Chapter 4
Measures of Visuospatial Ability

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Visuospatial functioning, while important for interaction with the world in general, is critical for deaf and hard of hearing individuals as it is the primary means of accessing language for this population. Whether the person uses American Sign Language (ASL), another signing or visual cuing system, or oral communication, visual access is the key to accurate language reception. Due to its spatial nature, full and accurate reception of ASL also depends on well-developed spatial processing (Bosworth et al. 2003). Indeed, an increasing body of research indicates that deaf individuals who have had early and ongoing exposure to and use of ASL process visuospatial information somewhat differently than their hearing peers and have enhancements in certain aspects of visuospatial processing (e.g., Bavelier et al. 2001, 2006; Bosworth and Dobkins 1999, 2002a, b; Hauser et al. 2007).

Clearly, visuospatial processing is important for the processing of ASL. While the relationship is not clear (Musselman 2000), and some have found little relationship between ASL skills and reading competence (Moores and Sweet 1990), recent research has supported ASL competence as a critical factor in the development of literacy for deaf signers based on the need for a strong first language (Chamberlain and Mayberry 2008; DeLana et al. 2007; Perfetti and Sandak 2000; Strong and Prinz 1997; Wilbur 2000). These relationships suggest that in addition to the visual capacity required to perceive print, visuospatial functioning may have unique associations with literacy and academic success in deaf students, particularly those for whom ASL is the primary mode of communication.

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Despite its critical nature, due to time constraints only two measures of visuospatial functioning were selected for the VL2 Psychometric Toolkit. One represents visuospatial analysis and memory, while the other measures skills in mental rotation. As discussed below, each of these areas is significant in the ability to communicate effectively via ASL.

Visuospatial Memory

Visuospatial memory reflects the person's ability to retain and retrieve information about both the content and location of objects in space. In practice, this is typically a three-dimensional process, such as remembering both what book one has misplaced as well as where it was placed in the environment. Since ASL is a visuospatial language, the ability to retain and retrieve information related to both the content (handshapes, etc.) and spatial location relative to the general environment as well as to the signer is critical for effective reception and comprehension of ASL. Most visual memory research has focused on working memory (WM), and that is investigated in the chapter on memory; however, as memory in the visual modality is so critical for ASL, a measure of simple retention and retrieval was included as well. While ASL is three dimensional, few measures of three-dimensional memory are available, so a two-dimensional task was used which has the advantage of being brief and having a delayed recall trial. This latter is important, as it would have implications for learning in the visual modality.

The Brief Visuospatial Memory Test-Revised

Test Characteristics

The Brief Visuospatial Memory Test-Revised (BVMT-R: Benedict 1997) is a measure of visuospatial memory. It is used in both research and clinical practice, investigating a range of conditions, including brain injury, multiple sclerosis, sleep apnea, and cardiovascular disease (Allen and Gfeller 2011; Beglinger et al. 2009; Cohen et al. 2009; Lim et al. 2007). The task involves presentation of six geometric figures presented in two rows of three designs. On each of three learning trials, the participant is allowed to see the design array for 10 s and is then asked to draw the items from memory, placing them in the correct locations on the page. Each drawing is scored for both location and accuracy, with two points awarded for an item drawn accurately in the correct location, one point if either the location or design was inaccurate, and zero if both were inadequate. The test has three learning trials on the immediate recall task, a delayed recall task following a 25-min delay, and a recognition trial on which the test items must be selected from among a set of 12

Table 4.1 BVMT-R—descriptive statistic

Test	Scale	Range	*N*	Mean (SD)
BVMT-R T-Scores	Total Recall	20–66	48	36.75 (13.33)
	Delayed Recall	20–63	48	35.56 (14.16)
	Discrimination Index (Index Score)	−1 to 6	46	5.53 (1.47)

designs. Performance on this task is affected by visual perception, visual memory (for both content and location), the graphomotor skills required for drawing, and, to a lesser extent, the organization of visuospatial information. Despite its graphomotor demands, this measure correlates more highly with visual memory tasks (with or without a drawing component) than with visual construction tasks without a memory component (Beglinger et al. 2009; Benedict 1997).

With the exception of the Discrimination Index, the scores are reflected in age-normed T-scores, with a mean of 50 and standard deviation of 10. The Discrimination Index reflects the difference between the number of correctly recognized items and the number of incorrectly identified foils. The highest and lowest possible scores are 6 and −6, respectively. The manual reports inter-rater reliability coefficients in the 0.90's and test–retest reliability coefficients between 0.60 and 0.84 for the free recall trials (Benedict et al. 1996).

Results

As can be seen in Table 4.1, which presents the descriptive statistics for the BVMT-R, contrary to expectations that deaf individuals would perform well on measures of visual memory, the group mean on the BVMT-R was more than one standard deviation below the normative mean on the learning trials and delayed recall trials. Nonetheless, the mean performance on the recognition task approached the maximum possible score, suggesting adequate encoding of the stimuli in memory despite the inadequate retrieval and production of the designs. Future research using these data could investigate the nature of the limitations on the recall tasks. Relevant questions include whether the low T-scores are related to errors in location or content, or whether the productions were poorly executed and therefore not given full credit despite adequate recall. The latter could relate to either poor motor control or limitations in executive functioning (EF) resulting in hurried drawings or drawings produced with inadequate care.

Table 4.2 presents the significant correlations between the BVMT-R Total Recall and the other Toolkit measures. Overall, the BVMT-R Total Recall correlated significantly with the measure of nonverbal intelligence as well as a number of WM, EF, and academic and linguistic measures, including the measures of linguistic memory. The fact that the BVMT-R Total Correct correlates with the Tower of London, WCST Total Correct, and WCST Categories Completed as well as the

Table 4.2 BVMT-R Total Recall—significant correlations

Test	*R*	*N*
BVMT Delayed Recall	0.78**	48
BVMT Discrimination Score	0.44**	48
Mental Rotation Test	0.41*	25
WJ-III: Reading Fluency	0.38**	47
WJ-III: Writing Fluency	0.42**	47
WJ-III: Academic Knowledge	0.38**	47
WJ-III: Passage Comprehension	0.35*	45
PIAT: Reading Comprehension	0.43**	48
WCST Total Correct	0.37*	36
WCST Categories Completed	0.38*	36
K-BIT2 Matrices	0.39**	48
Tower of London	0.37*	47
F-A-S: Food	0.31*	47
5–1–U	0.38**	48
5–1–U: Food	0.35*	46
M-SVLT List A Total Recall	0.46**	47
M-SVLT List B Total Recall	0.32*	47
M-SVLT Cued Recall	0.33*	46
M-SVLT Delayed List A Free Recall	0.37*	46
M-SVLT Delayed Cued Recall	0.34*	45
Finger Spelling Test: Total	0.34*	47
Finger Spelling Test: Real Word	0.37**	47
Corsi Blocks Computer Backward Span	0.34*	46
Corsi Blocks Manual Backward Span	0.38**	47
ASL Letter Forward Span	0.33*	47
ASL Letter Backward Span	0.38**	47

**Significance at $p<0.01$, *significance at $p<0.05$

MRT suggests that the lower than expected mean performance may be at least partially related to the proposed impacts of EF, rather than visual memory limitations, at least within a subset of the participants. On the other hand, consistent with previous research using the BVMT-R and English list-learning tasks with hearing participants, correlations between the BVMT-R and the M-SVLT, a sign-based list learning task, suggest that memory may indeed be involved.

The moderate significant correlations between the BVMT-R and a range of academic tasks contrast with the results of the BVMT-R normative study, which found nonsignificant to weak, but significant, (largest $r=0.17$) correlations between education and BVMT-R scores using a nonclinical sample (Benedict et al. 1996). Allen and Gfeller (2011) evaluated college undergraduates and found that the BVMT-R loaded with the Hopkins Verbal Learning Test-Revised (HVLT-R), an English list learning task similar to the SVLT on a principal component analysis. Benedict and colleagues also administered the BVMT-R as part of a battery of neuropsychological measures, this time to a clinical sample, and found correlations with the HVLT, as well as other measures of memory and learning. These data are consistent with

Table 4.3 BVMT-R Delayed Recall—significant correlations

Test	*R*	*N*
BVMT Total Recall	0.78**	48
BVMT Discrimination Score	0.37*	48
Mental Rotation Test	0.41*	25
WJ-III: Writing Fluency	0.30*	47
WCST Total Correct	0.40*	36
WCST Categories Completed	0.33‡	36
M-SVLT List A Total Recall	0.46**	47
M-SVLT Delayed List A Free Recall	0.29‡	46
Corsi Blocks Computer Backward Span	0.29‡	46
Corsi Blocks Manual Backward Span	0.31*	47

**Significance at $p<0.01$, *$p<0.05$, ‡$p=0.05$

the current outcomes despite the differences in the populations. Interestingly, they found minimal correlations between the BVMT-R scores and the FAS. Thus, the relationships seen with verbal learning measures in previous studies with hearing participants appear to reflect the impact of memory-based relationships, since more purely linguistic measures were not reported to produce significant correlations with this task.

This contrasts somewhat with the current data; however, while there was no significant correlation between the BVMT-R Total Correct and the F-A-S in the current sample, the sign-based task, 5–1–U did correlate significantly with this task. Furthermore, both the sign- and English-primed Food fluency tasks produced significant correlations, suggesting some relationship between visual language fluency and this visual learning task. Based on these data, it appears that the greater relationships between linguistic measures and the BVMT-R observed in the deaf signers in this study may relate to the visual nature of the primary language of this population.

Interestingly, as seen in Table 4.3, BVMT-R Delayed Recall correlated with a smaller subset of these tests associated with the BVMT-R Total Correct, primarily those related to visuospatial skills or memory. This suggests that the relationship of the initial learning trials, reflected in the Total Correct score, with the academic skills and larger set of linguistic tasks is important primarily during the learning phase, and that the retention of the designs over time relates more strongly to visuospatial processing, EF, and memory and learning, including language-based learning.

Despite the more limited relationships associated with retrieval and reproduction of these designs following a delay, many of the same associations seen with the initial learning trials were again observed with the recognition task, as revealed in the correlations with the Discrimination Index, presented in Table 4.4. Thus, there appears to be some ongoing relationship between language, both signed and English-based, in the ability of the participant to discriminate between the designs that had been learned and similar foils. This may relate to the "self-talk" involved in the

Table 4.4 BVMT-R Discrimination Index—significant correlations

Test	*R*	*N*
BVMT Total Correct	0.44**	48
BVMT Delayed Recall	0.37*	48
WJ-III: Passage Comprehension	0.34*	43
WJ-III: Math Fluency	–0.31*	45
PIAT: Reading Comprehension	0.45**	46
WCST Total Correct	0.36*	34
WCST Categories Completed	0.50**	34
Towers of Hanoi	0.36*	43
F-A-S: Food	0.36*	45
5–1–U: Food	0.34*	44
M-SVLT Delayed Cued Recall	0.30‡	43
ASL-SRT Total Correct	0.45*	30
TOSWRF SS	0.33*	45
Test of Syntactic Ability Percent Correct	0.70**	20
TSA Relativization Percent Correct	0.60**	20
Corsi Blocks Manual Backward Span	0.50**	44
ASL Letter Forward Span	0.34*	45

**Significance at $p<0.01$, *$p<0.05$, ‡$p=0.05$

decision-making process when selecting recognized designs from among the larger set. Interestingly, the strongest relationship with this score involves the participant's understanding of syntax as reflected in the correlations with the TSA scores. It is unclear if this reflects the impact of English skills on the discrimination task or whether there is an underlying factor affecting both skills. There is also a continued involvement of EF, which is consistent with the need to carefully review the stimuli and reason through the decision-making process.

Overall, the relationships between the BVMT-R and other Toolkit measures reveal significant relationships between this task and other measures of visuospatial processing and memory. Executive control appears to be associated with performance at all levels of this task, while language, both English and ASL, appears to be most significant during the learning phase of the task and later discrimination between the test items and similar design foils. While previous research has found associations between the BVMT-R and English-based list learning tasks, the visual nature of ASL may contribute to the other associations between language and visual memory observed in this study. The significant relationships between reading skills and two aspects of this test despite a lack of relationships with educational level in hearing populations (Benedict et al. 1996) suggest that English language competence, as reflected in reading skills as well as other language measures, may be a significant contributor to performance on the learning and discrimination aspects of visual memory. This relationship may be further elucidated by the relationships between mental rotation and other Toolkit measures, discussed below.

Mental Rotation

Mental rotation ability is considered important for success in a variety of areas, particularly the academic and vocational fields involving mathematics and science (Moè and Pazzaglia 2010). Mental rotation is the ability to perceive and cognitively manipulate two- and three-dimensional objects from different spatial perspectives. This process is used in a variety of everyday tasks; for instance, simple navigation relies on mental rotation to establish direction within the physical environment. The cognitive process of mental rotation was first recognized by Shepard and Metzler (1971) who, when presenting two similar objects at different perspectives, found a linear progression between time requirement and the difference in angles between the objects. Essentially, during Shepard and Metzler's task, the more an object was rotated, the more time was needed to determine that the two objects were similar. This was significant for cognitive psychology as a field as it was the first experiment to conclusively demonstrate that objects exist as cognitive representations.

The speed of mental rotation has been found to increase with age and familiarity (Kail and Park 1990; Kail et al. 1980). This suggests that processing of mental rotation can become increasingly automatic with experience; however, there does appear to be a limit to the benefit of the aging effect as participants older than 55 responded both more slowly and less accurately than younger participants (Dror and Kosslyn 1994). Research has also indicated that both training (Feng et al. 2007) and increased level of effort expended (Moè and Pazzaglia 2010) can improve performance on mental rotation tasks.

As previously noted, mental rotation has been historically tied to math, particularly math reasoning skills (Lubinski and Benbow 2006; Prescott et al. 2010; Shea et al. 2001). Within this relationship, males typically outperform females on both standardized math testing and mental rotation tasks (Ariniello 2000) and this difference in gender performance has remained stable over time (Masters and Sanders 1993). However, this gender difference reportedly disappears when mental rotation is tested through three-dimensional stimuli (Neubauer et al. 2010). Although mental rotation is commonly considered to contribute to math ability (Casey et al. 1995), research in a sample of deaf signers suggests that this is not the case for deaf individuals who use ASL (Halper 2009).

Deaf individuals have shown enhanced performance on mental rotation tasks compared to hearing peers (Emmorey 2002; Emmorey et al. 1998; Marschark 2003). However, despite the previously discussed relationship between mental rotation and math skills in the general population, this enhanced mental rotation ability has not resulted in corresponding gains in math performance among deaf students, many of whom graduate from high school having a sixth- to seventh-grade math level (Kelly 2008; Nunes and Moreno 2002; Qi and Mitchell 2012). Instead, research has suggested that mental rotation may correlate with English skills for deaf students who report their primary mode of communication to be ASL (Halper 2009). This relationship is thought to be secondary to the effects of sign language fluency, not deafness itself, as the previously noted mental rotation advantage is seen in both hearing and deaf ASL users, but not oral deaf individuals (Emmorey 2002; Marschark 2003; Parasnis et al. 1996). Indeed, both deaf and hearing signers appear to have enhanced mental rotation skills even when acquisition of ASL skills did not occur until early adulthood (Martin 2010, September). ASL is a spatial language that incorporates mental rotation and spatial relationships into its linguistic structure (Bosworth et al. 2003), and measurement of this ability is critical to the understanding of the complex role that mental rotation plays in learning and in language for deaf individuals.

The Mental Rotation Test

Test Characteristics

The MRT is an adapted form of the Vandenberg Mental Rotation Test (MRT: Vandenburg and Kuse 1978) that reflects both spatial organization and the ability to mentally visualize and rotate three-dimensional shapes. Shortened versions of Forms A and C of the redrawn Vandenberg Mental Rotation Test (Peters et al. 1995) were used in the present research as part of the counter-balanced battery administered within the VL2 Toolkit project. The current discussion will focus on Form A, which represented the bulk of the data.

The full version of this test is administered in two 12-item sections, each of which has a 3-min time limit. The version used in the present research consisted of one 3-min administration of the test with a total of 12 questions. On each item, participants are asked to indicate which two (out of four) shapes are the same as a target shape. Items in which both of the correct responses were indicated were scored as correct, other responses were scored as incorrect. Split half reliability on the full version of the Vandenberg Mental Rotation Test given to a comparable deaf adult sample showed a high degree of correspondence between performance on the first and second halves of the test, and patterns such as gender differences in performance and relative performance on Forms A and C were consistent with outcomes on the full test (Halper et al. 2011, June). These indicators support the use of the MRT short version as a valid representation of the abilities measured by the test.

Results

Overall, the current data on the short form of the MRT are consistent with the outcomes for the full (24 item) version of the MRT Form A as reported by Peters and colleagues, on which a sample of college students achieved a mean of 10.82 (SD 4.98). This indicates that the current sample of deaf college students is performing in a manner consistent with previous studies of hearing peers. Table 4.5 presents the descriptive statistics for the MRT.

Table 4.5 MRT, Short Form A—descriptive statistics

Test	Subtest	Range	*N*	Mean (SD)
Mental Rotation	Form A—short form	1–12	25	5.16 (2.97)

Table 4.6 MRT, Short Form A—significant correlations

Test	*R*	*N*
WJ-III: Reading Fluency	0.58**	24
PIAT-R: Reading Comprehension	0.42*	25
Tower of London Total Score	0.45*	25
Tower of London Total Moves	0.43*	25
Tower of London: Time Violations	0.45*	24
ASL-SRT	0.60*	15
ASL Letter Backwards Span	0.46*	25

**Significance at $p < 0.01$, *significance at $p < 0.05$

Table 4.6 presents the significant correlations between the MRT and the other Toolkit measures. Although significant relationships were observed with a relatively limited number of the Toolkit measures, as anticipated, moderate to large correlations between mental rotation and reading skills were obtained. This relationship is not typically found in hearing samples, although it is consistent with the above noted outcomes with deaf college students. Additionally, consistent with Halper (2009), the typical association with math skills was not observed with this deaf sample. In addition to the relationships with reading measures, again as expected, a strong relationship was observed with the measure of ASL skill, and moderate correlations were obtained between the MRT and one of the EF measures as well as an ASL-based measure of WM.

Of the correlations found with MRT, the strongest relationship was with the WJ-III Reading Fluency, a measure of fast, accurate reading of simple sentences. While this is consistent with Halper's (2009) research indicating a relationship between mental rotation and English skills for deaf students, it is also possible that multiple cognitive processes are common between these two tasks. For example, they may employ visualization of the items during the comprehension and decision-making process, allowing more rapid analysis of the item. As this is a timed task, this may result in an improved score. Additionally, as discussed elsewhere in this volume, having mastery of ASL as a first language may be able to support the acquisition of English print (Freel et al. 2011). Given the relationship between ASL fluency and mental rotation, it is possible that a high score on the Reading Fluency subtest could be indicative of underlying ASL fluency rather than a direct relationship between mental rotation and reading fluency.

A similar argument could be made concerning the significant relationship between the MRT and the PIAT-R Reading Comprehension subtest. While untimed, this reading comprehension task involves increased visual involvement in the task itself, as the participant must select a picture (out of four) which best represents a sentence which has been read. Thus, the processing speed demands are diminished, but there are increased demands on short-term memory. As Kelly (2003a, b) noted,

Table 4.7 Rasch Analysis Person and Item Statistics: Mental Rotation Test

	Persons	Items
Mean raw scores	4.9 (out of 12)	10.2 (out of 25)
SD of raw scores	2.7	4.6
Mean Rasch measures	–0.61	0
SE of means (for measures)	0.28	0.38
Measure range	−2.88 to 2.10	−1.45 to 2.58
# with MSq out-fit >2.0	2	1
Reliability (KR-20)	0.73	–

stronger language skills can decrease the cognitive load on WM during reading, leaving more resources for comprehension. Thus, if the MRT is reflective of ASL skills, this may partially explain the correlation seen between the MRT and this untimed reading measure.

The TOL test, as a problem-solving task, is commonly given to assess EF skills. Participants must solve visual problems in a limited amount of time, making few errors in the process in order to achieve higher scores. Phillips et al. (1999) found that mental rotation, as a component of spatial memory, plays a role in TOL success.

The ASL-SRT is a research measure of receptive ASL skills which requires a complex mixture of visual–spatial abilities, short-term memory, and motor skills to properly reproduce the sentence. Given the close relationship between ASL and mental rotation reported in previous research, it is not surprising to see a strong correlation between mental rotation and the ASL-SRT. The intervening impact of ASL skills on the ASL Letter Span task, which requires the participant to view a sequence of signed letters and repeat them in reverse order, may partially explain the correlation with this task.

Rasch Analysis

(Note: a brief explanation of the Rasch analysis procedures used in this book is provided in Chap. 3, as an introduction to the discussion of the Rasch analysis conducted on the item data for the K-BIT2.)

Table 4.7 presents the Rasch statistics for the MRT, and Fig. 4.1 presents the map of person ability and item difficulty logit scores. Figure 4.1 shows that there is considerable overlap between person abilities and item difficulties and that the range of item difficulties has a spread from −1.45 to 2.58 logits. The total range of just over four logits is considered narrow for most tests developed for Rasch analysis (Wright and Stone 1979). Table 4.7 shows that the mean ability level of participants was −.61, indicating that the MRT was a difficult test for many of the study participants. The range of ability levels for participants was from −2.88 to 2.10, and Fig. 4.1 shows that five participants had logit scores that fell below the item difficulty logit score for the easiest item on the test.

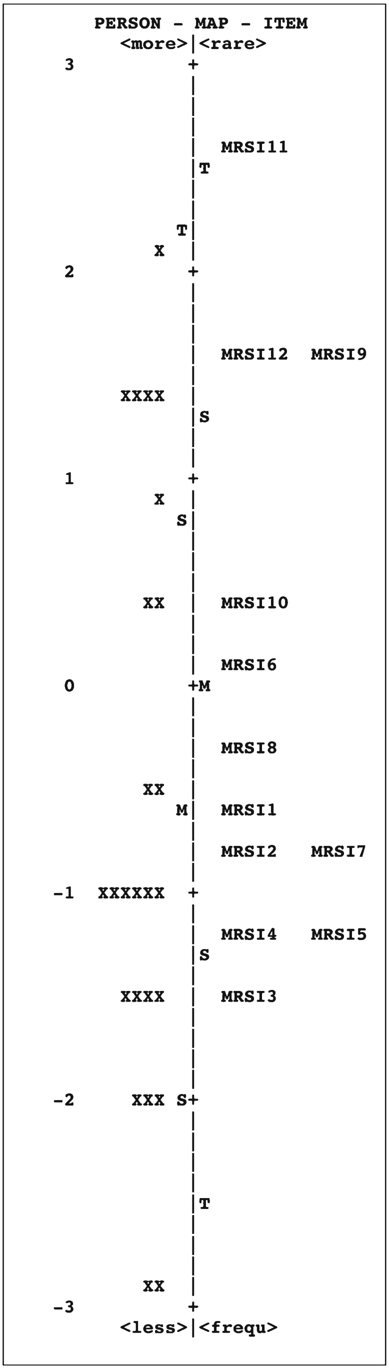

Fig. 4.1 Rasch person ability by item difficulty map: Mental Rotation Test

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The standard error for the Rasch person measure is 0.28 logits. This translates to a 95% confidence interval of ±0.55 logits, which is acceptable for an exploratory study (Linacre 1994). The standard error for the item difficulty measures is 0.38 logits, which is also acceptable. Table 4.7 shows that only 2 (out of 25) examinees had significant noise (Fit statistics >2) in their response patterns, as did only 1 of the 12 test items. This indicates a good "fit" of persons and items in this sample.

Finally, the KR20 reliability coefficient for this test (for these participants) is 0.73, a minimally acceptable level of internal test item consistency. In sum, this analysis reveals that the MRT was a difficult test with a narrow range of abilities measured. The standard errors for both persons and items were acceptable for an exploratory study. There was a good degree of fit between persons and items, and the internal consistency reliability was acceptable. Due to the small number of items, and the low number of participants taking this test, further research with larger samples, and, perhaps, a greater number of items covering a wider range of abilities would help to increase the test reliability and provide more stable estimates of examinee ability.

Conclusions

Overall, the data suggest that visuospatial functioning is significantly associated with literacy, ASL skills, and EF in this population. While visuospatial memory appears to have broader associations with academic functioning and linguistic memory, both English- and ASL based, the relationships with mental rotation were more restricted, focused on conceptually based reading comprehension (rather than that requiring a specific word to complete the task) and ASL skills. This suggests that while learning of this sample depends heavily on visual memory for both academic and language development (ASL and English), mental rotation has a more targeted impact on ASL skills. It is possible that the associations between mental rotation and the reading measures are mediated by ASL skills. This bears further investigation. Regardless, the associations between these visual measures and academic and linguistic functioning highlight the unique relationships among cognitive factors seen in this sample.

References

Allen, B. J., & Gfeller, J. D. (2011). The immediate post-concussion assessment and cognitive testing battery and traditional neuropsychological measures: A construct and concurrent validity study. *Brain Injury, 25*(2), 179–191.

Ariniello, L. (2000). *Gender and the brain*. Retrieved March 10, 2006, from web.sfn.org: web.sfn.org/content/Publications/BrainBrieffings/brain_lang_reading.htm.

Bavelier, D., Brozinsky, C., Tomann, A., Mitchell, T., & Liu, G. (2001). Impact of early deafness and early exposure to sign language on the cerebral organization for motion processing. *The Journal of Neuroscience, 21*(22), 8931–8942.

Bavelier, D., Dye, M. W. G., & Hauser, P. C. (2006). Do deaf individuals see better? *Trends in Cognitive Science, 10*, 512–518.

Beglinger, L. J., Duff, K., Moser, D. J., Cross, S. A., & Kareken, D. A. (2009). The Indiana Faces in Places Test: Preliminary findings on a new visuospatial memory test in patients with mild cognitive impairment. *Archives of Clinical Neuropsychology, 24*, 607–618.

Benedict, R. H. B. (1997). *Brief Visuospatial Memory Test-Revised (BVMT-R).* Odessa, FL: The Psychological Corporation.

Benedict, R. H. B., Schretlen, D., Groninger, L., Dobraski, M., & Shpritz, B. (1996). Revision of the Brief Visuospatial Memory Test: Studies of normal performance, reliability, and validity. *Psychological Assessment, 8*, 145–153.

Bosworth, R. G., & Dobkins, K. R. (1999). Left hemisphere dominance for motion processing in deaf signers. *Psychological Science, 10*(3), 256–262.

Bosworth, R. G., & Dobkins, K. R. (2002a). Visual field asymmetries for motion processing in deaf and hearing signers. *Brain and Cognition, 49*(1), 152–169.

Bosworth, R. G., & Dobkins, K. R. (2002b). The effects of spatial selective attention on motion processing in deaf and hearing subjects. *Brain and Cognition, 49*(1), 170–181.

Bosworth, R. G., Wright, C. E., Bartlett, M. S., Corina, D. P., & Dobkins, K. R. (2003). Characterization of the visual properties of signs in ASL. In A. E. Baker, B. van den Bogaerde, & O. Crasborn (Eds.), *Cross-linguistic perspectives in sign language research*. Hamburg: Signum Press.

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematical college entrance test scores across diverse samples. *Developmental Psychology, 31*(4), 697–705.

Chamberlain, C., & Mayberry, R. I. (2008). ASL syntactic and narrative comprehension in skilled and less skilled adult readers: Bilingual-bimodal evidence for the linguistic basis of reading. *Applied PsychoLinguistics, 29*, 368–388.

Cohen, R. A., Poppas, A., Forman, D. E., Hoth, K. F., Haley, A. P., Gunstad, J., et al. (2009). Vascular and cognitive functions associated with cardiovascular disease in the elderly. *Journal of Clinical and Experimental Neuropsychology, 31*(1), 96–110. doi:10.1080/13803390802014594.

DeLana, M., Gentry, M., & Andrews, J. (2007). The efficacy of ASL/English bilingual education: Investigating public schools. *American Annals of the Deaf, 152*(1), 73–87.

Dror, I., & Kosslyn, S. (1994). Mental imagery and aging. *Psychology and Aging, 9*(1), 90–102.

Emmorey, K. (2002). The impact of sign language use on visuospatial cognition. In K. Emmorey (Ed.), *Language, cognition and the brain: Insights from sign language research*. Mahwah, NJ: Lawrence Erlbaum Associates.

Emmorey, K., Klima, E., & Hickok, G. (1998). Mental rotation within linguistic and non-linguistic domains in users of American Sign Language. *Cognition, 68*(3), 221–246.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*(10), 850–855.

Freel, B., Clark, D., Anderson, M., Gilbert, G., Musyoka, M., & Hauser, P. (2011). Deaf individuals' bilingual abilities: American sign language proficiency, reading skills, and family characteristics. *Psychology, 2*(1), 18–23.

Halper, E. B. (2009). *The nature of relationships between mental rotation, math, and English in deaf signers*. Doctoral dissertation. Available from Dissertations and Theses database. (UMI Number: 3388611).

Halper, E., Hall, W. C., & Morere, D. A. (2011, June). Short form of the mental rotation test with deaf participants. Poster presented at the American Academy of Clinical Neuropsychology (AACN) 9th annual conference, Washington, DC. Abstract in *The Clinical Neuropsychologist, 25*(4), 516–607.

Hauser, P. C., Cohen, J., Dye, M. W. G., & Bavelier, D. (2007). Visual constructive and visual-motor skills in deaf native signers. *Journal of Deaf Studies and Deaf Education, 12*, 148–157.

Kail, R., & Park, Y. (1990). Impact of practice on speed of mental rotation. *Journal of Experimental Child Psychology, 49*(2), 227–244.

Kail, R., Pellegrino, J., & Carter, P. (1980). Developmental changes in mental rotation. *Journal of Experimental Child Psychology, 29*, 102–116.

Kelly, L. (2003a). Considerations for designing practice for deaf readers. *Journal of Deaf Studies and Deaf Education, 8*(2), 171–186.

Kelly, L. (2003b). The importance of processing automaticity and temporary storage capacity to the differences in comprehension between skilled and less skilled college-age deaf readers. *Journal of Deaf Studies and Deaf Education, 8*(3), 230–249.

Kelly, R. (2008). Deaf learners and mathematical problem solving. In *Deaf Cognition* (pp. 226–249). New York: Oxford University Press.

Lim, W., Bardwell, W. A., Loredo, J. S., Kim, E., Ancoli-Israel, S., Morgan, E. E., et al. (2007). Neuropsychological effects of 2-week continuous positive airway pressure treatment and supplemental oxygen in patients with obstructive sleep apnea: A randomized placebo-controlled study. *Journal of Clinical Sleep Medicine, 3*(4), 380–386.

Linacre, J. M. (1994). Sample size and item calibration stability. *Rasch Measurement Transactions, 7*(4), 328.

Lubinski, D., & Benbow, C. P. (2006). Study of mathematically precocious youth after 35 years: Uncovering antecedents for the development of math-science expertise. *Perspectives on Psychological Science, 1*, 316–345.

Marschark, M. (2003). Cognitive functioning in deaf adults and children. In M. Marschark & P. Spencer (Eds.), *Oxford handbook of deaf studies, language, and education* (pp. 464–477). New York: Oxford University Press.

Martin, A. J. (2010, September). *Age of acquisition effects of American Sign Language on mental rotation*. Poster presented at the Theoretical Issues in Sign Language Research 2010 conference, West Lafayette, IN. Poster retrieved from http://www.purdue.edu/tislr10/pdfs/Martin%20AJ.pdf.

Masters, M., & Sanders, B. (1993). Is the gender difference in mental rotation disappearing? *Behavior Genetics, 23*(4), 337–341.

Moè, A., & Pazzaglia, F. (2010). Beyond genetics in mental rotation test performance: The power of effort attribution. *Learning and Individual Differences, 20*, 464–468.

Moores, D., & Sweet, C. (1990). Relationships of English grammar and communicative fluency to reading in deaf adolescents. *Exceptionality, 1*(2), 97–106.

Musselman, C. (2000). How do children who can't hear learn to read an alphabetic script? A review of the literature on reading and deafness. *Journal of Deaf Studies and Deaf Education, 5*(1), 9–31.

Neubauer, A., Bergner, S., & Schatz, M. (2010). Two- vs. three-dimensional presentation of mental rotation tasks: Sex differences and effects of training on performance and brain activation. *Intelligence, 38*(5), 529–539.

Nunes, T., & Moreno, C. (2002). An intervention program for promoting deaf pupils' achievement in mathematics. *Journal of Deaf Studies and Deaf Education, 7*(2), 120–133.

Parasnis, I., Samar, V., Bettger, J., & Sathe, K. (1996). Does deafness lead to enhancement of visual spatial cognition in children? Negative evidence from deaf nonsigners. *Journal of Deaf Studies and Deaf Education, 1*(2), 145–152.

Perfetti, C., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Deaf Education, 5*(1), 32–50.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenburg & Kuse mental rotations test: Different versions and factors that affect performance. *Brain and Cognition, 28*, 39–58.

Phillips, L., Wynn, V., Gilhooly, K., Salla, S., & Logie, R. (1999). The role of memory in the tower of london task. *Memory, 7*(2), 209–231.

Prescott, J., Gavrilescu, M., Cunnington, R., O'Boyle, M. W., & Egan, G. F. (2010). Enhanced brain connectivity in math-gifted adolescents: An fMRI study using mental rotation. *Cognitive Neuroscience, 1*(4), 277–288. doi:10.1080/17588928.2010.506951.

Qi, S., & Mitchell, R. E. (2012). Large-scale academic achievement testing of deaf and hard-of-hearing students: Past, present, and future. *Journal of Deaf Studies and Deaf Education, 17*(1), 1–18. doi:10.1093/deafed/enr028.

Shea, D., Lubinski, D., & Benbow, C. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology, 93*(3), 604–614.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*(3972), 701–703.

Strong, M., & Prinz, P. M. (1997). A study of the relationship between American Sign Language and English literacy. *Journal of Deaf Studies and Deaf Education, 2*(1), 37–46.

Vandenburg, S., & Kuse, A. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47*(2), 599–604.

Wilbur, R. P. (2000). The use of ASL to support the development of English and literacy. *Journal of Deaf Studies and Deaf Education, 5*(1), 81–104.

Wright, B. D., & Stone, M. H. (1979). *Best test design*. Chicago: MESA Press.