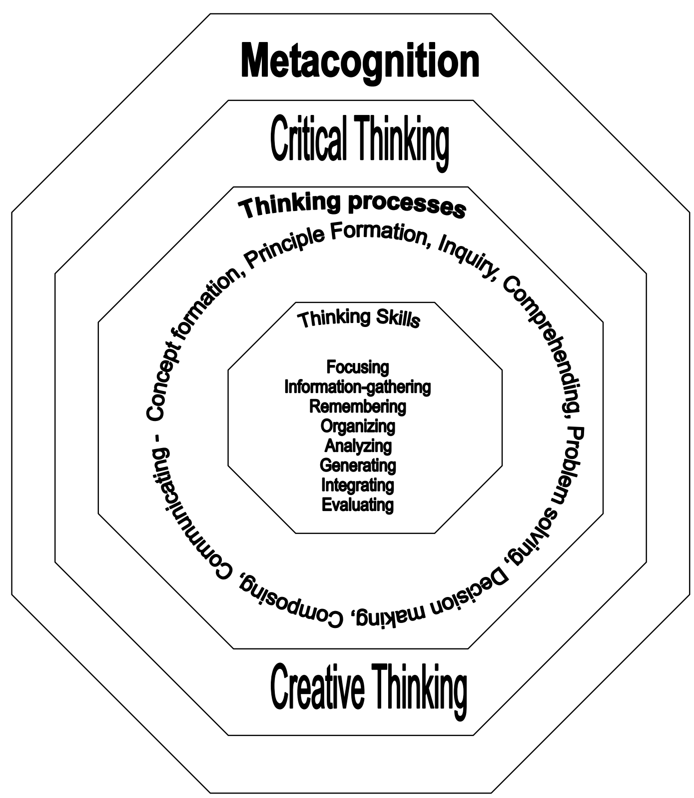

Figure 1. Framework for Developing Thinking
(Adapted from Schirmer, 2001; Based on Marzano, et al. 1988)

The most debilitating aspect of hearing impairment is not the loss of hearing, but the subsequent language impairment that may be a result of insufficient auditory input (deVillers & deVillers, 1978; Erber, 1982; Ling, 1984; McAnally, Rose, & Quigley, 1994). The central focus of educating children with hearing impairment has been and continues to be language acquisition (Easterbrooks & Baker, 2002). However, children with hearing impairment continue to demonstrate reading and writing skills significantly below those of individuals with normal hearing (Karchmer & Mitchell, 2003; Moores, 2000; Schirmer, 2000).

The degree to which language abilities are affected in children with hearing impairment depends on several factors which include the age of onset, the degree and the type of hearing impairment, the age of identification and amplification, and the amount and type of habilitation (Lenneberg, 1967; McKay, Sinisterra, McKay, Gomez, & Lloreda, 1978; Quigley & Kretschmer, 1982; Yoshinaga-Itano, Sedey, Coulter & Mehl, 1998). The language impairment that is a consequence of hearing impairment may affect the development of all components of language: phonology, syntax, semantics, pragmatics, reading, and writing (Paul, 2007).

In spite of hearing and language impairments, children with hearing impairment are not considered to be cognitively impaired. Standardized measures of intelligence contain a verbal section and a performance section. The combination of the scores from these two sections yields a full scale intelligence quotient (IQ) and component scores: verbal intelligence quotient (VIQ) and performance intelligence quotient (PIQ). For individuals who are hearing impaired, the VIQ is almost always poorer than the PIQ with the VIQ usually being lower than the normal limit (Ross, Brackett, & Maxon, 1991). It can be assumed that the VIQ is affected by the language impairment, which is the consequence of a hearing impairment. Therefore, the PIQ provides a measure of intelligence that minimizes the effect of the language deficit. When the PIQ is used alone as a measure of cognitive ability, there is evidence to suggest that no major quantitative differences exist in the range of cognitive abilities between individuals who are deaf and individuals who have normal hearing (Braden, 1984; Braden, 1994; Zwiebel, 1991).

Data from numerous investigators indicate that, on the average, children with hearing impairment are behind their hearing peers in academic achievement (Brackett & Maxon, 1986; Hine, 1970; Karchmer & Mitchell, 2003; Marschark, 2006; Meadow-Orleans, 2001; Moores, 2003; Nunes & Constanza, 1998; Paul & Young, 1975; Peckham, Sheridan, & Butler, 1972; Quigley & Thomure, 1968; Steer et al., 1961; Swanwick, Oddy, & Roper, 2005; Trybus & Karchmer, 1977). However, the body of literature about problem-solving skills in children with hearing impairment is small. Several investigators have recognized that children with hearing impairment have difficulty functioning outside of the educational environment (Greenburg & Kusche, 1989; McGehee & Prendergrass, 1979; Martin, 1984; Rohr-Redding, 1985). It is their interpretation that these children have poor problem-solving skills, although this interpretation was made without the benefit of formal assessment. To teach problem solving, they implemented intervention strategies demonstrating that children with hearing impairment proceed through the same stages of cognitive development as children with normal hearing. However, the children with hearing impairment in these studies were not compared directly to children with normal hearing. Therefore, it is not known whether children with hearing impairment ever achieve the same level of problem-solving ability as their hearing peers.

Luckner and McNeill (1994) compared the problem-solving ability of children with hearing impairment to those of children with normal hearing on a formal test of logic called the Tower of Hanoi -- a task with considerable complexity. Because the task requires minimal use of language (as is the case for the performance portion of an IQ test), it was expected that the children with hearing impairment would perform similarly to their peers without hearing impairment. The results of this study revealed that the children with hearing impairment were delayed in their ability to solve problems when compared to their hearing peers.

The ability to apply knowledge is a component of functioning. Problem solving is one form of the application of knowledge. Luckner and McNeill (1994) found that children with hearing impairment performed significantly poorer than their hearing peers when performing a nonverbal problem-solving task. The two groups were not equated on language because the task was non-linguistic; however, if language has a relationship to problem-solving ability, a difference in language ability could explain the results of the study.

A different approach to studying problem solving was a single participant study by Fisher (2000), who was interested in the ability of the parent and the teacher to estimate the problem-solving ability of a child with hearing impairment. She found that on a language-based problem-solving test, the child in the study did very poorly. This was in marked contrast to the report of the teacher and the parent who indicated the child's problem-solving skills were good. This suggests that informal impressions of problem-solving ability may not be accurate even by individuals who know the child well. Although the participant in this study exhibited a moderate language delay, her scores were poorer on the language-based problem-solving test than other children with comparable language impairments. Based on this finding, it was hypothesized that children with hearing impairment would have more difficulty on the language-based problem-solving test than other children with similar language abilities.

Vaden (2001) measured the language-based problem-solving test scores of children with hearing impairment and related them to language ability and vocabulary. On average, problem-solving ability was one standard deviation below the mean with a wide range of performance from above normal to well below normal on the tests. However, Vaden found that the performance on the language-based test of problem solving could be predicted with great accuracy from combined measures of receptive language, expressive language and receptive vocabulary. These results suggest that children with hearing impairment may have good problem-solving skills if their language and vocabulary skills are also good.

In summary, the literature on problem solving in children with hearing impairment provides an incomplete description of the factors of greatest importance. Informal estimates of problem solving may be misleading (Smiley & Welch, 2004). Children with hearing impairment perform poorer than their hearing peers on non-verbal problem-solving tasks; however, language ability may be the missing factor (Luckner & McNeill, 1994). Language-based problem solving appears to be related to language ability and especially receptive vocabulary (Vaden, 2001).

The present study was conducted to extend the understanding of the effects of hearing impairment on problem-solving ability – a functional skill requiring the application of knowledge. Participants with hearing impairment were required to solve mathematical problems that involved and did not involve the use of language. The performance of these participants was compared to participants who had no hearing impairment and who had comparable PIQs and language quotients (LQs). The primary research questions were as follows: Does the ability of children with hearing impairment differ from the ability of children with normal hearing to solve mathematical problems requiring computation alone? Does the ability of children with hearing impairment differ from the ability of children with normal hearing to solve mathematical word problems requiring the use of both language and mathematical computation?

Methods

Participants

The participants in the present study were two groups of school-aged children with 13 in each group. The experimental group was composed of children with hearing impairment (HI Group). The control group was composed of children with normal hearing (NH Group). The two groups were matched on gender, grade level, intelligence and language ability. The descriptive statistics for each qualification parameter for both groups are presented in Table 1. The criterion level for significance was $p = .05$ for these tests and all subsequent statistical tests.

All participants were from monolingual homes in which English was the only language spoken. Participants were selected who had no known physical or mental disabilities other than those considered in the present experiment. The participants were enrolled in the 4th, 5th or 6th grade in a regular school.

Table 1. Summary statistics for participant qualification tests.

	HI Group	**NH Group**	**HI – NH Difference**
Sex	7 males; 6 females	7 males; 6 females	
Grade			
4th	5	7	
5th	4	4	
6th	4	2	
Mean Age ± SD (Range)	10.38 ± 1.12 (9-12)	10.15 ± .80 (9-11)	0.23 $t(24) = 0.60$, $p = 0.55$
Mean LQ ± SD (Range)	84.69 ± 18.9 (50-112)	88.46 ± 17.98 (55-115)	-3.77 $t(24) = -0.52$, $p = 0.60$
Mean PIQ ± SD (Range)	102.77 ± 11.90 (84-130)	98.54 ± 6.57 (83-107)	4.23 $t(24) = 1.12$, $p = 0.27$
Mean PTA ± SD (Range)	61 ± 11.54 (45-88)	N/A	N/A

Note: SD = standard deviation; PTA = pure tone average

All participants in this study were required to have normal nonverbal intelligence or PIQ, as measured by the *Wechsler Intelligence Scale for Children – III* (WISC-III; Wechsler, 1991). The WISC-III is commonly used in school standardized testing as an evaluation instrument for intelligence. Normal PIQ was defined as an IQ score within the low average to above average range. PIQ scores were obtained either from a participant's academic record or from the administration of the WISC-III by a licensed psychological examiner as a part of this study. As shown in Table 1, the mean PIQ scores were not significantly different for the two groups.

All participants were evaluated for language ability using the *Clinical Evaluation of Language Fundamentals* (CELF-3: Semel, Wiig, & Secord, 1995), which is a test of receptive and expressive language. The CELF-3 is one of the most commonly used tests by speech-language pathologists in school settings. Language was considered to be impaired if the standard score was more than 1.25 standard deviations below the mean (standard score ≤ 81). Language quotient (LQ) scores were obtained either from a participant's academic record or from the administration of the CELF-3. If the student had not been given the CELF-3 within nine months prior to participation in the study, a speech-language pathologist, a trained graduate student in speech-language pathology or the primary investigator administered the test. Five of the 13 participants in each group were considered to have a language impairment based on the LQ score while the other eight participants in each group had normal language ability. As shown in Table 1, the mean LQ scores were not significantly different for the two groups.

In the HI Group, the degree of hearing impairment was determined by using the average of the pure tone air conduction thresholds at 500, 1000, and 2000 Hz in the better ear. Participants in the HI Group had hearing impairments ranging in degree from moderate to severe (Table 1). In addition, the following descriptions applied to each participant in the HI Group:

1. Hearing impairment was either known or assumed to be a congenital impairment;
2. Amplification was worn on a regular basis as reported by the participant and/or the parent;
3. Oral communication was the primary mode of communication; and
4. Education was provided in a regular school rather than a special school for the deaf.

The participants in the NH Group were given a pure tone hearing screening (500, 1000, 2000 and 4000 at 20 dB HL). Each participant passed the hearing screening at all frequencies in both ears.

Problem-Solving Materials and Procedures

The problem-solving test used for the present study was constructed of problems that were taken from a math series, *Math Advantage* (Burton et al., 1999) published by Harcourt Brace. *Math Advantage* is based on Polya's (1957) approach to problem solving. The key words -- understand, plan, solve and look back -- are used in every lesson as a method to teach the thinking process to students. Each textbook in this series for Kindergarten through 8th grade is accompanied by a separate problem-solving workbook.

In the construction of the test for this study, word problems were selected from each of the problem-solving workbooks for 2nd – 8th grade. Problems were selected from the 2nd - 8th grade workbooks to develop a problem-solving test with a level of difficulty below and above the grade level of each of the participants in this study (4th – 6th grade). For each workbook, problems were chosen to represent a distribution of information covered throughout each grade level.

The problem-solving test contained two types of math problems. The following is an example of a word problem: "Sue has eight pencils. She gives four of the pencils to Bob. How many pencils does Sue have left?" Each computation problem was constructed to match a word problem in the mathematical computations to be performed and in the computational difficulty. For the example above, an equivalent computation problem would be (7 – 3 = ___). Each part of the test contained 21 problems (three from each grade level) for a total of 42 problems. Within each of the two parts, problems were arranged progressively in grade-level order. That is, for both the computation and the word problem tests, the 2nd grade problems were at the beginning of the test with each successive grade level following up to the 8th grade problems.

The word problems contained in the test were analyzed for readability using the Flesch-Kincaid Grade Level Formula (Flesch, 1948). The readability for all sets of problems was either at or below grade level from which they were chosen.

The experimental procedures and instructions that were adopted for the administration of the mathematical test items were based on the observation of participant performance and on data obtained in a pilot study. Participants were allowed to have as much time as they needed for each part of the test. Participants were not allowed to use calculators while completing the test. The investigator had the participants read the first two word problems aloud. After this point, the participants were allowed to read the problems without assistance but were instructed to ask for help if there was a word that was unknown. Each participant was encouraged to show his/her work for each problem. All questions had a single answer and were scored as either correct or incorrect.

Vocabulary Assessment

After a child satisfactorily completed the requirements for participation in this study, the *Peabody Picture Vocabulary Test – Third Edition* (PPVT-III; Dunn & Dunn, 1997) was administered. The PPVT-III is a test of receptive vocabulary used to assess receptive semantic ability. Children with hearing impairment typically receive PIQ testing and language testing in a school setting; however, vocabulary testing is not routinely performed. Vaden (2001) found that language-based problem-solving ability could be predicted by using receptive vocabulary, receptive language and expressive language scores. For this reason, the PPVT-III was used, not as a means of qualifying participants, but as an additional language test that might be related to the problem-solving ability of the children with hearing impairment in the present study. The PPVT-III was administered by the primary investigator or a trained graduate student in speech-language pathology.

Experimental Test Protocol

Parents of potential participants were contacted by professional acquaintances (e.g., speech-language pathologists, teachers, and audiologists) of the investigator. If the parent agreed to be contacted, the investigator was given the name of the parent. Prior to being selected to participate in this study, each parent completed a questionnaire to ensure that the potential participant met the qualifications for the study. The parent/guardian also completed an informed consent form giving permission for their child to participate in the study. Each child gave assent to participate in the study.

Each child in this study participated in a single test session ranging in time from 60 to 180 minutes. In all testing sessions, snacks and frequent breaks were given to minimize participant fatigue. The testing sessions were divided into three sections: problem-solving tests, language tests, and intelligence test. The order of presentation of the sections was counterbalanced among participants. In addition, the order of the presentation of the computational test and the word problem test was counterbalanced among participants. The vocabulary and the problem-solving tests were administered to all of the participants as a part of the study. The PPVT-III took approximately 15 minutes to administer. The problem-solving tests took approximately 45 minutes for the participants to complete. Additionally, for the participants who needed to complete language testing and/or an intelligence test, it took approximately 60 minutes for each of these tests to be administered.

Data Analysis

An independent samples *t*-test was used to determine if there were differences among the groups on the qualification criteria of PIQ and LQ. One sample *t*-tests were used to determine if the group means for PIQ and LQ were significantly different from the test means of 100. A multivariate analysis of variance (MANOVA) was used to determine differences between the performance of the HI Group and the NH Group on the computational problems and the word problems. Additional analyses were made using a multiple linear regression.

Results

Descriptive Measures of the HI and NH Groups

Qualification tests (PIQ and LQ) were used to match the HI and NH Groups in the present study. These tests also provide a description of the level of functioning of the two groups. The mean PIQ was 103 for the HI Group and 99 for the NH Group. Neither of the mean scores for PIQ was significantly different from the mean standard score of 100 [HI Group: $t(12) = .839$, $p = .418$; NH Group: $t(12) = -.803$, $p = .438$]. For language, the mean LQ was 85 for the HI Group and 88 for the NH Group. Although these scores are within normal limits using accepted clinical criteria, they are significantly lower than the mean standard score of 100 [HI Group: $t(12) = -2.920$, $p = .013$; NH Group: $t(12) = -2.314$, $p = .039$].

The mean vocabulary test score was 86 for the HI Group and 94 for the NH Group. These scores are not outside the normal range using accepted clinical criteria; however, they are significantly lower than the mean standard score of 100 [HI Group: $t(12) = -2.198$, $p = .048$; NH Group: $t(12) = -2.174$, $p = .050$]. Thus, PIQ for the HI Group and NH Groups is not different from normal; however, the scores are significantly lower than the mean standard score for LQ and vocabulary for both groups.

Problem-Solving Abilities

A summary of the data for the problem-solving tasks for the HI and NH Groups is shown in Table 2. The number of correct answers ranged from 2/21 to 19/21, which indicates that there were no end effects due to either total failure to perform the task or perfect performance. On average, participants in the HI Group scored slightly better than the participants in the NH Group for both tasks.

The difference in performance for the HI and NH Groups was analyzed using a MANOVA that had one factor (group) with two

Table 2. Summary data for the HI Group and the NH Group on the computational and word problems tests.

	HI Group	**NH Group**	**HI – NH Difference**
Mean COMP $\pm$ SD (Range)	9.92 $\pm$ 4.42 (5-18)	8.54 $\pm$ 2.93 (4-14)	$F = (2, 23) = 0.497$
Mean WORD $\pm$ SD (Range)	8.54 $\pm$ 5.29 (2-19)	7.46 $\pm$ 4.03 (3-17)	$p = .615$

Note: The scores are reported as number of items correct with a possible maximum score of 21.
COMP = computation problem test; WORD = word problem test

levels (HI or NH) and two dependent variables (computation and word problems). There was not a significant difference between the HI Group and the NH Group for either the word problem scores or the computation problem scores [F (2, 23) = 0.497, p = .615]. These results indicate that problem-solving ability is not different for these groups.

The computation problem test and the word problem test were designed to be equivalent in respect to the mathematical operations to be performed and in computational difficulty. However, the word problem test had the added factor of language. The correlations between the computation problem test score and the word problem test score were significant and strong for both the HI Group (r = .889; p = .000) and the NH Group (r = .759; p = .003). These correlations indicate that performance on the computation problem test and the word problem test were related despite the added component of language in the word problems.

The scores on the word problem test were lower than the scores on the computation problem test for both groups. In the HI Group, the score on the word problem test was 14% lower, and in the NH Group, it was 13% lower. When the difference between the computation problem test and the word problem test was considered independently for each group, the difference was not significant. However, when the results for the two groups were pooled, the computation problem test scores were significantly better than the word problem test scores [$t(25)$ = 2.524, p = .018].

Relationship of Degree of Hearing Impairment to Other Measures

The attempt was made to determine if there was a relationship between degree of hearing impairment and any of the other measures of participant performance in the present study. Pearson product-moment correlation coefficients were calculated between measures of participant performance and degree of hearing impairment. Hearing loss was not significantly related to the ability to solve computation problems (r = .302; p = 1), the ability to solve word problems (r = .102; p = 1), PIQ (r = -.137; p = 1), LQ (r=-.170; p = 1) or receptive vocabulary (r = -.072; p = .815).

Predicting Problem Solving

A multiple regression analysis was performed to determine the ability to predict problem-solving ability using PIQ, LQ and vocabulary. The advantage of the multiple regression over correlations is that the contributions of all of the factors are considered simultaneously. It was found that the PIQ score did not contribute significantly to the predictions and, therefore, it was dropped as one of the predictive tests. When the LQ and vocabulary scores were used as the predictors in the regression analysis for both parts of the problem-solving test, the analysis yielded the following equations:

HI Group:

predicted computation problem score =

2.653 + .214 (vocab) - .131 (LQ) [R = .749]

$F(2,10)=6.375$, $p=.016$

predicted word problem score =

-6.726 + .240 (vocab) - .062 (LQ) [R = .892]

$\mathbf{F}(2,10)=19.369$, $p<.0005$

NH Group:

predicted computation problem score =

3.606 -.095 (vocab) + .157 (LQ) [R = .771]

$F(2,10)=7.343$, $p=.011$

predicted word problem score =

-13.296 + .124 (vocab) + .103 (LQ) [R = .710]

$F(2,10)=5.074$, $p=.030$

Based on adjusted r^2 scores, the relationship between the performance on the computation test and LQ and vocabulary explain a similar amount of variance for each group. In the HI Group, LQ and vocabulary account for 47% of the variability in the performance on the computation test. In the NH Group, LQ and vocabulary account for 51% of the variability in the performance on the computation test.

The performance on the word problem test is related more strongly to language and vocabulary in the HI Group than in the NH Group. For the HI Group, language and vocabulary account for 75% of the variability in the performance on the word problem test. In the NH Group, language and vocabulary account for only 40% of the variability in the performance on the word problem test.

Discussion

When the primary investigator in the present study served as an educational consultant to public schools, there was a concern that PIQ and LQ scores were being used to determine whether or not children with hearing impairment needed support services in order to function in the regular classroom. Children with hearing impairment were achieving scores within the normal limits on comprehensive language assessments, as well as on the performance section of an IQ test. However, when these children, who were assessed as having normal language and PIQ, were asked to function in the regular classroom without the support of the speech language pathologist or other support staff, they were not able to do so successfully. As a result, there was the concern that PIQ and LQ may not adequately represent the level of functioning of children with hearing impairment.

In an effort to understand the relationship between formal test scores (i.e., intelligence and language) and the aspects of functioning that might be expected in an educational setting, the investigators in the present study used the WHO ICF model of functioning and disability (2001). In this model, PIQ and LQ scores would be considered to be descriptions of an individual at the impairment level. In addition, the ICF provides a model for describing functioning beyond the impairment level by providing a way to describe the consequences of impairments on the daily activities and functioning of an individual. The information that can be obtained by using the ICF for the description of the consequences of hearing impairment and language impairment is extensive and complex. Therefore, when applying the WHO model to hearing impairment, it is evident that there are a large number of potential consequences of hearing impairment on a person's everyday life (Fisher & Thelin, 1999). Based on the large number of possible consequences of hearing impairment, the investigators in this study concluded that the measure of LQ and PIQ (impairment level) may not be enough to understand how a child functions in the classroom (activity and participation levels). For the present study, the activity of problem solving was chosen because of its relevance in the classroom, as well as in everyday life.

The results of this study indicate that there is no significant difference between the performance of the HI group and the NH group on the problem-solving task using mathematical problems. Furthermore, when mathematical problems were divided into those using language and those involving mathematical computations, the two groups' performance was not significantly different. Additionally, it was determined that among children with a moderate to severe degree of hearing impairment, there is no relationship between degree of hearing loss and problem-solving ability on either of the mathematical tasks. The implication of these findings is that the deficits noted in problem-solving ability by the present investigators, previous investigators, classroom teachers and speech-language pathologists are closely related to language ability and not degree of hearing loss.

The tasks in the present study were constructed to evaluate problem solving. They were modeled on a widely used mathematics curriculum for elementary school children based on Polya's (1957) model of problem solving. The findings in this study have two important implications. First, the knowledge of a child's language ability may serve as a useful predictor of function as defined by the WHO Model. One problem with the use of the WHO model is that, although it provides a comprehensive model of functioning and disability, it would be difficult to measure all aspects of function for an adequate description. Therefore, the results of the present study provide preliminary evidence to support the idea that when language is age appropriate, the function of problem solving should be age appropriate, as well.

Normal language development has been documented in children with hearing impairments who were identified, amplified, and provided with intervention prior to six months of age (Yoshinaga-Itano et al., 1998). In their study, children who were identified early showed significantly higher LQs than children who were identified after six months of age. The average LQ for children (with normal cognitive skills) identified by six months of age was 91.3; whereas, children identified after six months had a mean LQ of 70.2. Yoshinaga-Itano and her colleagues have concluded that, without early intervention, language development is delayed. However, if early intervention is provided before six months of age, the expectation is that language development will be normal. The results of the present study extend the findings of the Yoshinaga-Itano et al. study and indicate that problem solving, which is a higher level cognitive function, should be commensurate with language ability in children with hearing impairment. Therefore, if a child with hearing impairment develops normal language skills, the results of the present study would suggest there is reason to expect that cognitive abilities, such as problem-solving skills, may develop normally, as well. If this is borne out by subsequent research, then it greatly increases the justification for Early Hearing Detection and Intervention programs.

The second implication of the present study is that children with hearing impairment can solve problems requiring the use of the principles in Polya's model as well as children with normal hearing and equal language abilities. Therefore, the cognitive processes used by children with hearing impairment do not appear to be different from those of children with normal hearing – at least based on the tasks performed in the present study. These findings were not expected at the outset of the present study. It was the hypothesis of the investigators that the problem-solving ability of children with hearing impairment might be fundamentally different than children with normal hearing even when the language ability of the two groups of children was not significantly different.

Problem-solving ability, a necessary skill for educational achievement, has the potential of being negatively impacted by the disability of hearing impairment (WHO, 2001). It is also a topic that classroom teachers and speech language pathologists have discussed with the investigators as an area of functional inadequacy for a significant percentage of children with hearing impairment. In previous studies on problem solving, children with hearing impairment have not performed as well as children with normal hearing. One explanation offered by the investigators of those studies is that problem-solving ability may be affected by language ability for tasks requiring the explicit use of language (Vaden 2001) and for tasks considered to be nonverbal (Luckner

& McNeill, 1994). This was supported by the results of the present study in which it was found that when language ability was controlled, children with hearing impairment performed with the same proficiency as their normal hearing peers on a functional problem-solving task.

Attempting to control language ability was not without its problems because the majority of children with hearing impairment also have some degree of language impairment. Therefore, during the selection of participants the investigators found it necessary to compare some of the children with hearing impairment and language impairment to children who have normal hearing and specific language impairment (SLI). In the participant selection process, it was found that a number of the children with hearing impairment had greater language impairment than did any child with SLI. To match the groups on language ability, children with poorer language skills had to be excluded from the HI Group and children with better language skills had to be excluded from the NH Group. As a result, the children in the HI Group had better language abilities than the typical child with hearing impairment and the children in the NH Group had poorer language abilities than the typical child with normal hearing. This was necessary in order to make the comparison among participants with similar language abilities, but it reveals important differences between the groups. It indicates that, for children with normal hearing in the 4th, 5th or 6th grade, when PIQ is relatively normal, there is probably some limit to the degree of language impairment. It also indicates that language deficits can be much greater for children with hearing impairment than in children with SLI. Therefore, the conclusions about the problem-solving abilities or functioning of children with hearing impairment in the present study may not apply to children with greater language deficits.

Conclusion

The task called the Tower of Hanoi has been used to study problem-solving abilities in children who are developing typically, children with learning disabilities (Wansart, 1990), and children with hearing impairment (Luckner & McNeill, 1994). Wansart developed an analysis procedure to compare the processes used in problem solving by children who were typically developing and children with learning disabilities. The use of an analysis strategy, such as Wansart's, may be useful in studying the problem-solving processes used by children with hearing impairment, as well. In the present study, there was some evidence of differences between the processes used in problem solving for the two experimental groups. For the children with hearing impairment, there was a much stronger relationship between language and vocabulary and problem-solving ability – both in computational and word problems. This is somewhat unexpected because both groups would have been expected to have received significant amounts of language therapy. If this difference were understood it might shed some light on the processes used by children in both groups.

The relationship demonstrated in the present study between problem solving and language in children with hearing impairment may exist at other levels of thinking (Figure 1). It would be of interest to apply the design of the present study to the thinking processes (other than problem solving), such as concept formation and composing. In addition, the investigation of the effect of language and vocabulary skills on the foundational thinking skills might provide information relative to the influence of language and vocabulary on problem solving. Further study is warranted to determine the influence of language and vocabulary in children with hearing impairment on creative and critical thinking skills, as well as metacognition.

There is an increasing amount of evidence that supports that early identification of hearing impairment in children is critical in the acquisition of normal language skills. It will be important to document not only the effects of early identification on language development, but also the effects on higher-level cognitive functions, such as problem solving.

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References

Anderson, J. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Brackett, D., & Maxon, A.B (1986). Service delivery alternatives for the mainstreamed hearing impaired child. *Language, Speech and Hearing Services in the Schools, 17,* 115-125.

Braden, J. P. (1984). The factorial similarity of the WISC-R Performance Scale in deaf and hearing samples. Personality and Individual Differences, 5, 403-409.

Braden, J. P. (1994). *Deafness, deprivation and IQ.* New York: Plenum.

Burton, G., Maletsky, E., Bright, G., Helton, S., Hollis, L. Y., Johnson, H. C., et al. (1999). *Math Advantage.* Orlando, FL: Harcourt Brace.

Carney, A.E., & Moeller, M.P. (1998). Treatment efficacy: Hearing loss in children. *Journal of Speech, Language, and Hearing Research, 41,* S61-S84.

Dunn, L.M., & Dunn, L.M. (1997). *Peabody Picture Vocabulary Test – Third Edition*. Circle Pines, MN: American Guidance Service.

Easterbrooks, S.R., & Baker, S. (2002). *Language learning in children who are deaf or hard of hearing: Multiple pathways*. Boston: Allyn & Bacon.

Edeh, O. M. (2007). Cross-cultural investigation of interest-based training and social interpersonal problem solving in students with mental retardation. *Education and Training in Developmental Disabilities, 41*, 163-176.

Erber, N. (1982). *Auditory training*. Washington, DC: Alexander Graham Bell Association for the Deaf.

Fisher, D. L. (2000). *Problem solving in a school age child with hearing loss.* Unpublished doctoral project, University of Tennessee, Knoxville.

Fisher, D. L., & Thelin, J. W. (1999). The World Health Organization model of functioning and disability applied to audition. *Journal of Educational Audiology, 7,* 42-49.

Flesch, R. F. (1948). A new readability yardstick. *Journal of Applied Psychology, 32,* 221-233.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligence.* New York: Basic Books.

Granger, C. V. (1984). A conceptual model for functional assessment. In C. V. Granger, & G. E. Gresham (Eds.), *Functional assessment in rehabilitation medicine* (pp. 14-25). Baltimore: Williams & Wilkins.

Greenburg, M., & Kusche, C. (1989). Cognitive, personal, and social development of deaf children and adolescents. In M. Wang, M. Reynolds, & H. Walberg (Eds.), *The handbook of special educators: Vol. 3. Research and practice* (pp. 95-129). Oxford, England: Pergamon.

Hine, D.W. (1970). The attainments of children with partial hearing. *Teacher of the Deaf, 68,* 129-135.

Johnson-Laird, P. N. (1983). *Mental models.* Cambridge, MA: Harvard University Press.

Karchmer, M.A., & Mitchell, R. E. (2003). Demographic and achievement characteristics of deaf and hard of hearing students. In M. Marschark & P.E. Spencer (Eds), *Oxford handbook of deaf studies, language, and education* (pp.21-27). New York: Oxford University Press.

Krulick, S., & Rudnick, J. A. (1988). *Problem solving: A handbook for elementary school teachers.* Boston: Allyn & Bacon.

Lenneberg, E. H. (1967). *Biological foundations of language.* New York: John Wiley and Sons.

Ling, D. (Ed.). (1984). *Early intervention for hearing–impaired children: Total communication options*. San Diego, CA: College Hill Press.

Luckner, J. L., & McNeill, J. H. (1994). Performance of a group of deaf and hard of hearing students and a comparison group of hearing students on a series of problem solving tasks. *American Annals of the Deaf, 139,* 371-377.

McAnally, P., Rose, S., & Quigley, S. (1994). *Language learning practices with deaf children* (2nd ed.). Austin, TX: PRO-ED, Inc.

McGehee, L., & Prendergrass, R. A. (1979). Social problem solving for hearing impaired students. *Teaching Exceptional Students, 12,* 20-21.

McKay, H., Sinisterra, L., McKay, A., Gomez, H., & Lloreda, P. (1978). Improving cognitive ability in chronically deprived children. *Science, 200,* 270-278.

Martin, D. S. (1984). Cognitive modifications for the hearing impaired adolescent. *Exceptional Children, 51,* 235-242.

Marschark, M. (2006). Intellectual functioning of deaf adults and children: Answers and questions. *European Journal of Cognitive Psychology, 18*(1), 70-89.

Marzano, R. J., Brandt, R. S., Hughes, C. S., Jones, B. F., Presseisen, B. Z., Rankin, S.C., et al. (1988). *Dimensions of thinking: A framework for curriculum and instruction.* Alexandria, VA: Association for Supervision and Curriculum Development.

Meadow-Orleans, K.P. (2001). Research and deaf education: Moving ahead while glancing back. *Journal of Deaf Studies and Deaf Education, 6*(2), 143-147.

Moores, D. (2000). *Educating the deaf: Psychology, principles and practices (5th ed.)*. Boston: Houghton Mifflin.

Moores, D.F. (2003). Short term memory, morphology, and reading (editorial). *American Annals of the Deaf, 148*(1), 3-4.

Nagi, S. Z. (1965). Some conceptual issues in disability and rehabilitation. In M.B. Sussman (Ed.), *Sociology and rehabilitation* (pp. 100-113). Columbus, OH: Ohio State University.

Nagi, S. Z. (1991). Disability concepts revisited: Implications for prevention. In A.M. Pope, & A. R. Tarlov (Eds.), *Disability in America: Toward a national agenda for prevention* (pp. 309-327). Washington, DC: National Academy Press.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Nunes, T., & Constanza, M. (1998). Is hearing impairment a cause of difficulties in learning mathematics? In C. Donlan (Ed.). *The development of mathematical skills* (pp. 227-254). New York: Psychology Press.

Paul, R. (2007). *Language disorders from infancy to adolescence: Assessment and intervention (3rd edition).* St. Louis, MO: Mosby.

Paul, R.I., & Young, B. (1975). *The hard of hearing child in the regular classroom* (ESEA Title Project). Pontiac, MI: Oakland Schools.

Perkins, D. N. (1981). *The mind's best work.* Cambridge, MA: Harvard University Press.

Polya, G. (1957). *How to solve it* (2nd ed.). Garden City, NY: Doubleday Anchor Books.

Pope, A. M., & Tarlov, A. R. (1991). *Disability in America: Toward a national agenda for prevention.* Washington, DC: National Academy Press.

Quigley, S., & Kretschmer, R. (1982). *The education of deaf children: Issues, theory and practice.* London: Edward Arnold.

Quigley, S., & Thomure, R.E. (1968). *Some effects of hearing impairment upon school performance.* Urbana, IL: University of Illinois, Institute for Research on Exceptional Children.

Rohr-Redding, C. (1985). Can thinking skills be incorporated into a curriculum? In D.S. Martin (Ed.), *Cognition, education, and deafness: Directions for research and instruction* (pp. 168-171). Washington, DC: Gallaudet College Press.

Ross, M., Brackett, D., & Maxon, A. B. (1991). *Assessment and management of mainstreamed hearing-impaired children*. Austin, TX: Pro-Ed.

Schirmer, B.R. (2000). *Language and literacy development in children who are deaf.* Boston: Allyn & Bacon.

Semel, E. M., Wiig, E. H., & Secord, W. (1995*). Clinical evaluation of language fundamentals - 3.* San Antonio, TX: The Psychological Corporation.

Steer, M.D., Hanley, T.D., Speuhler, H.E., Barnes, N.S., Burk, K.W., & Williams, W.G. (1961). *The behavioral and academic implications of hearing loss among secondary school children* (Purdue Research Foundation, Project No. P.U. 2040). West Lafayette, IN: Purdue University.

Swanwick, R., Oddy, A., & Roper, T. (2005). Mathematics and deaf children: An exploration of barriers to success. *Deafness and Education International, 7*(1)*,* 1 – 21.

Thornton, S. (1995). *Children solving problems.* Cambridge, MA: Harvard University Press.

Trybus, R., & Karchmer, M. (1977). School achievement scores of hearing impaired children: National data on achievement status and growth patterns. *American Annals of the Deaf Directory of Programs and Services, 122,* 62-69.

Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension.* Hillsdale, NJ: Erlbaum.

Vaden, K. A. (2001). *Language in relation to problem-solving abilities in children with hearing impairment*. Unpublished master's thesis, University of Tennessee, Knoxville.

Wansart, W. L. (1990). Learning to solve a problem: A microanalysis of the solution strategies of children with learning disabilities. *Journal of Learning* Disabilities, 23, 164-170, 184.

Wechsler, D. (1991). *The Wechsler Intelligence Scale for Children – Third Edition (WISC-III).* San Antonio, TX: Psychological Corporation.

Wickelgren, W. A. (1974). *How to solve problems.* San Francisco: Walt Freeman.

World Health Organization (WHO). (1980). *International classification of impairments, disabilities and handicaps.* Geneva: Author.

World Health Organization (WHO). (1997*). ICIDH-2: International classification of impairments, activities and participation: A manual of dimensions of disablement and functioning.* [Beta-1 draft for field trials]. Geneva: Author.

World Health Organization (WHO). (1999*). ICIDH-2: International classification of functioning and disability.* [Beta-2 draft, full version]. Geneva: Author.

World Health Organization (WHO). (2000). *ICIDH-2: International classification of functioning, disability and health.* [Prefinal version]. Geneva: Author.

World Health Organization (WHO). (2001). *ICF: International classification of functioning disability and health.* Geneva: Author.

Yoshinaga-Itano, C., Sedey, A. L., Coulter, D. K., & Mehl, A. L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics, 102*(5), 1161-1171.

Zwiebel, A. (1991). Intellectual structure of hearing-impaired children and adolescents. In D. S. Martin (Ed.), *Advances in cognition, education, and deafness* (pp. 210-215). Washington, DC: Gallaudet University Press.