

Visual Constructive and Visual–Motor Skills in Deaf Native Signers

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Visual constructive and visual–motor skills in the deaf population were investigated by comparing performance of deaf native signers ($n = 20$) to that of hearing nonsigners ($n = 20$) on the Beery–Buktenica Developmental Test of Visual–Motor Integration, Rey–Osterrieth Complex Figure Test, Wechsler Memory Scale Visual Reproduction subtest, and Stanford–Binet Intelligence Scale Paper Folding and Cutting subtest. Deaf signers were found to perform similarly to hearing controls, suggesting that these tests are valid assessment instruments to use with deaf individuals.

Myklebust (1964) was one of the first researchers to propose that the lack of auditory stimulation experienced by deaf individuals may result in a shift within cognitive organization. Since then, the literature has documented modifications in a variety of perceptual and cognitive processes in deaf individuals. There is much debate however about which skills are modified and whether performance is enhanced or rather hindered. Early studies reported that deaf children perform worse than hearing children on the Keystone Visual Survey (Myklebust, 1950), the Marble Board Test, figure-ground tests, and tachistoscopically presented materials (Werner & Strauss, 1942). Recently, Quittner et al. (Quittner, Smith, Osberger, Mitchell, &

Katz, 1994; Smith, Quittner, Osberger, & Miyamoto, 1998) observed that deaf children performed worse than hearing controls when asked to detect a prespecified sequence of digits among a stream of visually presented digits, suggesting difficulties in visual selection. These results have led some to propose that deafness results in deficits in visuospatial cognition (e.g., Quittner, Leibach, & Marciel, 2004).

These studies included deaf subjects with various backgrounds and with possible additional disabilities, which may have confounded some of their results. Indeed, studies that focus on a very small subsample of the deaf population with no associated confounds, also known as deaf native signers, report either no change or enhancement in visuospatial skills in this population. These individuals, who make up less than 5% of the deaf population (Mitchell & Karchmer, 2002), are born to deaf parents, have acquired American Sign Language (ASL) from birth, and are selected to have no known associated neurological disorder. Studies of this population have led to the proposal that early deafness per se enhances visuospatial skills, such as the processing of peripheral visual information and of motion information when attended (Bavelier, Dye, & Hauser, 2006; Bavelier et al., 2000; Bosworth & Dobkins, 1999; Neville & Lawson, 1987a, 1987b, 1987c; Proksch & Bavelier, 2002; Stevens & Neville, 2006). Sign language fluency in this population has also been shown to facilitate mental rotation (Chamberlain & Mayberry, 1994; McKee, 1988), image generation (Emmorey & Kosslyn, 1996; Emmorey, Kosslyn, & Bellugi, 1993), some

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aspects of face processing (Arnold & Murray, 1998; Bellugi et al., 1990; Parasnis, Samar, Bettger, & Sathe, 1996), and spatial memory span (Capirci, Cattani, Rossini, & Volterra, 1988; Parasnis et al., 1996; Wilson, Bettger, Niculae, & Klima, 1997).

These studies document changes in deaf native signers primarily in visual functions that rely on the dorsal visual pathway. This has led us and others to propose that altered experience such as deafness and/or signing may induce plastic changes more readily in dorsal visual functions (Armstrong, Neville, Hillyard, & Michell, 2002; Bavelier & Neville, 2002; Stevens & Neville, 2006). Recent findings indicate, however, that not all visual functions typically thought of as dorsal are modified. For example, several different aspects of motion processing were found to be equivalent between deaf signers and hearing controls (see Bavelier et al., 2006 for a review). Here we propose to extend this work to another set of skills known to engage the dorsal visual pathway—visual constructive and visual-motor skills (Rappport, Dutra, Webster, Charter, & Morrill, 1995; Rappport & Webster, 2003). Deaf native signers were administered a battery of psychological assessment tests aimed at characterizing their visual constructive and visual-motor skills, as follows: Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI; Beery, 1997, Pro-Ed, Austin, TX); Rey-Osterrieth Complex Figure Test (ROCF; Osterrieth, 1944; Rey, 1941); Wechsler Memory Scale-III Visual Reproduction I (VR I) subtest (Wechsler, 1997, Psychological Corporation, San Antonio, TX); and the Stanford-Binet Intelligence Scale-4th Edition (SB4) Paper Folding and Cutting subtest (Thorndike, Hagen, & Sattler, 1986, Riverside Publishing, Itasca, IL). These tests were selected as they are frequently used in clinical practice for psychological, psychoeducational, and neuropsychological evaluations. As we review below, the effect of deafness per se on such visual constructive and visual-motor abilities is at present unknown.

Beery-Buktenica Developmental Test of Visual-Motor Integration

The VMI is a low-level test of visual perception and motor integration that involves copying a series of geo-

metric shapes of increasing complexity. It is one of the most widely used psychological assessment measures of visual-motor skills and is used to identify learning and neuropsychological deficits (Kooistra, Crawford, Dewey, Cantell, & Kaplan, 2005). A study of preschool children in Australia with severe to profound hearing loss found that these subjects' performance on the VMI did not differ from established norms for their mean chronological age (Dodd, Woodhouse, & McIntosh, 1992). Another study, that examined the VMI performance of 7- to 8-year-old deaf and hard-of-hearing children in the United States, compared with age-matched hearing students, found similar results (Spencer & Delk, 1989). Spitz and Kegl (2004) also found no differences in VMI performance between deaf language isolates from Nicaragua (deaf individuals with no formal education who have not acquired a sign or spoken language), deaf signers of Idioma de Señas de Nicaragua, and hearing speakers of Spanish and/or Creole English.

Rey-Osterrieth Complex Figure Test

The ROCF consists of a hierarchically organized figure, comprised of global elements (e.g., a main rectangle) and local elements (e.g., single line details). Examinees are first instructed to copy the figure. The figure is then removed and the patient is asked to reproduce it from memory. The ROCF has been shown to identify, at least in the hearing population, deficits in visual constructive and visual-motor skills (see Knight, 2003 for a review). The few studies available testing deaf individuals on the ROCF suggest equivalent performance between deaf and hearing individuals in the accuracy of the reproduction but possible changes in overall strategy as measured by how subjects break down the reproduction problem (Eldredge, 1984; Eldredge & Zhang, 1988; Parasnis & Kirk, 2004). Hearing adults typically start with drawing the base rectangle of the ROCF and then add elements with increasingly more detail. This global to local strategy has been termed the *base rectangle strategy* (Kirk, 1982, 1985; Waber & Holmes, 1985). All populations do not share this approach. For example, until approximately 9 years of age, most children use a *piecemeal approach* to copying the ROCF where

the details of the figure are juxtaposed without any apparent overall plan, but in the end the figure is often globally recognizable (Anderson, Anderson, & Garth, 2001; Askhoomoff & Stiles, 2003; Karapetsas & Kantas, 1991; Kirk, 1985; Osterrieth, 1944; Waber & Holmes, 1985). By late adolescence, over 90% use the base rectangle strategy for copying the figure (Kirk, 1982, 1985; Waber & Holmes, 1985). Young adult deaf subjects have been reported to use the base rectangle strategy less often than hearing subjects (for example 46% in Eldredge, 1984; see also Eldredge & Zhang, 1988; Parasnis & Kirk, 2004). In all these studies, the number of errors in the ROCF reproductions, regardless of strategy used, was equivalent between deaf and hearing. The study by Spitz and Kegl (2004) extends these latter results to deaf language isolates from Nicaragua and deaf signers of Idioma de Señas de Nicaragua. When compared to hearing speakers of Spanish and/or Creole English, the accuracy of all groups' ROCF reproductions was similar except that language isolates performed worse than the other two groups in the immediate recall condition. Unlike the other studies, the approach the subjects took in reproducing the figure was not analyzed.

Wechsler Memory Scale-III Visual Reproduction I

The VR I is a test of visual memory and involves reproducing simple geometric figures from memory. The VR I is different from the ROCF in that (a) subjects are explicitly asked to memorize the figure, (b) subjects do not have the opportunity to practice drawing before recalling from memory, and (c) the forms are geometrically simpler.

Stanford-Binet Intelligence Scale-4th Edition Paper Folding and Cutting Subtest

The Paper Folding and Cutting subtest consists of a sequence of drawings that show a rectangular piece of paper being folded a number of times and then a cut being applied. The subject has to decide how the paper would appear when unfolded. The Paper Folding and Cutting test is a purer assessment of visual constructive skills than the other tests as it mostly relies

on the ability to mentally manipulate information in visual working memory.

Among the tests chosen, the ROCF provides a general assessment of visual-motor constructive skills, whereas the VMI and VR I provide purer assessments of visual-motor capacity and the Paper Folding and Cutting Test a purer assessment of visual working memory. There are no studies that have investigated deaf or hard-of-hearing individuals' performance on VR I or the Paper Folding and Cutting test. The bulk of studies on ROCF and VMI included deaf subjects from hearing families, which introduces two possible confounds. First, deaf individuals from hearing parents almost always experience a language delay (and associated delay in psychosocial development) because their hearing loss is usually not detected until around the age of 18 months and they are not exposed to a natural language that they can readily grasp until a later age (Mertens, Suss-Lehrer, & Scott-Olson, 2000; Samuel, 1996). Second, the etiology of their hearing loss could have caused some associated neurological changes (Hauser, Wills, & Isquith, 2006; King, Hauser, & Isquith, 2006). The Eldredge (1984) study, for example, reports that 23% of the subjects had an "other handicapping condition." The effects of deafness, without these confounds, on these visual constructive and visual-motor tests are unknown. To investigate performance of deaf individuals with minimal contamination from these confounds, we tested performance using deaf native signers exclusively. These individuals were selected to not have the secondary disabilities that are often associated with non-genetic causes of hearing loss. Unlike deaf children of hearing parents, these individuals are also known to achieve their sign language development milestones at the same rate as hearing individuals (e.g., Caselli & Volterra, 1994; Newport & Meier, 1985; Pettito & Marentette, 1991; Ross & Newport, 1996; Singleton & Newport, 1994) indicating no delay in language development.

Method

Participants

Twenty congenitally deaf (dB loss > 85 in better ear), native ASL signers were recruited from Gallaudet

University in Washington, DC (13 female, 7 male; $M_{\text{age}} = 20.9$, $SD = 2.1$). All deaf signers were exposed to ASL from birth by their deaf parents, considered ASL as their primary language, and reported daily ASL use. Twenty age- and gender-matched hearing native English speakers (unfamiliar with ASL) were recruited from Monroe Community College in Rochester, NY (13 female, 7 male; $M_{\text{age}} = 22.9$, $SD = 3.1$). All subjects were right-hand dominant. No subjects had histories of neurological illness, head trauma or loss of consciousness, significant psychiatric illness, current or past use of psychoactive medication, or uncorrected vision problems. All subjects were recruited through flyers and e-mail announcements. Written informed consent was obtained from all participants, and they were paid for their participation in this study.

Materials and Procedure

All subjects were tested individually. All deaf subjects were tested by fluent signers, and instructions were given in ASL. All hearing subjects were tested by hearing individuals in spoken English. After informed consent was given, subjects were required to complete a demographic questionnaire. Tests were given in the same order to both groups to avoid a between-group order effect. Blind scoring of the VMI, ROCF, and VR I reproductions was performed by a licensed clinical neuropsychologist.

Beery–Buktenica Developmental Test of Visual–Motor Integration. The VMI stimulus and response sheet was presented on paper taped on top of a Wacom 9" × 12" Intuos2 graphics tablet (Wacom Technologies Corporation, Vancouver, WA), connected to a Dell Pentium 4 computer (Dell Computers, Round Rock, TX). Subjects were given an Intuos2 Inking Pen (ball-point pen) that allowed the computer to record a video of the drawing process via a drawing program (Procreate Painter Classic v2.0.0 by Procreate, Ottawa, Ontario, Canada) coupled with video screen capture software (Capture Professional v5.06a by Creative Softworx, Alpharetta, GA). The standard administration procedures described in the VMI manual (Beery, 1997) were followed. Subjects were not required to

imitate the first three shapes. Subjects were automatically granted the first three points and thus began with item four. The only exception to the standardized instructions was that all images were copied rather than discontinuing the test after failing three consecutive items as suggested by the manual. This modification of procedures provided more data; however, the scores reported here were computed as suggested by the manual. Correct drawings made after three consecutive errors were not included in the final raw score.

Rey–Osterrieth Complex Figure Test. The ROCF stimulus was presented horizontally on an 8" × 11" piece of paper. The Wacom tablet was placed between the ROCF stimulus and the subject. A blank piece of 8" × 11" paper was taped to the tablet. Subjects were given the Intuos2 Pen, and their drawings were recorded using the same equipment and software that were used for the VMI. The administration and scoring procedures of Meyers and Meyers (1996) were used here. Subjects were shown the complex figure and asked to copy it. They were not told they would have to reproduce it again from memory. The figure was removed after the copy was completed, and 3 minutes later subjects were asked to reproduce the figure from memory. Only the copy and immediate recall trials of the ROCF were administered as we were interested in comparing visual constructive skills across populations and not longer-term memory decay of such information. The examiner did not provide any feedback during the copy and recall trials, and the same recording equipment was used throughout both trials.

The ROCF reproduction accuracy was scored using the Rey–Osterrieth 36-point scoring system (Rey & Osterrieth, 1993) where 18 elements of the ROCF were awarded two points each if the elements were reproduced correctly in the correct placement. However, one point was awarded if an element was reproduced incorrectly or in the wrong placement, a half point if distorted and placed poorly, and zero points if absent or not recognizable (see Meyers & Meyers, 1996). The procedure used by Parasnis and Kirk (2004) was used to identify subjects who used the base rectangle strategy. If a subject drew the base rectangle or the five-sided global shape in the beginning, before

drawing any of the other elements (with the exception of the cross on the left), then it was marked that the subject used the base rectangle strategy.

Wechsler Memory Scale-III Visual Reproduction I. The VR I and VR Copy were administered using the same instructions outlined in the test manual (Wechsler, 1997). Five pages of geometric designs are shown, one at a time. After viewing each stimulus page for 10 s, the subjects are instructed to draw the designs as accurately as possible from memory. After completing the recall task, subjects are presented with the designs again and asked to copy each while viewing the design (VR Copy). The Wacom tablet was not used for this test. VR I was scored according to the criteria outlined in the scoring manual. Each design had a specific set of criteria to be met for full credit and some criterion allowed for partial credit. Although the VR Copy was administered after the VR I, it will not be discussed further as it is an optional subtest and is rarely used in the clinical setting.

Stanford-Binet Intelligence Scale-4th Edition Paper Folding and Cutting Subtest. The Paper Folding and Cutting subtest was administered using the standardized instructions provided by the SB4 manual (Thorndike et al., 1986). The Paper Folding and Cutting subtest consists of a sequence of drawings that show the process of a rectangular piece of paper being folded a number of times. The number of folds increases and directions of the folds vary in complexity throughout the test. The final sketch shows a gap on the paper indicating where the paper has been cut. The subject is asked to select one of five drawings that correctly represents how the paper would appear when

unfolded. Subjects were awarded one point for each correct response, and the total number of correct responses for each subject was recorded.

Results

To determine whether there was a population difference in test performance, all raw scores were converted to z -scores, and a multivariate analysis of variance (MANOVA) was performed with the standardized test scores as dependent measures (VMI, ROCF Copy, ROCF Immediate Recall, VR I, and SB4 Paper Folding and Cutting) and group (deaf, hearing) as a between-subjects factor. The effect of group was found to be significant, $F(5, 34) = 2.94$, $p < .03$, Wilk's lambda = 0.698 (see Table 1 for means and standard deviations and effect of group on each test).

The results of the MANOVA suggest that when combined, the distribution of these measures can differentiate between deaf and hearing populations. However, because the effect size direction varies as a function of the different measures, this overall effect cannot be attributed to better global performance on visuoconstructive tests in one population over the other. In addition, taken individually, each of these tests alone is not sufficient to differentiate between the two populations—differences in test performance were not found in the follow-up univariate analyses of variance for each test. There was a trend ($p = .08$) for hearing subjects to perform slightly better than the deaf subjects on the VMI—a task that requires copying alone. There was an opposite trend where deaf subjects recalled slightly more features of the ROCF in the immediate recall trial ($p = .10$). This pattern is

Table 1 Means and standard deviations of raw scores and analyses of variance for effect of deafness on test performance

Test	Deaf		Hearing		df	F	p	η^2
	M	SD	M	SD				
VMI	23.2	1.2	24.1	1.6	1, 38	3.31	.08	.080
ROCF Copy	29.1	3.3	29.7	4.4	1, 38	0.24	.63	.006
ROCF Immediate Recall	20.1	5.1	17.4	4.8	1, 38	2.24	.10	.072
VR I	87.3	7.7	88.4	1.6	1, 38	0.22	.64	.006
Paper Folding and Cutting	11.7	3.3	12.8	3.9	1, 38	0.95	.34	.024

Note. The analyses of variance were computed using z -scores.

Table 2 ROCF: Percentage of subjects (and frequency out of 20 per population) who used the base rectangle strategy (BRS)

Strategy	Copy		Immediate Recall	
	Deaf	Hearing	Deaf	Hearing
BRS	35% (7)	20% (4)	60% (12)	55% (11)

suggestive of a possible dissociation between the two populations when it comes to component processes of visuospatial constructive skills. However, it will be for future research to determine whether this trend can be confirmed and will not be discussed further.

A chi-square analysis was conducted to determine whether there was a population difference in the utilization of the base rectangle strategy between the deaf and hearing subjects in the two conditions of the ROCF. No population differences were found in the copy condition, $\chi^2(1, N = 40) = 1.13, p = .28$, or in the immediate recall condition, $\chi^2(1, N = 40) = .10, p = .75$ (see Table 2).

Discussion

This study provided a controlled investigation of the visual constructive and visual-motor skills of deaf adults. Deaf subjects from deaf families who learned ASL from birth were used to control for the delayed language development that is often found in deaf children of hearing families and to control for neurological deficits that are sometimes associated with non-genetic causes of hearing loss. In addition to this strict inclusion criterion, subjects with histories of neurological illness, head trauma or loss of consciousness, significant psychiatric illness, current or past use of psychoactive medication, or uncorrected vision problems were excluded from this study. Using these selection criteria, and considering in turn each of the tests administered, we conclude that the measured visuospatial constructive abilities are comparable between deaf and hearing populations.

Our findings that deaf and hearing perform similarly on these clinical measures is in line with previous reports. Indeed, deaf and hearing subjects, including those from other countries and those who did not have formal language exposure, have been reported to perform similarly on the VMI (Dodd et al., 1992;

Spencer & Delk, 1989; Spitz & Kegl, 2004). Our findings that deaf native signers do not differ from hearing controls are in accord with this earlier work. The VMI therefore can be considered a robust nonverbal test that is not affected by language skills, language modality, or deafness. Our data are also in line with previous work using the ROCF (Eldredge & Zhang, 1988; Parasnis & Kirk, 2004). However, a surprising outcome in these results is the fact that hearing subjects used the base rectangle strategy during the copy and recall trials less frequently than documented in previous literature (38% versus 90% or more; Kirk, 1982, 1985; Waber & Holmes, 1985). Psychologists do not conduct a base rectangle strategy analysis in clinical evaluations, and therefore, this result does not have any clinical significance. However, the source of this discrepancy is unclear and it might be worth investigating, in a future study, why previous results from hearing subjects were not replicated. Overall, the lack of a population difference on the ROCF fits well with previous reports using deaf individuals with more mixed backgrounds. In addition, our study extends the lack of effect of deafness on clinical tests of visuomotor constructive skills to the Visual Reproduction subtest of the WMS-III and the Paper Folding and Cutting subtest of the Stanford-Binet Intelligence Scale.

The finding that deaf native signers performed similarly to their matched hearing controls on five different tests of visual constructive and visual-motor skills establishes the robustness of these tests in the face of altered experience such as deafness or signing. Although there was a lack of power due to the small sample size, the amount of variance attributable to deafness each test was small, suggesting that any genuine effects that have not been detected in this study are of neither theoretical nor clinical importance. Clinical tests are designed to identify significant deviations in performance, not minor variations within the normal range. The present findings establish that at the

grain assessed by the clinical tests we have used, performance is comparable in deaf signers and hearing controls. The tests under study are currently used with deaf and hard-of-hearing individuals in clinical settings as, for almost a century, nonverbal cognitive tests have been considered the most appropriate tools for assessing cognitive abilities of deaf and hard-of-hearing children and adults (Maller, 2003; Pintner & Paterson, 1915; Vernon & Andrews, 1990). Our results indicate that psychologists who administer these tests to deaf and hard-of-hearing individuals and find scores outside of the normal range can assume a psychological or neuropsychological weakness that is not secondary to auditory deprivation *per se*.

A note of caution about test administration may be warranted, however. We used ASL translations of the instructions for the tests included in this study, and this did not have an apparent impact on the performance of our deaf native signer sample. As the deaf participants and their experimenters were all signers, it is likely that test administration relied on the appropriate linguistic mediation strategies to provide clear instructions and to allow for correct or rapid responses. For the deaf population in general, test instruction often needs to be given in a visual mode (e.g., signing, cueing, or lip-reading) or in a combination of auditory and visual modalities, depending upon which communication mode is most readily accessible to the patient. In essence, this means that almost every time a test is administered to this population, the standard administration procedures are violated (Braden, 1994; Maller, 2003), and the patient is at risk of being given less than optimal instruction. The extent to which performance remains stable under such conditions should be of concern as individual patient data are considered.

Our study establishes comparable performance in deaf signers and hearing individuals on five clinical measures designed to assess visuospatial constructive abilities. This finding contrasts with reports of significant population differences in other aspects of visual spatial processing. In particular, deaf signers are more accurate (McKee, 1988) and faster (Emmorey et al., 1993) in performing mental rotation tasks than hearing nonsigners. Importantly, deaf nonsigners performed similarly to hearing nonsigners (Chamberlain &

Mayberry, 1994) demonstrating that sign language fluency, but not deafness, enhances mental rotation. Similarly, deaf signers have a significantly longer spatial memory span than hearing nonsigners as measured by the Corsi Blocks Task (Wilson et al., 1997). The causal role of sign language in this effect was documented by reports that deaf children who have no exposure to sign language perform as well as, but not better than, hearing children on the Corsi Blocks Task (Parasnis et al., 1996), and hearing children (aged 6 years) who attended a one-year course in Italian Sign Language (*Lingua Italiana Dei Segni/LIS*) exhibited increased spatial memory span on the Corsi Blocks Task compared to their peers who did not attend the course (Capirci et al., 1998). These results demonstrate that sub-areas of functioning in the visuospatial domain (e.g., mental rotation and visuospatial memory) are modified in signers and contrast with the lack of a population difference reported here when testing visuospatial constructive abilities. It is worth noting that our sample size of 20 subjects per group, albeit small, compares favorably with that used in the studies mentioned above which have reported positive effects. This difference in outcome may be attributable, in part, to the greater sensitivity of the tests used in assessing visuospatial skills in those previous studies. For example, assessment of mental rotation skills was performed using tests specially designed to evaluate this particular component of visuospatial processing. Such tests may be more likely to detect small variations within the normal range than clinical tests, such as the Paper Folding and Cutting subtest, which are typically designed to be robust in the face of such small changes. In addition, it remains possible that not all aspects of visuospatial processing are equally modified by altered experience. The use of sign language makes heavy demands on mental rotation abilities and memory for visuospatial trajectories as embodied in the Corsi Blocks Task; in contrast, the ability to copy shapes or to draw them from memory is not central to signing. In this framework, the different outcome as a function of the skills tested supports the view that plastic changes tend to be highly specific after altered experience and do not generalize broadly to all aspects of a given cognitive domain, but rather stay confined to the specific subprocesses that are tapped by the altered

experience (see Bavelier & Neville, 2002; Bavelier et al., 2006; Fahle & Poggio, 2002 for discussion).

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