Mathematical Ability of Deaf, Average-Ability Hearing, and Gifted Students: A Comparative Study

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Abstract

The purpose of this study was to explore the performance of three groups of students, gifted hearing students (GH), average-ability hearing students (AH), and deaf students (DF) on mathematical ability. The sample consisted of a total of 167 students (91 males and 76 females). Deaf students came from the Al-Amal School (an inclusive school for deaf students in Muscat, the capital of Oman) while average-ability hearing and gifted students came from public school students in Muscat in grades 6, 7, and 8. The tools of the study consisted of mathematical ability tests and Snigders-Oomen Non-verbal Intelligence (SON-R 5½-17). The researchers used the two-way ANOVA to answer the study questions. The results showed a significant main effect of the group (GH, AH, and DF). Post hoc analyses indicated that gifted students' level of mathematical ability was higher than AH and DF students. Deaf students scored the lowest among the three groups. The main effect of gender was not significant. The results of this study are discussed in relation to educational practices required to diminish the gap between hearing and deaf students in mathematical ability.

Keywords: deaf, high-achieving, mathematical ability

Introduction

Insufficient access to sound may lead to academic delays for deaf children (Madell & Flexer, 2008). Deaf children show a slower achievement rate than their typically hearing peers in mathematical proficiency (Pagliaro & Kritzer, 2013; Edwards, Edwards, & Langdon, 2013). The focus of recent calls related to reform in mathematics education for deaf students was on word problem solving and reasoning skills (Pagliaro, 1998). Researchers encouraged following the National Council for Teachers of Mathematics (NCTM) standards, which focus on problem solving which is “not only a goal of learning mathematics, but also a major means of doing so” (NCTM, 2000, p. 52). Research has shown that deaf students do no perform well in problem-solving tasks compared to their hearing peers. There is a delay in mathematical performance of about two years at the age of and increases to three to four years at the age of 11 in mathematical performance between deaf and hearing children (Traxler, 2000). Researchers attributed this low performance to linguistic, cognitive, and experiential factors. Braham and Bishop (1991) concluded that teachers of deaf students, “when asked about the problems their students are having with mathematics, seem to have an intuitive feeling is at the heart of their difficulties” (p. 180). Deaf students fall behind their hearing peers in standardized achievement tests (Austin, 1975), fractions (Titus, 1995), and arithmetic knowledge (Ansell & Pagliaro, 2006; Kelly, Lang, Mousley, & Davis, 2003). The reasons of delay in numerical and mathematical skills for deaf are not clear.

Hearing impairment is not the cause of low mathematical performance; rather it is more related to the riming, type of instruction, and learning opportunities available to deaf students (Numes & Moreno, 1998). Researchers pointed out that some factors affect deaf students’ mathematical learning. For example, Nunes and Moreno (2002) found that young deaf children lack additive composition, additive reasoning (e.g. two more), multiplicative reasoning (e.g. three children sharing two pencils each), ratio (e.g. 2:2 correspondence), and fractions (e.g. pieces of a whole pizza). Nunes and Moreno (1998) found that deaf students had slower reaction times on basic numeral and arithmetic skills. Other researchers focused on deaf students’ automatization of number through examining the symbolic distance effects in magnitude decisions, the internal number line, and the skills involving estimation (Bull, Marschark, & Blatto-Vallee, 2005; Bull, Blatto-Vallee, & Fabich, 2006). Researchers also posited that deaf students’ observed mathematical difficulties are not the result of low basic numerical skills.

Research also showed that deaf individuals perform poorly on tasks related to considering the relationship between two or more dimensions than their hearing peers (Ottem, 1980). Marschark and Johnson- Laird (2003) posited that deaf individuals have difficulty in benefiting from automatic relational processing in a number of tasks. Ansell and Pagliaro (2006) examined primary level deaf children’s ability to solve mathematical story (word) problems and found that they did not connect the story language to the arithmetic functions necessary for the solution. Research shows evidence of deaf children’s challenges in acquiring numerical sequence necessary to counting (Nunes, 2004; Zarfarty; Nunes, & Bryant, 2004).

Deaf children have a similar developmental trajectory as their hearing peers in non-linguistic cognitive functions such as block construction, spatial memory, and spatial localization (Bavelier, Newport, Hall, Supalla, & Boutla, 2006; Blatto-Vallee, Kelly, Gaustad, Porter, &

Fonzi, 2007). In a synthesis of research on deaf and hearing children's mathematical achievement, Gottardis, Nunes, and Lunt (2011) concluded that most of the studies reported a delay in deaf children's mathematical achievement. Four studies did not report this delay on preschool children (Aref et al., 2011; Barbosa, 2010; Zarfaty et al., 2004) and elementary school children (Gottardis, 2009). Young deaf children do not seem to have a delay in number representation and deaf children with mild loss may not have a significant delay compared to hearing peers in tasks that involve counting or arithmetic knowledge (Gottardis, 2009). Research shows that deaf children's mathematical achievement from 8 to 18 years tend to have a delay of one year in the first years of schooling while this delay widens to 3 years in the last years (Traxler, 2000).

Deaf Education in Oman

Deaf education in Oman started in 1979 in a special class in a public school. In 1997, Al-Amal school for the deaf was first established. The school has 300 students. The school has a residential unit for male students outside the capital, Muscat. The purpose of the school includes: a) providing educational and instructional services and skills needed to develop students' skills, b) training students on speech, c) informing students' families and society on causes of disability and ways of prevention, and d) sharing with local community in celebrations, symposia, and increasing awareness of students' abilities. The school receives students from 5 to 18 years of age. Conditions for admission are: students should be deaf and do not have any other handicapping conditions, the intelligence quotient (IQ) should not be below 90, and that students should be seen by a physician before they join the school. The educational system in the school developed in parallel with the educational policy in Oman. In the beginning, three levels exist. The first was the preparatory period and lasts for two years. In this period, the student learns the pronunciation of letters and words using earphones for hard-of-hearing students. The second period is the elementary period which lasts for 6 years and the last period is the middle vocational period which lasts for 3 years. Afterwards, with the development of the educational system in Oman and the establishment of basic education system, the Deaf School's educational system was the preparatory period and cycle-one period (grades from 1-4) and cycle two (grades from 5-10). The fourth period was post-basic education which started in 2006/2007 with grades 11 and 12. In these grades, students study adapted basic education curricula according to students' abilities. Services provided by the school include: a) meal services for low-income students, b) school health and dental clinic, c) assessing and diagnosing speech disorders and developing remedial programs, d) providing counseling guidelines to prevent speech disorders, and e) maintenance of hearing aids

The purpose of this study is to examine the performance of gifted students, average-ability hearing students, and deaf students on tests of mathematical ability. Two questions guided the study:

1. Is there a statistically significant effect of gender and ability state (gifted, average and deaf students) on mathematical ability?
2. Is there a statistically significant effect of grade level and ability on mathematical ability?

Participants

The sample of the study was randomly selected from students in grades 6, 7, and 8 from Al-Amal School for the Deaf for deaf students and cycle-two (grades 5-10) schools in the governorate of Muscat for gifted and average-ability hearing students. The total sample was 167 male and female students with 91 males and 76 females. The distribution of the study sample according to grade level, gender, and academic status is presented in Table 1.

Table 1

Distribution of the Study Sample according to Grade Level, Gender, and Academic Status

Group			Grade level			
			6.00	7.00	8.00	Total
Deaf	Gender	Male	11	8	9	28
		Female	8	7	6	21
	Total		19	15	15	49
Average-ability hearing	Gender	Male	7	16	8	31
		Female	11	9	8	28
	Total		18	25	16	59
Gifted	Gender	Male	8	13	11	32
		Female	8	6	13	27
	Total		16	19	24	59

Deaf students had mild hearing impairment. Their ages ranged from 12 to 18 years with a mean age of 15.4 years. Average-ability and gifted hearing students' ages ranged from 12 to 15 years. Most of the deaf students had hearing parents. The parental hearing status for 3 students was not reported. IQs obtained from the Snigders-Oomen Non-verbal Intelligence (*SON-R 5½-17*) ranged from 125 to 135 for gifted students, 95 to 118 for average-ability hearing students, 92 to 115 with a mean of 101.5 and a standard deviation of 15. Deaf students' IQs ranged from 90 to 112 with a mean of 101 and a standard deviation of 15.1.

Instruments

The Mathematical Ability Test. The authors developed a mathematical ability test for each of the three grade levels (6, 7, and 8). Each test consisted of eight main questions. Each question consisted of four sub-questions. For grade 6 test, the standards covered in the test were numbers and number theory, operations on numbers, geometry and trigonometry, pre-algebra and algebra, and data processing and probabilities. An example of one of the questions that assess pre-algebra and algebra is "What is the number that if we add to 11 and divide the result by 9, then subtract the result from 7, the results will be 4". Another example on operations on numbers is "The appropriate number to put in the blank is: 1000 = ………-0.125 X 8888". The student gets one point for each correct answer and zero for each incorrect answer. For grade 7 test, the standards covered in the test were numbers and number theory, operations on numbers, geometry and trigonometry, pre-algebra and algebra, and data processing and probabilities. An example of a question on operations on numbers is "What is the sum of: 0.764+ 0.858+ 0.55+0.45+ 0.236+

0.142?" Another example on data processing and probabilities is "Mohamed chose four different numbers and he recorded by using them 24 possible numbers (resulting from changing the order of numbers) and he added them. John said that the result he obtained was 186648. Which numbers did he choose? And how many solutions are for this problem?" The standards covered in the test were measurement, numbers and number theory, operations on numbers, geometry and trigonometry, pre-algebra and algebra, and data processing and probabilities. An example of a question on measurement is "Ahmed and Sami went from Muscat to Sohar (cities in Oman) with their car. At the same time, it is known that Ahmed was driving half the distance with a speed 100 km/hour, and the other half with a speed 80km/hour. While Sami travelled half the time that he needed to travel all of this distance with a speed of 100km/hour and half of the other time with a speed of 80km/hour. Which one of them got to Sohar first?" An example of a question on algebra and pre-algebra was "Prove that (X-3)(X+7)(3X-8)= 0 and prove that $(x-1)^2 + (x^2+1)^2 = 0$. Another question on pre-algebra and algebra is "Calculate using a fast way: $(75.5)^2 - (24.5)^2$.

The mathematical ability test content validity was examined using a group of mathematics professors, math supervisors, and teachers. The test items on the three grades were shown to this panel of experts to capture a feedback. They were told to evaluate each test based on four criteria: (a) language appropriateness, (b) suitability of the concepts used, (c) the suitability of the graphics used to convey the concepts in the test, and (d) whether the test items reflect the math standards in the Ministry of Education books for each grade level. There was a high consensus among the reviewers regarding the four criteria. Few corrections have been suggested by them and the researchers modified the test items accordingly.

The criterion-related validity was obtained by exploring the relationship between the mathematical ability test total score and students' mathematics achievement in the school. Students' mathematics achievement was calculated using an averaged math GPA in three months. The correlation was significant at the .01 level (r = .37, p = .01). Item difficulty, discrimination, and reliability were investigated using ITEMAN 4 using a sample of 30 students from the three grade levels. The results shown in Table 2 indicate that all the test questions and sub-questions have an acceptable level of difficulty, discrimination, and reliability.

Table 2

Levels of Difficulty, Discrimination, and Reliability of the Mathematical Ability Test Items

Questions and Sub-questions	Grade 6			Grade 7			Grade 8		
	Rel.	Disc.	Diff.	Rel.	Disc.	Diff.	Rel.	Disc.	Diff.
1	.75	.66	.55	.85	.82	.44	.80	.79	.41
2	.88	.93	.56	.77	.80	.38	.82	.82	.39
3	.77	.76	.66	.79	.69	.39	.77	.81	.50
4	.92	.59	.49	.88	.84	.47	.85	.75	.38
5	.88	.65	.39	.77	.53	.32	.78	.85	.33
6	.82	.84	.61	.82	.69	.54	.89	.83	.41

7	.75	.79	.55	.91	.72	.33	.79	.78	.49
8	.83	.81	.36	.86	.82	.45	.82	.86	.45
9	.77	.54	.43	.76	.66	.42	.87	.82	.32
10	.85	.74	.64	.85	.43	.32	.90	.66	.41
11	.80	.82	.52	.83	.62	.51	.82	.73	.48
12	.83	.73	.49	.86	.51	.49	.81	.79	.51
13	.78	.65	.43	.91	.67	.39	.82	.55	.44
14	.83	.78	.66	.85	.79	.41	.77	.81	.56
15	.85	.74	.51	.82	.85	.44	.69	.76	,41
16	.77	.73	.33	.79	.79	.53	.82	.70	.69
17	.87	.52	.59	.87	.84	.46	.61	.64	.80
18	.80	.77	.46	.91	.72	.62	.52	.86	.82
19	.84	.69	.34	.84	.69	.40	.41	.69	.77
20	.84	.86	.41	.81	.89	.41	.33	.80	.85
21	.69	.65	.41	.76	.63	.39	.42	.75	.78
22	.77	.84	.46	.85	.72	.46	.54	.69	.89
23	.82	.66	.51	.83	.84	.51	.35	.80	.79
24	.84	.50	.38	.75	.77	.40	.59	.73	.82
25	.77	.70	.59	.87	.91	.61	.34	.77	.87
26	.82	.55	.46	.82	.58	.44	.52	.59	.90
27	.83	.85	.34	.78	.62	.36	.29	.84	.82
28	.78	.81	.41	.85	.86	.38	.33	.79	.81
29	.69	.55	.61	.86	.66	.45	.30	.66	.82
30	.75	.61	.31	.83	.59	.53	.45	.76	.77
31	.85	.78	.48	.90	.73	.45	.39	.69	.69
32	.82	.88	.33	.83	.59	.36	.45	.89	.82

Note. Rel. = reliability, Disc. = discrimination, Diff. = difficulty The Patterns subtest of *SON-R 5½-17*:

The most recent test version for older children was used, the Snigders-Oomen Non-verbal Intelligence (*SON-R 5½-17*) (Tellegen, Winkel, Wijnberg-Williams & Laros, 1998). Only one subtest of SON-R 5.5-17 (the Patterns subtest) was used in this study. The Patterns subtest contains two groups of items; each has 7 items. The items on each group are ranked based on item difficulty from the easiest to the most difficult items. In the middle of a repeating pattern of one or two lines in each item, a part is left out. The subject has to draw the missing part of the lines in such a way that the pattern is repeated in a consistent way. The difficulty of the items is related to the number of lines, the complexity of the line pattern and the size of the missing part. The participants gets the item correct (1) if he/she completes the line fully correct, otherwise, the item is wrong (0). As a result, the subtest scores range between 0-14. These instruments were used to measure the intelligence level for deaf students in Sultanate of Oman. Various types of evidence for the reliability and validity of the instrument were collected. Results showed that the Patterns subtest scores have both high internal consistency reliability and test-retest reliability. In addition, the psychometric properties of the items were acceptable and as expected in terms of the order of items on the test by the values of difficulty index. In addition, the Patterns subtest scores were high for both normal students and deaf students but low for mental handicapped students. (Hassan, Al-Mahrazi, Al-Dhafri & Al-Nabhani, 2011). Performance of the students on the test was in the normal range. Their normative scores ranged between 96 and 116 with a mean of 106 and a standard deviation of 15.2. This test was used to make sure that their mental ability fall within the normal level.

Procedure

Tests of mathematical ability were shown to experts and teachers of mathematics to evaluate the appropriateness of the items to students' levels. Few comments related to changing the wording of some items were received. The Technical Office for Studies and Development (TOSD) at the Ministry of Education to granted the researchers the access to school and administration of study tools. Two research assistants consented parents and students to participate in the study. The two research assistants had an experience in Omani sign language. They were available during the administration of the mathematical ability tests to explain any unclear items.

Results

Means and standard deviations of the students' scores on mathematical ability are shown in Tables 3 and 4.

Table 3 Means and Standard Deviations of the Study Participants According to Academic Level on the Mathematical Ability Test and School Adjustment Behavior Scale

		Grade	M	SD
	Deaf	6	3.62	.13
		7	4.26	.28
Math.		8	3.86	.16
	Average-ability hearing	6	4.88	.25
		7	5.04	.21
		8	5.87	.30
	Gifted	6	6.43	.25
		7	6.57	.17
		8	6.62	.17

Table 4

Means and Standard Deviations for Math Ability of the Group and Grade Level

Group	Grade	*M*	*SD*	*N*
Deaf	6.00	7.0526	1.02598	19
	7.00	7.5333	.91548	15
	8.00	7.7333	.88372	15
	Total	7.4082	.97721	49
Average-ability hearing	6.00	9.4444	.92178	18
	7.00	9.4800	.91833	25
	8.00	10.1250	1.45488	16
	Total	9.6441	1.11049	59
Gifted	6.00	11.2500	1.00000	16
	7.00	11.3684	.76089	19
	8.00	11.2917	1.04170	24
	Total	11.3051	.93319	59
Total	6.00	9.1321	1.98104	53
	7.00	9.5932	1.69297	59
	8.00	9.9818	1.85083	55
	Total	9.5749	1.86084	167

To answer the first question "Is there any statistically significant effect of group and grade level on mathematical ability?" a two-way ANOVA was used. The results indicated a significant main effect of group ($F(2, 158) = 195.846$, $p < 0.001$) and the main effect of grade level was not significant ($F(2, 158) = 2.883$, $p < 0.059$). The interaction between group and grade level was not significant as well ($F(2, 158) = 1.058$, $p < 0.379$). Results are shown in Table 5.

Table 5

Two Way Analysis of Variance for Group and Grade Level on the Mathematical Ability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	416.387[a]	8	52.048	51.908	.000
Intercept	14521.180	1	14521.180	14481.963	.000
Group	392.753	2	196.377	195.846	.000
Grade	5.781	2	2.891	2.883	.059
Group * Grade	4.245	4	1.061	1.058	.379
Error	158.428	158	1.003		
Total	15885.000	167			
Corrected Total	574.814	166			

a. R Squared = .724 (Adjusted R Squared = .710)

Then a *Post hoc* using Bonferroni test was performed to see the differences among the three groups (deaf, hearing, and high-achieving). The results indicated that high-achieving students outperformed both deaf and hearing students. Also, hearing students outperformed deaf students. Results are shown in Table 6.

Table 6
Results of Post Hoc Test for Group

(I) group	(J) group	Mean Difference (I-J)	Std. Error
Deaf	Average-ability hearing	-2.23*	.19
	Gifted	-3.89*	.18
Average-ability hearing	Deaf	2.23*	.19
	Gifted	-1.66*	.18
Gifted	Deaf	3.89*	.19
	Average-ability hearing	1.66*	.18

Note *. The mean difference is significant at the .05 level.

To answer the second question “Is there any statistically significant effect of the group and gender on students’ mathematical ability?”, a two-way ANOVA was used. A two-way ANOVA revealed a main effect of ability state ($F(2, 158) = 200.736$, $p < 0.001$) and there was no significant effect of grade level ($F(2, 158) = 7.062$, $p < 0.009$). The interaction between group and grade level was not significant ($F(2, 158) = 2.665$, $p < 0.073$). Results are shown in Table 7.

Table 7

Two Way Analysis of Variance for Gender and grade level on the mathematical ability

Source	Type III Sum of Squares	df	Mean Square	*F*	Sig.
Corrected Model	418.433[a]	5	83.687	86.158	.000
Intercept	14712.005	1	14712.005	15146.487	.000
Group	389.956	2	194.978	200.736	.000
Gender	6.860	1	6.860	7.062	.009
Group * Gender	5.176	2	2.588	2.665	.073
Error	156.382	161	.971		
Total	15885.000	167			
Corrected Total	574.814	166			

a. R Squared = .728 (Adjusted R Squared = .719)

Then, a *Post hoc* using Bonferroni test was performed to see the differences among the three groups (deaf, hearing, and high-achieving). The results showed that high-achieving students’ level of mathematical ability was significantly higher than both hearing and deaf students’. Also, hearing students' mathematical ability was significantly higher than hearing students. Results of the *Post hoc* test are illustrated in Table 8.

Table 8
Results of Post Hoc Test for Group and Gender

(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.
Deaf	Average-ability hearing	-2.2359*	.19049	.000
	Gifted	-3.8969*	.19049	.000
Average-ability hearing	Deaf	2.2359*	.19049	.000
	Gifted	-1.6610*	.18146	.000
Gifted	Deaf	3.8969*	.19049	.000
	Average-ability hearing	1.6610*	.18146	.000

Discussion

The purpose of this study was to explore the differences among gifted hearing students, average-ability hearing students, and deaf students in mathematical ability. The results of the study showed that gifted students' performance was significantly higher both average-ability and deaf students. We expected that that deaf students' performance on mathematical ability tasks would be lower than the other two groups. This result corroborates the finding of Noorian, Azud Maleki, & Abollhassani (2013) who concluded that normal hearing students are better than deaf students in learning mathematics. Also, the results are similar to Ariapooran (2017) who concluded that deaf students' mathematics performance was lower than their hearing peers. Also, mathematics self-efficacy was lower in deaf students than their hearing counterparts. However, Antia, Jones, Reed, & Kreimeyer (2009) concluded that students with hearing loss had average to above average abilities in mathematics.

In addition to the issues associated with reading and writing, achievement in math has been below expectations compared to typical peers, particularly in the area of math problem solving (Kelly & Gaustad 2007 ; Nunes & Moreno 2002 ; Traxler 2000). The source of this is unclear, but educational approaches have been implicated, in addition to potential impacts of language and differences in cognitive processing and experience (Kelly et al. 2003). Deaf students have a difficulty in math word problems due to their lack of coping skills with reading skills (Knight & Hargis, 1977). The biggest difference between deaf and hearing students in is math applications which is more dependent on language (Kidd, Madsen, & Lamb, 1993). Deaf students' difficulty in understanding mathematics (Kritzer, 2009; Pagliaro & Kritzer, 2013), reading, and writing numbers (Kritzer, 2009) may lead to inability to benefit from mathematics classes.

In order to diminish the math achievement gap between deaf and hearing students, there should be a collaboration between mathematics and language arts teachers to focus on reading comprehension and language arts in mathematics classes such as journal entries. Also, all forms of vocabulary forms such as symbols, examples, activities involving proper sign, and correct fingerspelling should be introduced to deaf students (Kidd et al., 1993). Some social and economic issues such as class attendance, family income, parents' education, teacher-student ratio, presence of expert teachers are indicators of poor mathematics performance for deaf students (Rono, Onderi & Owino, 2014). Deaf students' mathematical performance can not only be improved by resources such as books and learning accommodations, but also they need good teachers who use appropriate teaching methods and maintain appropriate classroom management (Baldacchino & Farrugia, 2002).

Researchers pointed out that barriers facing deaf students in regular schools result from lack of teaching resources, lack of motivation and communication problems (Kiplagat, Role & Makewa, 2012). Deaf students' academic achievement in inclusive classrooms is higher than those in self-contained classrooms (Holt, 1994). The deaf sample in this study came from a self-contained school for the deaf in the county. General-education classrooms are not ready for inclusion services for deaf students although there are hard-of-hearing inclusive classrooms in public schools all around the country. Research shows that deaf students in self-contained programs feel more secure with students with hearing loss (Stinson & Whitmore, 2000). Deaf adolescents, however, had more withdrawal behaviors and depression than their mainstreamed deaf peers and hearing peers (Van Eldik, 2005).

Some limitations of the presents study should be noted. First, deaf students who participated in this study were male and female middle schools students. Accordingly, this limitation may diminish the generalizability of results. Second, the use of mathematical ability test was based on some general problem solving abilities. Future studies may consider different mathematical skills in deaf mathematics curriculum. Despite these limitations, the present study supports the need to inform policy makers, special education professionals, school administrators, and classroom teachers regarding the challenges faced by deaf students in understanding mathematical concepts and the need to provide them with educational accommodations needed to improve their levels of math skills.

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