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Are Deaf Students Visual Learners?

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Abstract

It is frequently assumed that by virtue of their hearing losses, deaf students are visual learners. Deaf individuals have some visual-spatial advantages relative to hearing individuals, but most have been linked to use of sign language rather than auditory deprivation. How such cognitive differences might affect academic performance has been investigated only rarely. This study examined relations among deaf college students' language and visual-spatial abilities, mathematics problem solving, and hearing thresholds. Results extended some previous findings and clarified others. Contrary to what might be expected, hearing students exhibited visual-spatial skills equal to or better than deaf students. Scores on a Spatial Relations task were associated with better mathematics problem solving. Relations among the several variables, however, suggested that deaf students are no more likely to be visual learners than hearing students and that their visual-spatial skill may be related more to their hearing than to sign language skills.

Keywords

deaf; visual-spatial processing; visual learners; mathematics

1.1 Introduction

Teachers, deaf individuals, and others frequently describe deaf students as *visual learners* (e.g., Dowaliby & Lang, 1999; Marschark & Hauser, 2012). Interestingly, despite numerous such descriptions available online, there does not appear to be a peer-reviewed research literature indicating that deaf students are any more likely than hearing students to be visual learners or even whether a deaf individual having a *visual learning style* is any different than a hearing individual having one. Certainly, deaf students are relatively more dependent than hearing peers on vision, but the vast majority of children and youth labeled as deaf *also* have some amount of residual hearing (Gallaudet Research Institute, 2011). The extent to which

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deaf students as a group are appropriately labeled visual learners is thus unclear, as are the potential benefits of that label to students or teachers.

What does it mean to be a visual or verbal learner – that is, to have a visual or verbal learning style? Educators and investigators interested in learning styles suggest that teaching and learning are most effective when related methods and strategies match students' learning styles. Learning styles are multidimensional, however, with the visual-verbal continuum representing only one aspect of an individual's learning style. Describing any one student, let alone a group of students, on a single dimension thus is an oversimplification of questionable educational utility. With regard to visual learning in particular, recent research has indicated that there are at least two visual learning styles (see below), suggesting that applying such a label to deaf (and hard-of-hearing) students may not be very helpful.

1.1.1 Visual Learning Styles and Visual Learners

Learning styles typically are attributed to individuals either via administration of standardized assessments or simply by asking them, for example, how they prefer information to be presented or what kind of mental activity they find most appealing. In the case of the visual-verbal dimension, individuals may report preferring instruction via language (either printed or through the air) or via diagrams or pictures (static or animated). The assumption is that “visualizers” will learn better with visual methods of instruction, while “verbalizers” will learn better with verbal methods. Despite its popularity, the predicted interaction, referred to as the *attribute-treatment interaction* (ATI) (Mayer & Massa, 2003; Sternberg & Zhang, 2001) has received remarkably little support from empirical research.

Massa and Mayer (2006) conducted three experiments to determine whether visual and verbal learners learned better from multimedia materials in which help screens used pictures or words. Although they found that students who reported themselves to be visualizers consistently relied more on pictorial help screens and those who reported themselves to be verbalizers consistently relied more on verbal help screens, Massa and Mayer failed to find a consistent relation between learning styles and performance. They concluded that visual versus verbal cognitive *abilities* have to be distinguished from students' cognitive styles and learning preferences. Similarly, Litzinger, Lee, Wise, and Felder (2007) found a strong relation between (hearing) students' self-reported preferences for visual versus verbal presentation of information and scores on a learning styles assessment but noted that neither classification need be related to students' actual information processing abilities in those modalities.

In an extensive review of the research literature, Pashler, McDaniell, Rohrer, and Bjork (2008) acknowledged that individuals readily indicate their preference for visual versus verbal presentation of information and that there is considerable evidence that the visualizer-verbalizer dimension is a valid one. Consistent with the Mayer and Massa (2006) findings, however, they found “virtually no evidence for the [ATI] interaction pattern” that assumes the visual-verbal dimension to be relevant to educational applications (p. 105). Yet the belief persists in educational settings and with regard to deaf students, in particular.

With his landmark book *Imagery and Verbal Processes*, Paivio (1971) was perhaps the first investigator to fully describe the visualizer-verbalizer dimension. A wide variety of studies by Paivio and his colleagues over several decades demonstrated differences in memory, problem solving, and other cognitive domains as a function of whether individuals tended to rely on visual imagery or verbal processes (see Paivio, 1986, for a review). Importantly, his work showed that visual and verbal abilities were not two ends of a single continuum, but individuals could be high in both visual and verbal ability (Paivio & Harshman, 1983). In a

related study involving 15- to 17-year-old deaf and hearing students, Conlin and Paivio (1975) predicted that because visual experience is central to both deaf and hearing learners, both groups would show better memory for high- than low-imagery words. Signability, or the ease with which a word brings to mind an equivalent sign, in contrast, was assumed relevant as a verbal dimension only for the deaf students, who were expected to show better memory for high- than low-signability words. Conlin and Paivio found that hearing students recalled more words than their deaf peers, high-imagery words were recalled better than low-imagery words by both groups, and high-signability words were recalled better than low-signability words by the deaf students but not by the hearing students.

The finding that the availability of signs can affect deaf students' memory has two important implications. The first relates to the fact that the notion of deaf students being visual learners is sometimes equated with their reliance on sign language as opposed to spoken language. Learning via sign language, however, is a verbal skill, as is reading, even if it depends on vision rather than voice. A preference for sign over speech as the language of instruction thus is not sufficient to make someone a visual learner. Further, despite the knowledge difficulties of deaf students in reading (e.g., Qi & Mitchell, 2012), recent studies have shown deaf students from 12 years old through university age to learn no more from sign language than they do from text (Borgna, Convertino, Marschark, Morrison, & Rizzolo, 2011; Marschark, Leigh, et al., 2006; Marschark, Sapere, Convertino, Mayer, Wauters, & Sarchet, 2009). Meanwhile, the verbal abilities of deaf students are often overlooked by investigators, beyond those interested in literacy, apparently on the assumption that their use of sign language is sufficient to level the academic playing field with hearing peers (Marschark, 1993). This assumption is clearly wrong, and investigations into the verbal abilities and verbal intelligence of deaf students – beyond reading and writing – are clearly needed (Akamatsu, Mayer, & Hardy-Braz, 2008; Maller & Braden, 2011).

The second important implication of the Conlin and Paivio (1975) findings is that they demonstrate that there are interactions of language and cognitive abilities in deaf students likely to have implications for learning in formal and informal educational settings (Marschark & Hauser, 2012). Marschark and Knoors (2012) emphasized the particular need to recognize such differences in inclusive classrooms. In that context, deaf and hearing students might have different cognitive strengths as well as different needs, but their teachers are likely to be less aware of them than would be teachers of the deaf. A number of investigators have explored memory and visuospatial abilities in deaf individuals, but few have examined their roles in educational settings, and even fewer have sought to develop interventions utilizing deaf students' strengths in those areas (see Spencer & Marschark, 2010).

1.1.3 Visual-Spatial Abilities and Academic Performance

Proponents of utilizing an ATI approach in educational settings suggest that in order for students to learn most effectively, those who are visualizers should be taught using materials such as hands-on activities, pictures, graphs, videos, and diagrams (e.g., Gilakjani, 2012). Precisely the same argument has been made with regard to deaf students (e.g., Marschark, Lang, & Albertini, 2002), even though what little empirical evidence is available does not support that view. Dowaliby and Lang (1999), for example, provided deaf students with animated film clips and/or sign language interpretations to support learning from a science text, but neither improved performance. Periodic interjection of adjunct questions simply requiring restatement of presented information, in contrast, did significantly improve the deaf students' subsequent test scores.

More generally, the role(s) of visual-spatial abilities in academic performance are likely to be domain-specific. The manipulation of complex mental images, an area of strength for

deaf individuals (Emmorey, Kosslyn, & Bellugi, 1993), for example, would be expected to support geometry and other mathematical abilities (Blatto-Vallee, Kelly, Gaustad, Porter, & Fonzi, 2007). Their wider visual fields and greater sensitivity to visual information in the environment (Marschark & Hauser, 2012, Ch. 6), in contrast, likely would be more helpful in science than in mathematics. Assumptions about general advantages accruing to deaf students as visual learners, however, risk failing to capture nuances in teaching and learning that support academic success or create barriers to it. It therefore is important to consider the roles that specific cognitive abilities might have in specific academic areas.

Bavelier, Dye, and Hauser (2009) and Marschark and Wauters (2011) reviewed literature indicating that deaf individuals show better visual-spatial skills than hearing individuals in some domains, but no better in others. Bavelier et al., however, argued many early memory studies in children were compounded by variables such as language fluency and the etiology of hearing losses which might result in neurological dysfunction in deaf individuals (e.g., Fagan, Pisoni, Horn, & Dillon, 2007). They noted that when confounding variables are controlled, deaf individuals generally show enhanced visual cognition in tasks that are attentionally demanding. The fact that this advantage is found in aspects of visual processing that would normally benefit from the correlation of auditory and visual information led them to conclude that it results from reorganization of multisensory areas in the brain. For example, deaf individuals are faster in shifting visual attention (Rettenback, Diller, & Sireteanu, 1999) and demonstrate enhanced peripheral visual attention compared to hearing individuals (Proksch & Bavelier, 2002). These advantages presumably derive from the importance of the visual system for identifying important stimuli in the periphery and resulting in developmental, neurological reorganization (e.g., Bosworth & Dobkins, 2002; Neville & Lawson, 1987). A number of studies, however, have shown that hearing individuals can acquire similar sensitivity through either real-world experience (e.g., use of sign language, Emmorey et al., 1993; video games; Dye, Green, & Bavelier, 2006) or by altering task demands (e.g., the proportion of peripheral detection trials; Chen, Zhang, & Zhou, 2006).

Importantly, the studies described by Bavelier et al. (2006) generally have involved native-signers, that is, deaf people with deaf parents. Those investigators and others have argued that this population is most appropriate for studies investigating cognitive abilities among deaf individuals because it avoids confounds frequently found among deaf people with hearing parents (i.e., associated with a relative lack of access to fluent language). While theoretically sound, there are two difficulties with that position. First, although Bavelier et al. and others assume that deaf individuals of deaf parents “achieve their language development milestones at the same rate and time as hearing individuals by virtue of being born within a signing community” (p. 512), this is not universally true. Evidence that deaf children of deaf parents demonstrate language development comparable to that of hearing children of hearing parents primarily comes from studies conducted with children up to age 2 years (e.g., Meier & Newport, 1990). Recent longitudinal studies involving deaf children of deaf parents growing up with ASL or British Sign Language (BSL), in contrast, have revealed vocabularies 20-30% below that normally seen in hearing children at age three (Anderson & Reilly, 2002; Woolfe, Herman, Roy, & Woll, 2010).

Further, only about 5% of deaf individuals have deaf parents themselves and hence acquire a sign language as their first language (Mitchell & Karchmer, 2004). Limiting cognitive research to 5% of deaf individuals might be theoretically enlightening, but it does little to increase our understanding of ways that visual-spatial abilities – both strengths and weakness – might affect classroom learning and academic achievement among the other 95% of deaf students. Greater sensitivity to peripheral stimuli and the ability to more rapidly shift visual attention suggests that deaf children might use those advantages in formal and

informal learning situations, but it does not help us to understand the extent to which they are “visual learners.” Nor can one infer that the use of visual instructional materials will be any more beneficial for deaf students as a group than they are for hearing students who are visual learners (Massa & Mayer, 2006). Further, Dye, Hauser, and Bavelier (2008) pointed out that deaf students’ greater sensitivity to changes in the periphery also makes them more visually distractible in the classroom. All of this does not mean that visual-spatial abilities are unimportant for learning; they clearly are in some domains. It simply means that we need to better understand what deaf students’ visual-spatial abilities are and how they can be applied in specific academic tasks rather than assuming that the simple availability of visual materials is the key to their success in those tasks.

1.1.4 Academic Achievement of Deaf Students

There is a long history of academic underachievement by deaf students (see Marschark et al., 2002). Reading comprehension and mathematics have been the primary areas of inquiry, both because of their importance for academic and employment purposes but also because they constitute the domains most frequently addressed by standardized educational testing (see Mitchell & Karchmer, 2011; Stinson & Kluwin, 2011, for reviews). For reasons still to be elucidated, performance in both of these areas has seen little improvement over the past 30 years. Median scores on the Stanford Achievement Test Reading Comprehension subtest for 18-year-old deaf and hard-of-hearing students, for example, have increased only from grade level 2.7 to grade level 4.0, from levels expected of hearing 8-year-olds to that of hearing 9-year-olds (Allen, 1986; Qi & Mitchell, 2012; Traxler, 2000).

If reading and mathematics continued to be the primary topics of concern in deaf education, similar and perhaps related challenges have been observed across the curriculum. Studies by Borgna et al. (2011) and Marschark et al. (2009), for example, found that deaf college students learned significantly less science content taught under a variety of conditions relative to hearing peers, replicating studies involving learning of mathematics (Blatto-Vallee et al., 2007; Marschark, Sapere, Convertino, & Seewagen, 2005). Similar results have been obtained with children (e.g., Roald & Mikalsen, 2000, in science; Ansell & Pagliaro, 2006, in mathematics). Mathematics and science learning are particularly relevant to visual-spatial abilities given the importance of diagrams and visualization of problem components and problem spaces (Ansell & Pagliaro, 2006; Blatto-Vallee et al., 2007; Hegarty & Kozhevnikov, 1999). The present study was part of a larger research program examining foundations of mathematics performance in deaf children and young adults, focusing on visual-spatial ability as part of broader cognitive and academic functioning.

1.1.4.1 Visual-spatial Abilities and Mathematics Performance—Hegarty and Kozhevnikov (1999) demonstrated that the visual-spatial mental representations used by 11- to 13-year-olds while solving math problems could be classified as either *schematic*, including relations among elements that could help to support problem-solving, or *pictorial*, including visual properties (as in a picture) but not reflecting conceptual, mathematical aspects of the problems (see also Kozhevnikov, Kosslyn, & Shepard, 2005). The generation of schematic representations was associated with both an independent measure of spatial ability and greater success in solving mathematics problems. Further, Hegarty and Kozhevnikov found that children who could be classified as visualizers rather than verbalizers tended to be either high in spatial ability (generating schematic images) or low in spatial ability (generating pictorial images), suggesting two different cognitive styles within a population that would be considered visual learners.

Blatto-Vallee et al. (2007) obtained results similar to those of Hegarty and Kozhevnikov in a study involving deaf and hearing students in middle school through university. Overall, the

deaf students were less likely than hearing peers to utilize schematic, spatial-relational representations that would support problem-solving. Instead, they appeared to rely primarily on pictorial representations, which included incidental visual aspects of the problems but not quantitative relations important to their solution. Performance on the problems was predicted by students' scores on the Primary Mental Abilities (PMA) Spatial Relations Test, in which participants have to select the missing part that would complete a square, and the Revised Minnesota Paper Form Board Test (MPFB), in which participants examine the component parts of a figure and then select the correct form of the whole figure if the parts were assembled. However, contrary to expectations if deaf students generally are to be considered visual learners, Blatto-Vallee et al. found that the hearing students at all levels scored higher than the deaf students on the visual-spatial tasks. Consistent with their being more likely than the deaf students to use schematic representations, they also performed better on the math problems.

In summary, deaf individuals do have some visual-spatial advantages relative to hearing individuals, although their possible relevance to academic performance remains to be determined. If deaf (or hearing) students have cognitive skills especially suited to a particular task or learning situation, however, they have to know when and how to deploy them. In their review of research involving cognitive and metacognitive abilities of deaf learners, Marschark and Knoors (2012) noted that deaf students tend to be less likely than hearing peers to automatically utilize cognitive abilities and knowledge that we know they have. They also may have fewer metacognitive skills at their disposal. Marschark and Knoors therefore emphasized that such findings indicate the need for teachers of deaf students to determine in advance the appropriateness of instructional materials, ensure that students have the skills to take advantage of them, and verify that they are being used correctly by their students. One way to encourage students to utilize both skills and knowledge during learning is to provide tasks that are particularly suited to their abilities and gradually become more complicated or abstract so as to foster generalization and transfer (Mousley & Kelly, 1998). In the present study, we sought to provide such a situation for mathematics problem-solving while at the same time examining the impact of deaf students' visual-spatial skills on performance.

2.1 The Present Study

This study had two primary purposes. At a general level, it was intended as a step toward determining the extent to which deaf students can be considered visual learners in any sense beyond or different from hearing students. At a more specific level, we were interested in possible relations among various visual-spatial skills, language, and related cognitive abilities as they relate to mathematics performance. The problem-solving task in the Blatto-Vallee et al. (2007) study consisted of 15 word problems drawn from Hegarty and Kozhevnikov (1999). Here, we selected problems from the American College Test (ACT) mathematics subtest that included diagrams. The expectation was that the availability of the diagrams would in some sense prime students to use their visual-spatial skills to a greater extent than the word problems of Blatto-Vallee et al., thus increasing performance relative to their findings.

On the basis of the Hegarty and Kozhevnikov and Blatto-Vallee et al. results, we expected that students' spatial abilities would be associated with their mathematics performance. A broader range of visual-spatial abilities was examined in an effort to better understand the extent to which deaf students are visual learners. Although we did not limit participation by deaf students to those who were native signers, we did focus on those who preferred sign language over spoken language as the language of instruction. At the same time, we allowed the amount of hearing the deaf students had to vary. Although hearing thresholds typically

are found to be related to language development and reading ability (Holt, 1993; Yoshinaga-Itano & Downey, 1996), they generally do not predict either academic achievement or classroom learning more broadly (Convertino, Marschark, Sapere, Sarchet, & Zupan, 2009; Powers, 1999, 2003; Tymms, Brien, Merrell, Collins, & Jones, 2003; but see Karchmer, Milone, & Wolk, 1979). However, as hearing thresholds increase and students are more likely to rely on vision (and sign language), there may be a link to spatial abilities and their use in mathematics or other content areas (Hauptman & Eliot, 1986).

2.2 Method

2.2.1 Participants

A total of 39 deaf students and 32 hearing university students at Rochester Institute of Technology (RIT) volunteered to participate in the study for \$15 each. The deaf students included 18 males and 21 females; the hearing students included 16 males and 16 females. Fourteen of the deaf students reported using cochlear implants (CIs). Hearing thresholds were available for 36 of the 39 deaf students. The mean pure tone average (PTA) in the better ear was 102.92 dB (SD =15.56). As described in section 1.1, for the purposes of this study interest focused on deaf students whose primary mode of communication with sign language, intentionally creating a bias toward greater visual-spatial functioning, at least in theory. As will be described below, all of the deaf students indicated good ASL skills, with all but one rating themselves either 4 or 5 on a five-point scale ranging from “none” to “excellent” (mean =4.69). All but four of the hearing students indicated not knowing any ASL; four indicated only minimal knowledge.

2.2.2 Materials

Language and communication skills of deaf students entering RIT are evaluated for the purposes of service provision through the Language and Communication Background Questionnaire (LCBQ). RIT utilizes this self-report measure in lieu of face-to-face communication interviews because it is faster than interview assessments, can be administered online, and correlates around .80 with interview assessments (Hatfield, Caccamise, & Siple, 1978; McKee, Stinson, & Blake, 1984). The research version of the LCBQ utilized here asked students the age at which they learned to sign and had them rate their skill in understanding ASL, their skill in understanding signed English (without voice), their skill in understanding simultaneous communication (speech and sign together), and their skill in understanding spoken language (without sign), all rated on five-point Likert scales. Use of hearing aids and CIs and sign language histories were also queried.

In order to examine visual-spatial functioning in learning-related domains, seven individual differences tests were utilized. Five were drawn from the Woodcock-Johnson III Tests of Cognitive Abilities (WJ-III), both because of the frequency with which they are used in school settings and our desire, in the future, to tie results from this research program to studies involving the Cattell-Horn-Carroll theory of cognitive functioning (e.g., Akamatsu et al., 2008) and the National Longitudinal Transition Study 2 (www.nlts2.org). *Spatial Relations* requires individuals “to identify the two or three pieces that form a complete target shape” tapping both spatial relations and visualization abilities (Mather & Woodcock, 2001, p.13). *Picture Recognition* also is described as tapping an aspect of visual-spatial cognition, measuring visual memory of pictures, as the individual has to recognize “a subset previously presented pictures within the field of distracting pictures.” (pp. 14-15). *Visual Matching* is a visual-spatial test of perceptual speed. It measures “the speed at which an individual can make visual symbol discriminations... the subject is asked to locate and circle the two identical numbers in a row of six members.” (p.13). *Decision Speed* is a visual-spatial task that measures cognitive efficiency, measuring “the speed of processing simple concepts. In

each row, the subject's task is to locate quickly the two pictures that are most similar conceptually" (p.15). *Pair Cancellation* taps both executive functioning (interference control) and attention/concentration (sustained attention) in visual-spatial working memory (p. 16).

In addition to the WJ-III tasks, there were two other visual-spatial tasks. An *Embedded Figures* task examined the ability to separate figure and ground. Embedded figures tasks typically are described as determining an individual's ability to identify objects hidden within a background (Hauptman & Eliot, 1986). Our task was chosen from a "hidden figures" game in *Highlights for Children* magazine and included 18 objects embedded within a background scene of birds and flowers. Pretesting in another study had indicated the task to be sufficiently difficult for deaf and hearing college students, avoiding floor and ceiling effects. The *Corsi* test is a block-tapping task that assesses visuospatial working memory (see Richardson, 2011). The experimenter identifies to-be-recalled sequences by tapping on nine blocks permanently fixed in a haphazard manner on a board. Sequences with increasing numbers of blocks tapped have to be repeated by the participant. Finally, in order to examine the relation of deaf and hearing students' visual-spatial abilities to solving mathematics problems (Blatto-Valle et al., 2007), six word problems that included accompanying diagrams were chosen randomly from the mathematics subtest of the American College Test (ACT).

2.2.3 Procedure

Each student was tested individually by one of three experimenters, all of whom were both full-time-researchers and highly-skilled interpreters with 12-30 years of experience in the RIT setting. They were trained in the Woodcock-Johnson tasks by a Ph.D.-level school psychologist who uses the battery regularly. All tasks were scored by at least two of the experimenters and a few disagreements resolved in conference. All students received the pencil and paper visual-spatial tasks first, followed by the ACT questions, the LCBQ and then the Corsi blocks task.

3.1 Results

Preliminary analyses of the all tasks included the number of items completed within the time limits and, for all but the Corsi blocks, the proportion of items completed correctly. The Corsi blocks task is scored both by the number of trials completed and the highest span reached. Analyses of the proportion correct and the number of items completed in the time allotted yielded the same results for all tasks; only results from the analyses involving proportions and Corsi spans will be reported. In the analyses described below, all and only those results described were significant at or beyond the .05 level.

An initial analysis compared the scores of deaf and hearing students on the seven visual-spatial tasks using a one-way MANOVA in order to reduce the possibility of Type I error. Two of the visual-spatial tasks yielded significant differences, *Pair Cancellation*, $F(1,69) = 4.32$, and *Embedded Figures*, $F(1,69) = 4.86$, and it was a marginal effect of *Decision Speed*, $F(1,69) = 3.60$, $p = .062$. There was also a significant difference between the two groups on their ACT scores, $t(69) = 3.92$. As can be seen in Table 1, all of the significant differences (as well as those differences that were not significant) were in favor of the hearing students. In particular, visual-spatial measures of cognitive efficiency, executive functioning, and figure-ground discrimination indicated hearing students to be stronger than deaf students. However, the low power of variables in the MANOVA (ranging from .21 for the Corsi blocks to .59 for the *Embedded Figures*) suggests that the samples may have been too small and the variability on some of the tasks too large to reveal other significant differences between the groups.

Table 2 provides correlations between deaf and hearing students' ACT scores and their scores on the visual-spatial tasks. These indicate that there were significant associations between the deaf students' mathematics performance and their performance on four of the six visual-spatial tasks: Spatial Relations, Visual Matching, Embedded Figures, and Decision Speed, and marginal relations with Corsi block scores and Corsi span scores. For the hearing students, there were significant correlations between mathematics performance and two of the visual-spatial tasks: Spatial Relations and Embedded Figures. Table 2 reveals another interesting difference between the deaf and hearing students. For the deaf students, relations among the visual-spatial tasks were all positive, even if they were not significant. For the hearing students, in contrast, those relations frequently were negative or near zero.

Because scores on the several visual-spatial tasks (and their underlying abilities) are related, predictors of deaf and hearing students' solving of mathematics word problems involving diagrams were investigated using two stepwise multiple regressions, one for the deaf students and one for the hearing students, with ACT performance as dependent variable and the seven visual-spatial tasks as independent (predictor) variables. The regression analysis for the deaf students also included their PTA hearing thresholds and five communication variables drawn from the LCBQ: the age at which they learn to sign and their receptive skills in ASL, signed English, simultaneous communication, and spoken language. The only significant predictor of their ACT scores in the final regression equation, however, was Spatial Relations, $R^2 = .31$, $\beta = 3.71$. That finding is consistent with the results of Blatto-Vallee et al. (2007) who found that deaf students' scores on the PMA Spatial Relations test predicted their mathematical problem-solving abilities from middle school through university. For the hearing students, only their Embedded Figures scores predicted their ACT performance, $R^2 = .21$, $\beta = .64$.

Deaf students' hearing thresholds were not significantly related to their ACT scores or any of the visual-spatial tasks except for Spatial Relations, $r(34) = .34$. Although there also were no significant correlations between the several communication variables and deaf students' ACT scores, given the importance of communication for deaf students in the classroom, a final analysis examined the possible relation of deaf students' sign language skills and their visual-spatial abilities. Our work typically utilizes the LCBQ because of its established reliability and validity for deaf college students (Hatfield, Caccamise, & Siple, 1978; McKee, Stinson, & Blake, 1984), most investigators do not have such a tool available. Further, the lack of reliable, validated ASL assessments that can be done in a timely fashion means that most investigators do not provide measures of deaf individuals' sign language skills at all. Instead, whether a study involves children or adults, samples typically are divided into early signers and late signers (e.g., Emmorey et al., 2003). Using a similar approach, the present sample of 39 deaf students was divided using a median split. Seventeen students reported learning to sign at age 2½ or before (five from birth and at a mean of 1.42 years for the others), and 18 reported learning to sign later (mean = 5.67 years). Independent sample *t* tests indicated no significant differences between the early and late signers on any of the visual-spatial tasks, all $t_s(33) < 1.14$. In fact, the late signers scored slightly higher than the early signers on all but the Pair Cancellation task. The two groups of deaf students also did not differ in their ACT scores, $t(33) = .77$.

4.1 Discussion

This study explored the notion that deaf students are visual learners (e.g., Dowaliby & Lang, 1999; Lang, McKee, & Conner, 1993) and examined interrelations among several dimensions of their visual-spatial processing as compared to hearing students. It also explored possible links between visual-spatial skills and mathematics performance, an area of documented difficulty for deaf students (Qi & Mitchell, 2012). Given the importance

typically laid to building on the visual-spatial strengths of deaf learners in educational settings (Easterbrooks & Stephenson, 2006; Marschark et al., 2002), our focus was on deaf students who use sign language, the group most often referred to and studied as visual learners (Marschark & Hauser, 2012).

Consistent with the results of Blatto-Vallee et al. (2007), rather than deaf students' demonstrating any particular advantage in the visual-spatial domain, hearing students in the present study significantly outperformed deaf peers on two out of five tests of visual-spatial processing (Embedded Figures, Pair Cancellation); the groups did not differ significantly on the other two although there was a marginal difference on Decision Speed. Both deaf and hearing students' spatial abilities (as indicated by Spatial Relations test) were significantly related to their performance on math problems that included diagrams (Hegarty & Kozhevnikov, 1999). The several aspects of visual-spatial ability tapped by tasks in the present study were positively interrelated in the deaf students, even if not strongly so, while most of the correlation coefficients among hearing students' scores were small or even negative (Table 2). This result suggests that, at some level, the visual-spatial tasks used here tap somewhat slightly different cognitive abilities in deaf and hearing individuals, independent of whether or how they are used in problem-solving. For example, the Pair Cancellation task, which is both a visual-spatial task and an executive functioning task may be predominately the former for deaf participants, who tend to be weaker in executive functioning (Hauser, Lukowski, & Hillman, 2008). Given the difficulties of deaf individuals on sequential working memory tasks relative to visual-spatial working memory tasks (Hall & Bavelier, 2010), the visual-spatial aspect of the Corsi blocks task would have predominated for the deaf participants, while its sequential aspect likely would have been more salient for hearing participants.

The present study did not reveal any advantage in the visual-spatial abilities of early signers over late signers among the deaf students, even though one would expect that early signers would have greater visual-spatial skills (e.g., Bettger, Emmorey, McCullough, & Bellugi, 1997). More generally, although deaf students have to depend on vision more than their hearing peers (regardless of whether they use sign language or spoken language) there apparently is no evidence to indicate that they are more likely to be visual learners or to be better visual learners than hearing individuals. Deaf native signers display better visual-spatial working memory than hearing individuals (Proksch & Bavelier, 2002), but there also is no evidence that this superiority extends to the other 95% of deaf individuals (not including those with age-related hearing loss or *presbycusis*). Rather, findings from both memory studies (Marschark, 1993, chapters 8 & 9) and studies of visual-spatial abilities of the sort tapped by the WJ-III tasks (e.g., Blatto-Vallee et al., 2007) indicate either no difference or a moderate advantage for hearing individuals. Whether this is the result of hearing children developing with a natural correlation between vision and audition and thus greater flexibility in deploying such skills remains to be determined (Pisoni, Conway, Kronenberger, Henning, & Anaya, 2010). In any case, while the diversity of the sample of deaf students involved in the present study might be seen as a weakness from a theoretical purity perspective, the participants and their results are more representative of the real academic world of deaf students than would be the case with a sample of native signers.

The finding that greater hearing thresholds (i.e., less hearing) were associated with higher scores on the Spatial Relations test but not the other visual-spatial tasks is another puzzle to be solved. Spatial relations tasks, including the PMA and WJ-III versions, tap individuals' ability to see component parts as a whole; and the greater an individual's hearing loss the more they presumably have to depend on vision to identify objects and events in noisy environments (Silva-Moreno & Sanchez-Marin, 2003). That explanation leads to a prediction of an association between performance on spatial relations and embedded figures,

a relation found here for both deaf and hearing groups but significant only for the deaf students when other variables were controlled. Both for the purposes of theoretical clarification and the potential for fostering mathematics problem-solving among deaf students, future studies should examine Spatial Relations performance across a broader population of deaf students in terms of age, hearing loss (i.e., with and without cochlear implants), and language fluencies.

Finally, consider the educational implications of the present study. Mathematics is one area of the curriculum in which deaf students typically underperform relative to hearing students (Qi & Mitchell, 2012), and hearing students outperformed deaf students on problems from the ACT by a wide margin in the present study. Although performance on those problems (with diagrams) may not be directly comparable with the problems (without diagrams) used by Blatto-Vallee et al. (2007) and Hegarty and Kozhevnikov (1999), performance in the two studies that involved deaf students may be informative. We suggested in section 2.1 that providing diagrams might “prime” deaf students’ to deploy visual-spatial processes that would support mathematics problem solving. In the Blatto-Vallee et al. study, deaf college students’ scores, on average, were 57% of the hearing students’ scores (47% versus 83%), whereas in the present study deaf student scores were 69% of hearing students’ scores (49% versus 71%). Whether or not the difference is a reliable one, it suggests that providing deaf students with diagrams representing conceptual, relational information within a math problem may facilitate their arriving at a solution, at least for those students with greater spatial relations skills. More generally, demonstrations that deaf students sometimes do not utilize knowledge and skills we know they have in learning and problem-solving contexts (e.g., Liben, 1979; Marschark & Everhart, 1999) suggest that in addition to identifying possible visual-spatial strengths among deaf students, we also need to evaluate when and how they are used in the classroom (or not).

Deaf students’ visual-spatial skills in the present study were more strongly related to their mathematics performance than was the case for hearing students. Only the Embedded Figures task was significantly correlated with mathematics performance in the latter group, while Spatial Relations, Visual Matching, Embedded Figures, and Decision Speed all were significantly related to mathematics performance for the deaf students, and scores on the Corsi blocks were marginally related. Although the present results are consistent with previous studies, the low power of the comparisons between deaf and hearing participants leaves open the possibility that there were additional differences between the groups that were not detected due to the relatively small sample sizes, a common difficulty in studies involving deaf individuals. It therefore remains to be determined whether this pattern of results indicates that deaf students rely more on visual-spatial skills in mathematical problem-solving while hearing students utilize other cognitive processes as well as, or instead of, their visual-spatial abilities.

Taken together with previous findings, the present results indicate that assuming that deaf students are in some broad sense *visual learners* will be of only limited educational utility. Clearly, we need a better understanding of how their visual-spatial and other cognitive abilities affect learning if we want to develop interventions to take advantage of their strengths and accommodate their needs. In mathematics, where visual-spatial skills would seem to be particularly beneficial for problem-solving and learning, deaf students generally either do not have visual-spatial abilities that distinguish them from hearing students or fail to deploy them effectively. Deaf students believe that they are visual learners (Lang et al., 1993) apparently because of their reliance on vision for language (sign language and speechreading) and other forms of information transfer. Whether learning style assessments would confirm that belief is a question for future study. In any case, the present findings

suggest that deaf students' preference for visual presentation of information does not necessarily mean that it supports their learning any more than it does for hearing students.

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Highlights

- Visual-spatial abilities predicted mathematics problem-solving by deaf and hearing students
- Hearing students outperformed deaf students on visual-spatial tasks
- Deaf students' visual-spatial abilities were related to hearing thresholds but not sign language
- There was no indication that deaf students, in general, are visual learners

Table 1

Means (and standard deviations) for deaf and hearing students' performance on seven visual-spatial tests and the ACT Mathematics subtests. **Bold** indicates significant difference.

Test	Deaf	Hearing
Spatial Relations	.88 (.06)	.90 (.06)
Visual Matching	.85 (.11)	.89 (.08)
Picture Recognition	.88 (.06)	.89 (.04)
Embedded Figures	.38 (.15)	.46 (.17)
Decision Speed	.92 (.10)	.96 (.05) [$p=.62$]
Pair Cancellation	.94 (.05)	.96 (.04)
Corsi Block Trials	33.26 (5.45)	34.31 (5.38)
Corsi Block Span	5.70 (.99)	7.55 (9.80)
ACT Mathematics	.49 (.23)	.71 (.24)

Table 2

Correlations among visual-spatial tasks and ACT mathematics subtest for deaf and hearing students. Significance ($p < .05$) indicated by *.

DEAF									
	Spatial Relations	Visual Matching	Picture Recognition	Embedded Figures	Decision Speed	Pair Cancellation	Corsi Trials	Corsi Span	ACT Math
HEARING	Spatial Relations	.48*	.33*	.46*	.41*	.38*	.41*	.39*	.56*
	Visual Matching	-.21	.25	.46*	.69*	.18	.39*	.34*	.44*
	Picture Recognition	.15	.13	.28	.31	.34*	.13	.13	.22
	Embedded Figures	.58*	.10	.37*	.51*	.18	.16	.11	.50*
	Decision Speed	-.07	.47*	.28		.25	.28	.22	.32*
	Pair	-.12	.25	.13	.09		.16	.20	.13
	Cancellation								
	Corsi Trials	-.29	.29	-.003	-.22	.20		.97*	.30
	Corsi Span	.10	-.02	.02	.19	.22	.19		.28
ACT Math	.42*	.14	.05	.46*	-.006	.002	.04	.10	