American Educational Research Journal
Winter 2005, Vol. 42, No. 4, pp. 727–761

Classroom Interpreting and Visual Information Processing in Mainstream Education for Deaf Students: Live or Memorex®?

Marc Marschark
Rochester Institute of Technology and University of Aberdeen
Jeff B. Pelz, Carol Convertino, Patricia Sapere,
Mary Ellen Arndt, and Rosemarie Seewagen
Rochester Institute of Technology

This study examined visual information processing and learning in classrooms including both deaf and hearing students. Of particular interest were the effects on deaf students' learning of live (three-dimensional) versus video-recorded (two-dimensional) sign language interpreting and the visual attention strategies of more and less experienced deaf signers exposed to simultaneous, multiple sources of visual information. Results from three experiments consistently indicated no differences in learning between three-dimensional and two-dimensional presentations among hearing or deaf students. Analyses of students' allocation of visual attention and the influence of various demographic and experimental variables suggested considerable flexibility in deaf students' receptive communication skills. Nevertheless, the findings also revealed a robust advantage in learning in favor of hearing students.

Keywords: deaf education, inclusion, interpreting, mainstream education, multimedia

According to the National Center for Health Statistics (2000), more than 200,000 school-aged children in the United States have significant hearing losses. Largely as a consequence of the 1975 passage of Public Law 94-142, the Education of All Handicapped Children Act (known as IDEA since being combined with the 1990 Individuals with Disabilities Education Act [Public Law 101-476]), the majority of these children attend regular public schools rather than separate schools designed for deaf students (Gallaudet Research Institute, 2004). Also as a result of IDEA, Section 504 of the Rehabilitation Act of 1973, and the Americans with Disabilities Act (Title III), the number of deaf individuals seeking postsecondary education has grown considerably. More than half of the colleges and universities in the United

States now report serving deaf students, with approximately 26,000 enrolled annually—an increase of more than 25% since 1990 (National Center for Education Statistics, 1999). As impressive as this growth may be, only about one in four deaf students enrolled in 4-year college programs actually graduate (Marschark, Lang, & Albertini, 2002).

Enrollment of deaf students (or other students with special needs) in local public schools is alternately known as *mainstreaming* or *inclusion.* Mainstreaming often involves deaf children attending special, "segregated" classes in addition to classes that include hearing peers. It also frequently includes the availability of a resource room and specially trained teachers or aides. Inclusion, in contrast, entails deaf students receiving all instruction and support services within their regular classroom. For the purposes of the present discussion and research, however, it is not necessary to distinguish between these two types of programs, and we use the terms interchangeably.

MARC MARSCHARK is a Professor at the Center for Education Research Partnerships, National Technical Institute for the Deaf, Rochester Institute of Technology, 96 Lomb Memorial Drive, Rochester, NY 14623; e-mail: *marc.marschark@rit.edu.* He is also a Professor in the School of Psychology, University of Aberdeen, Aberdeen, Scotland. His primary research interests concern relations of language and learning in deaf children and adults.

JEFF B. PELZ is an Associate Professor of Imaging Science, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623; e-mail: *pelz@cis.rit.edu.* His research focuses on task-dependent visual perception and attention through monitoring of observers' distribution of gaze in images or real scenes.

CAROL CONVERTINO is a Certified Sign Language Interpreter and Research Associate at the Center for Education Research Partnerships, National Technical Institute for the Deaf, Rochester Institute of Technology, 96 Lomb Memorial Drive, Rochester, NY 14623; e-mail: *carol.convertino@rit.edu.* She specializes in language, literacy, and learning among deaf students.

PATRICIA SAPERE is a Certified Sign Language Interpreter and a Research Associate at the Center for Education Research Partnerships, National Technical Institute for the Deaf, Rochester Institute of Technology, 96 Lomb Memorial Drive, Rochester, NY 14623; e-mail: *patricia.sapere@rit.edu.* Her research interests focus on sign language interpretation and deaf education.

MARY ELLEN ARNDT is a User-Interface Engineer, Xerox Global Services, 800 Phillips Road, 0111-02J, Webster, NY 14580; e-mail: *marndt@sdi.usa.xerox.com.* At the time of this project, she was a graduate student at the Rochester Institute of Technology. Her interests include applying gaze tracking to human-computer interface design and usability evaluation.

ROSEMARIE SEEWAGEN is a Project Assistant at the Center for Education Research Partnerships, National Technical Institute for the Deaf, Rochester Institute of Technology, 96 Lomb Memorial Drive, Rochester, NY 14623; e-mail: *rosemarie.seewagen@rit.edu.* Her primary research interest is learning by deaf students in various academic settings.

A primary assumption underlying mainstream/inclusive education is that, in the case of the majority of deaf students who depend on signed communication, a skilled sign language interpreter will provide access to classroom communication comparable to that of their hearing peers (for discussion, see Aldersley, 2002; Dubow, Geer, & Strauss, 1992; Winston, 1994). Nevertheless, among researchers and educators of the deaf, there is consensus that educational interpreting often falls short of deaf students' needs, especially at the secondary and postsecondary levels (Harrington, 2000; Kluwin & Stewart, 2000; Redden, Davis, & Brown, 1978; Stewart & Kluwin, 1996). There is a national shortage of qualified interpreters (even though the United States leads most countries in terms of availability of interpreters), and many deaf students struggle when there is a lack of interpreting or when interpreting is of questionable quality (Baily & Straub, 1992; Jones, Clark, & Stoltz, 1997; Schick, Bolster, & Williams, 1999).

The dynamics of a K–12 mainstream classroom that includes deaf and hearing students, a hearing teacher who typically is unfamiliar with the implications of early hearing loss, and a sign language interpreter (as another adult in the classroom) are such that IDEA's promise of a free and appropriate public education often seems hollow. At the postsecondary level (where different laws, for example Section 504 of the Rehabilitation Act of 1973, apply), few programs enrolling deaf students have available the knowledge or resources necessary to provide full access to even general academic curricula. The content knowledge necessary for interpreting in today's science, technology, and mathematics classrooms is often beyond the educational backgrounds of interpreters (see Harrington, 2000; Lang, 2002), and we have little idea how deaf students cope with impoverished communication in the classroom. If we are to provide deaf students of all ages with full access to educational opportunities, we have to better understand the cognitive underpinnings of and requirements for learning in various academic settings.

What Do We Know About Learning via Sign Language Interpreting?

Of primary interest here is how deaf students deal with the visual demands of learning via sign language interpreting. Several studies have examined learning through interpreting, but only a few studies have compared deaf and hearing students' learning in mainstream/inclusive classrooms. It appears that the first such study was conducted by Jacobs (1977), who found significantly greater learning from a classroom lecture among hearing college students than among their deaf peers, who depended on interpreting. Subsequent outcome studies focused almost exclusively on the effectiveness of alternative interpreting modes, especially American Sign Language (ASL) interpreting versus English transliteration (Cokely, 1990; Fleischer, 1975; Livingston, Singer, & Abramson, 1994; Murphy & Fleischer, 1977; Power & Hyde, 1997).[1] These studies failed to demonstrate any consistent advantage for a particular mode of interpreting, and only Livingston et al. (1994) found a significant benefit of mode-preference matching (and this benefit was observed in only one of several conditions).

More recently, Marschark, Sapere, Convertino, Seewagen, and Maltzan (2004) explored learning via sign language interpreting in a series of experiments in which deaf college students who varied in their sign language skills and preferences for ASL and English transliteration viewed lectures that were either interpreted or transliterated (i.e., a full 2 × 2 design). Regardless of whether learning was assessed through written tests (Experiments 1 and 3) or signed tests (Experiment 2), there was neither an effect of mode of interpreting nor any interaction with student skills or preferences. These null findings were replicated in a larger study conducted by Marschark, Sapere, Convertino, and Seewagen (2005a). Together with earlier studies, these consistent findings suggest that mode of interpreting has little if any effect on learning, at least at the college level. More important for the present purposes, deaf students in these experiments scored between 60% and 75% on multiple-choice tests of learning, as compared with scores of 85% to 90% obtained by their hearing peers.

The level of performance observed in the Marschark et al. studies is fully consistent with all of the findings of the studies mentioned earlier. Nevertheless, a potential shortcoming of the new studies is their use of videotaped materials (life-sized video projection). Earlier studies all had involved live interpreting, thus requiring interpreters to be aware of the different experimental manipulations or including multiple interpreters across multiple testing sessions. Use of videotaped lectures and interpreting in the Marschark et al. studies was intended to eliminate such confounds but may have introduced new impediments to deaf students' learning: removal of three-dimensional spatial cues and elimination of possible student-interpreter feedback. Elimination of three-dimensional cues might be expected to impede learning through interpreting because sign language entails grammatical use of the space. Although it is emphasized as important in interpreter training (Seal, 2004), the role of student-interpreter feedback during interpreting has not been explicitly studied (but see Johnson, 1991).

One shortcoming of all of the previous studies on learning via interpreting is that they included only an interpreter or an interpreter and an instructor and did not include the kinds of visual display materials typically used in the classroom. With the recognition that such controls may be important methodologically, it remains unclear how the findings observed would have been affected if deaf students had been required to attend to both an interpreter and instructional materials. This issue goes beyond the possibility of methodological caveats. A variety of distance learning initiatives have been established around the United States, and both legislative and economic concerns are leading institutions to create distance programming that is accessible to deaf students (National Technical Institute for the Deaf, 2004). Video-based sign language interpreting services (*video relay services*) also are becoming available throughout the country with the support of the Federal Communications Commission. To this point, however, there have been no empirical evaluations of the extent to which deaf viewers are able to comprehend sign language transmitted to two-dimensional video displays. On the assumption that such communication is less than optimal, various efforts are under way to create three-dimensional sign language interpreting technology (e.g., VCOM3D [http://www.vcom3d.com] and the LIACS Visual Sign Language Translator [http://skynet.liacs.nl/medialab/bin/showpage?doc=92]; see Parton, in press, for a review).

Even with regard to hearing students, the educational value of distance learning remains unclear. In their meta-analysis of studies comparing the benefits of distance education and classroom learning, Bernard et al. (2004) found wide variability, with each educational approach obtaining support in various studies. When they distinguished synchronous (live) and asynchronous (recorded) distance education, Bernard et al. found that student achievement (in terms of effect sizes) following classroom instruction generally surpassed live (synchronous) distance instruction, whereas recorded distance education (asynchronous) surpassed classroom learning in terms of student achievement. Video-based distance learning—either synchronous or asynchronous—involving deaf students and sign language interpreters creates another level of complexity, one that has interesting implications for basic research on cognition and information processing as well as for the education of deaf students.

Using Visual Materials in Educating Deaf Students: Solution or Challenge?

Educational researchers frequently cite the dependence of deaf students on the visual modality and encourage the use of visual materials and displays in the classroom (e.g., Livingston, 1997; Marschark et al., 2002, chap. 9). Yet the introduction of visual displays would also appear to carry its own challenges, as deaf students would have to divide their visual attention across central and peripheral visual fields to be aware of information coming from the instructor, the display, and the interpreter while rapidly shifting among them. Presentation of real-time text in the classroom via currently available technologies (e.g., C-Print or CART) further compounds problems for deaf students insofar as their well-documented reading difficulties (e.g., Traxler, 2000) are such that classroom "captioning" is likely to exceed their reading speeds by up to 100% (Braverman & Hertzog, 1980; Jensema, McCann, & Ramsey, 1996). Of interest here, however, is the more fundamental question of how deaf students can simultaneously deal with visual information from multiple sources. In education and psychology, "visual" is typically contrasted with "verbal" (e.g., Paivio, 1986), but in the case of deaf students who depend on sign language interpreting in the classroom, verbal input comes through the visual modality.

Research conducted by Paivio and his colleagues has clearly demonstrated that the combination of verbal and visual information leads to better learning and retention than either type alone (see Paivio, 1971, 1986). Paivio's dual coding theory, originally developed in the context of learning and memory research, has now been extended to learning in science and technology classrooms (e.g., Hegarty & Just, 1989; Narayanan & Hegarty, 1998; Tiene, 2000) and to learning via multimedia technologies (e.g., Iding, 2000; Presno, 1997). Mayer (1989; Mayer & Morena, 1998), for example, has emphasized that students with less content knowledge relating to a lecture will benefit more from combined verbal and visual materials. Sequential presentation of verbal and visual materials, in contrast, increases cognitive load and jeopardizes the utility of visual displays in laboratory and classroom settings (Iding, 2000; Mousavi, Low, & Sweller, 1995; see Todman & Seedhouse, 1994, with regard to deaf students). Tiene (2000) and Gellevij, van der Meij, Jong, and Pieters (2002) further demonstrated that there is an advantage of redundant verbal and visual information (with hearing students) only when they are presented simultaneously and in different modalities. Whatever the benefits of offering visual material simultaneously with verbal material to hearing students—allowing them to see the redundancy in alternative forms of the same information, emphasizing interconnections in complementary information, or helping them to better follow verbal descriptions (Presno, 1997)—if deaf students depend on sign language interpreting for reception of verbal material in the classroom, how can they simultaneously use their visual systems to receive other visually presented information?

Visual Compensation in Deaf Adults and Children

A variety of findings—and much more speculation—have suggested that deaf individuals may have enhanced visual abilities relative to their hearing peers because of their reliance on the visual modality (Myklebust, 1964; Tharpe, Ashmead, & Rothpletz, 2002). Most obvious, perhaps, is the suggestion that deaf individuals would have greater peripheral visual acuity as a consequence of the necessity of attending to visual (including linguistic) signals that occur outside of central visual fields. Swisher and her colleagues, for example, demonstrated in several studies that deaf children 8–18 years of age are able to perceive and recognize signs presented in the periphery, 45° to 77° from center (see Swisher, 1993, for a review). None of these investigations, however, compared deaf individuals with hearing individuals.

Neville and Lawson (1987) apparently were the first to demonstrate advantages for deaf individuals relative to hearing individuals with regard to peripheral vision. Using a task in which participants had to identify the direction of motion of a stimulus presented in either the left or right visual field, they found that deaf individuals who were native signers were significantly faster than hearing individuals, both signers and nonsigners (Loke & Song, 1991; Rettenback, Diller, & Sireteanu, 1999; Reynolds, 1993). This enhanced peripheral vision among deaf native signers apparently stems from the allocation of greater visual resources or capacity made possible by changes in neural organization during development (Bavelier et al., 2001; Neville, 1990). Proksch and Bavelier (2002), however, demonstrated that deaf individuals' greater attentional resources in regard to peripheral stimuli come at the cost of reduced resources in central visual fields. Hearing individuals who were native users of ASL did not show this effect in their study, leading to the conclusion that some aspects of enhanced peripheral vision are a consequence of early auditory deprivation.

Other visuospatial benefits have been found to accrue to deaf individuals who are fluent signers. Emmorey, Kosslyn, and Bellugi (1993) and Emmorey and Kosslyn (1996), for example, demonstrated that deaf adults who used ASL and hearing adults who had acquired ASL as their first language from deaf parents were faster than nonsigning adults in generating complex (but not simple) mental images. Emmorey et al. (1993) showed that such individuals also respond significantly faster in a mental rotation task involving two-dimensional block stimuli, the result of an enhanced ability to make judgments of whether the stimuli are in normal orientation or are mirror images (see also Emmorey, Klima, & Hickok, 1998). The locus of these effects in skilled sign language use rather than hearing loss per se was further evidenced by Chamberlain and Mayberry's (1994) finding that deaf individuals who relied on spoken language did not differ from hearing nonsigners in their response speed in a mental rotation task. Talbot and Haude (1993) also found that level of sign language expertise but not age of acquisition affected performance on a rotation task.

Given these findings, it may be that use of visual materials in the interpreted mainstream classroom is not as much of a challenge for deaf students as might be supposed. At least among students who are skilled signers, greater peripheral visual acuity or ability to detect motion in the periphery may provide the tools necessary to perceive and integrate multiple sources of visual information. To date, however, research in this area has been confined to relatively narrow laboratory paradigms, and the extent to which such abilities might influence learning remains uncertain. Thus, we designed three experiments to evaluate learning via sign language interpreting.

Experiment 1

Experiment 1 compared live and video-based interpreting of college-level lectures. Live interpreting provided deaf students with three-dimensional visuospatial cues in support of sign language comprehension; one condition allowed student-interpreter feedback, whereas a second condition did not. Video-based interpreting eliminated both three-dimensional cues and student-interpreter feedback. One video condition involved life-sized video projection, and a second involved computer screen–sized viewing as in distance learning or remote interpreting.

Method

Participants

One hundred eighty-seven student volunteers from the Rochester Institute of Technology (RIT) were involved in the study and were paid for their participation. There were 145 deaf participants. RIT includes the National Technical Institute for the Deaf (NTID) as one of its colleges, but deaf students from across the entire university participated. Previous studies of this sort (Marschark et al., 2004, 2005a) have failed to reveal any differences between students registered at the associate degree level (NTID) and students registered at the baccalaureate level (other RIT colleges), and that variable was not considered here. A comparison group included 32 hearing students. As is common on the RIT campus, some of the hearing students knew sign language, an issue addressed subsequently in the Results section.

Both deaf and hearing students were recruited via posters and contacts with student groups. All volunteers were accepted into the study. Demographic data were available for 142 of the deaf students from institutional records, although there were some missing data. Pure tone hearing thresholds (better ear) among the deaf students ranged from 50 to 120 dB, with a mean of 100 dB. Fifteen of the deaf students had cochlear implants; 81 used hearing aids. Nine of the hearing students reported knowing sign language to some degree, and this was considered in the analyses described subsequently.

The two interpreters involved in the study were associated with the National Sign Language Interpreting Project at NTID. Each has more than 25 years of interpreting experience, and both are recognized as among the most skilled of the 120 full-time interpreters on the RIT campus. They did not see the materials in advance and were unaware of the purposes of the study.

Materials

Two hearing members of the RIT faculty were recruited to be videotaped while presenting short, introductory-level lectures without supplementary materials (e.g., visual aids or handouts); both instructors were unaware of the purpose of the study until taping had been completed. One lecture focused on visual perception and the other on soil mechanics. Each was approximately 13 minutes long. Digital recording of the instructors took place in a small studio setting with lighting designed to avoid any shadows.

To prepare relatively naturalistic tests of lecture content, the investigators created 15 multiple-choice questions for each lecture together with four plausible answer options, only one of which was correct. The questions and answers were shared with the instructors to ensure that questions were relevant and fair and that answers were clear and unambiguous. The instructors provided some editing, and several questions were replaced with their assistance. To provide an indicator of students' prior knowledge of the lecture content, the investigators and instructors similarly collaborated on a six-question pretest for each lecture covering the same general content area but not overlapping the lecture.

Deaf students completed a communication questionnaire adapted from the NTID Language and Communication Background Questionnaire. NTID uses the latter instrument rather than face-to-face communication interviews to obtain information on student language skills because it is more efficient and has been found to correlate highly with interview assessments. The questionnaire was not intended as a definitive assessment of student language skills, but it provided estimates sufficient for the purposes of this study. Demographic and communication information obtained from students and institutional files is shown in the Appendix.

Design and Procedure

Testing was conducted in a laboratory performing arts classroom with tiered seating that held up to 30 students. The room had theater lighting that permitted execution of the experimental conditions. Lighting was adjusted by a professional stage manager and instructor of lighting and stagecraft at NTID familiar with the lighting needs associated with interpreted performances and classes.

Each deaf student viewed a lecture under one of four test conditions. Two *live interpreting conditions* involved life-sized video projection of the instructor with one of the two interpreters standing beside the screen. Interpreter-instructor proximity was comparable to that of a typical classroom situation (2–3 m). In the first live session for each interpreter, normal classroom lighting was used so that students and interpreters were able to make full eye contact (i.e., three-dimensional cues and feedback). In the second live session for each interpreter (balanced over interpreters and lectures), lighting allowed students to see the interpreter, but the interpreter could not distinguish the students (i.e., three-dimensional cues but no feedback).

The interpretation was videotaped during the first live testing session with each interpreter, and thus students in the live and video conditions all saw spontaneous interpretations. The *video interpreting condition* involved life-sized video projections of both interpreter and instructor on side-by-side screens. Finally, a *television interpretation condition* involved the videotaped materials used in the video interpreting condition, but these materials were presented via side-by-side television monitors (i.e., computer screen–sized viewing). Hearing students participated in television conditions only. Testing sessions in all but the television conditions involved approximately 20 students each. The television conditions (with both deaf and hearing students) involved the testing of several small groups so that the televisions were clearly visible.

The complete experiment could be viewed in different ways, but all of the factors were between subjects. With regard to deaf students, there was a 2 (lecture) × 2 (interpreter) component of the design. The design also could be considered to involve a live versus video projection versus television variable, and the live condition could be divided into feedback and no feedback conditions. All of these issues are considered subsequently.

At the beginning of each testing session, students completed the lecture-specific pretest. After the lecture, they completed the postlecture learning assessment, followed by the communication questionnaire.

It is perhaps noteworthy that in the live, full-lighting condition, an additional manipulation was included to examine the role of student-interpreter feedback. Along with videotaping the interpreters for the video interpretation conditions, cameras also videotaped the students, who were sitting in numbered desks (recorded by the experimenters). Immediately after the experiment, the interpreters were shown the tapes of their own interpretation synchronized with the tapes of the students. They were asked to identify deaf students' expressions and actions that might have influenced their interpretations. Students were identified by desk number, and their test scores were examined. In fact, the interpreters were unable to identify many student behaviors that specifically influenced them, and, because it had no apparent relations to student scores, this manipulation was not evaluated further (but see Experiment 3).

Results and Discussion

Unless otherwise noted, significant results described in this and the subsequent experiments were reliable at the .05 level. All post hoc tests included Bonferroni adjustments to confidence intervals.

Hearing students who reported knowing sign language scored significantly higher on the pretest than hearing students who reported not knowing sign language, $F(1, 26) = 9.72$, $MSE = 109.57$. However, the two groups did not differ in their learning assessment scores after seeing the interpreted lectures, $F(1, 26) < 1$, $MSE = 236.92$, and this variable is not considered further.

A preliminary analysis of the deaf students' scores involved the 2 (interpreter) × 2 (lecture) design. In the analysis of their pretest scores, reliable main effects were neither expected nor obtained (see Table 1). Deaf students' learn-

Table 1

Mean Pretest (Content Knowledge) and Postlecture Learning Assessment Performance (Proportion Correct): Experiment 1

	Deaf		Hearing	
Condition	*M*	*SD*	*M*	*SD*
Live-feedback				
Pretest	.66	.22		
Learning assessment	.59	.19		
Live–no feedback				
Pretest	.56	.22		
Learning assessment	.50	.17		
Video projection				
Pretest	.60	.23		
Learning assessment	.53	.20		
Monitor				
Pretest	.68	.22	.86	.13
Learning assessment	.54	.18	.84	.14

ing assessment scores, however, were significantly higher for the soil mechanics lecture ($M = 60.40$, $SD = 2.42$) than for the visual perception lecture ($M = 50.58$, $SD = 2.38$), $F(1, 141) = 8.38$, $MSE = 318.88$. There was also a related reliable Lecture × Interpreter interaction, $F(1, 141) = 3.94$, $p = .05$: Whereas students scored approximately the same with the two interpreters in the visual perception lecture (55.7 vs. 52.6), they scored better with one interpreter than the other in the soil mechanics lecture (65.1 vs. 48.5). Because of the need for spontaneity in the interpretations and the resulting requirement that the two interpreters interpret different lectures in the live and videotaped conditions, this interaction could not be examined further. Importantly, however, analyses of individual questions revealed no significant interactions involving hearing status, indicating that the interpreting did not differentially affect comprehension of particular test questions.

As can be seen in Table 1, presentation condition—and the effects of three-dimensional cue availability in particular—had little effect on learning either when live, video, and television presentations were considered, $F(2, 142) < 1$, $MSE = 342.37$, or when live-feedback and live–no feedback conditions were considered separately, $F(3, 141) = 1.54$, $MSE = 334.27$. Table 1 indicates that performance was somewhat higher in the live-feedback condition than in the other conditions, but post hoc analyses revealed that none of the individual differences were reliable.

Table 1 also indicates that performance of the deaf students was rather low, ranging from 50% to 59% across the four conditions. Hearing students performed significantly better than deaf students, both when the entire groups were considered, $F(1, 175) = 74.08$, $MSE = 315.6$, and when only deaf students in the television condition were compared with hearing students (all of whom were in the television condition), $F(1, 175) = 52.61$, $MSE = 260.02$. Even in the live-feedback condition, deaf students did not perform as well as their hearing peers did after viewing the lectures via a television monitor.

The results just described replicate earlier findings indicating that deaf students in mainstream educational classrooms supported by sign language interpreters do not take as much away from lectures as their hearing peers (Jacobs, 1977; Marschark et al., 2004, 2005a). Although visual contact/feedback between deaf students and interpreters may be important in the learning process, the present results suggest that the effect is not a large one and is not sufficient to "level the playing field" in the classroom. This issue was addressed further in Experiment 3, but three other factors might be deemed important in explaining the present results.

First, previous studies have suggested that deaf students come into the classroom with less world and academic knowledge than their hearing peers (see Marschark, Sapere, Convertino, & Seewagen, 2005b). Consistent with this suggestion, hearing students scored significantly higher on the pretest than their deaf peers, indicating that they had greater content knowledge concerning the material covered in the two lectures overall, $F(1, 175) = 34.22$, $MSE = 440.67$, as well as when the lectures were considered separately, $F(1, 173) = 36.78$, $MSE = 431.80$. There was no Lecture × Hearing Status interaction in the latter analysis. When the effects of previous content knowledge were removed via an analysis of covariance in which pretest performance was held constant, hearing students still outperformed their deaf peers (78.4% vs. 55%), $F(1, 174) = 42.18$, $MSE = 285.66$.[2]

It might be suggested that postlecture assessments are simply a reflection of prior knowledge.[3] However, pretest and learning assessment scores were not significantly related among the hearing students, $r(31) = .26$, and were only relatively weakly (although reliably) related among the deaf students, $r(144) = .32$. Another way to evaluate this possibility is to consider only deaf students who had pretest scores comparable to those of the hearing students and compare their learning assessment scores. Use of a cutoff score of .67 on the pretest left 42 deaf and 26 hearing students in the pool and eliminated the reliable difference between them, $F(1, 66) = 1.10$, $MSE = 66.5$. Analysis of the learning assessment scores among these students still yielded a reliable effect of hearing status, $F(1, 66) = 28.15$, $MSE = 288.17$. Previous content knowledge, therefore, does not appear to be sufficient to explain the observed performance difference between deaf and hearing students, although deaf students' K–12 academic preparation certainly influences their readiness to benefit from college-level instruction (Marschark et al., 2005b).

A second question with regard to the present results is whether deaf students' demographic/background characteristics might help predict their learning in college-level mainstream classrooms. Previous studies in which such variables have been considered occasionally have yielded significant predictors, but there has yet to be a single robust predictor even across experiments that have been similar in design (see Marschark et al., 2004, 2005a). Examining relations among achievement test scores, demographic characteristics, and learning in several experiments of this sort, Fabich (2005) failed to find any significant predictors in a meta-analysis involving more than 500 students across several similar experiments. Nevertheless, the demographic and communication variables listed in the Appendix were used here as predictor variables in stepwise multiple regression analyses that involved pretest scores (a priori content knowledge) and learning assessment scores as dependent variables.

The analysis focusing on pretest scores yielded only Michigan Reading Test score as a reliable predictor, accounting for 24% of the total variance. The analysis involving learning assessment scores yielded only ACT English subtest score as a reliable predictor, accounting for 17% of the total variance. Given earlier findings indicating that deaf students perform equally well regardless of whether multiple-choice learning assessment tests are provided in written form or in sign language, it is unlikely that these results reflect a confound favoring students who were better able to comprehend the written test. Although it is tempting to suggest that these findings indicate that better deaf readers will perform better in college-level courses (something that is undoubtedly true, on average), the inconsistency of the results obtained here and previously (e.g., Fabich, 2005) suggests caution in drawing such a conclusion.

A third potential factor in the results of the present experiment is the possibility that the interpreted lecture somehow biased the learning situation against deaf students. An analysis of learning assessment scores by question did not yield a reliable Hearing Status × Question interaction, $F(1, 13) = 1.35$, suggesting that the interpretations did not create a bias for particular test questions. Nevertheless, and despite the recognized excellence of the two interpreters involved in this study, it may be that these particular interpretations were not especially comprehensible. That possibility was evaluated in Experiment 2, which also served an important theoretical purpose.

Experiment 2

One explanation for the consistent findings indicating that deaf students learn less from college-level lectures than their hearing peers concerns the potential challenge of "mediated instruction." Mediated instruction through technology has been of interest for a number of years, typically with regard to hearing students (e.g., Bernard et al., 2004). The literature on mediated instruction/learning through sign language interpreting, in contrast, has been focused almost entirely on intuitions and institutionalized "best practices" for interpreters (e.g., Seal, 2004; Winston, 2005), with little attention given to the outcomes of educational interpreting (Cokely, 2005; Marschark et al., 2005b).

In response to the findings of Marschark et al. (2004, 2005a), reviewers and commentators have argued that the observed learning challenges of deaf students in mainstream classrooms may be attributable to their having to rely on mediated instruction. The only study to directly compare mediated and direct instruction among deaf students was that of Kurz (2004). Deaf middle school and high school students in that study saw six science lessons given by (a) a hearing science teacher with an interpreter (mediated instruction) and (b) a deaf science teacher (direct instruction). Test scores indicated that students learned significantly more in two of the six lessons involving direct instruction. Two of the 19 students learned more in the interpreted condition, 7 students learned essentially the same amount in the two conditions, and 10 students learned more in the direct instruction condition. Direct instruction required almost twice as long as the interpreted lectures, however, so the locus of Kurz's findings is unclear.

Experiment 2 provided a simple check on the clarity and comprehensibility of the two interpretations used in Experiment 1 while also addressing the question of whether mediated instruction is inherently inferior to direct instruction. A group of highly skilled educational interpreters (including several among whom ASL was their first language) saw the lectures of Experiment 1 under two conditions. In one condition they saw a video recording of one instructor presenting a lecture (direct instruction), and in the other they saw a video recording of the other instructor and the synchronized interpretation (mediated instruction). Although these interpreters probably were more skilled in sign language than most of the students involved in Experiment 1, that difference was not at issue here. Rather, the methodological issue was whether the interpreters comprehended the two interpretations sufficiently well to consider them fair and appropriate renderings for the purposes of this research. Theoretically, the extent to which the interpreters' performance was inferior in the interpretation condition relative to the spoken condition would provide insight into the possible challenge of mediated instruction over direct instruction.

Method

Participants

Thirty sign language interpreters participated as volunteers. They were recruited from among the more than 120 interpreters employed by NTID. The criterion for recruitment was bilingual fluency, agreed upon in all cases by the interpreter-investigators and the participants' departmental administration. Twenty interpreters participated in the experiment proper. The other 10 interpreters were administered the learning assessment tests without having seen the related lectures to allow determination of whether the lecture information was already part of interpreters' world knowledge. The 20 interpreters who viewed the lectures included 5 who had deaf parents, 18 who were certified by the Registry of Interpreters for the Deaf, and 5 who had graduate degrees (including three doctorates). Their experience as professional interpreters ranged from 2 to 36 years, and their regular use of ASL ranged from 10 to 52 years.

Design and Procedure

Testing was conducted in small groups. Interpreters who took only the learning assessment tests completed them in counterbalanced order. Interpreters who were exposed to the lectures saw one via direct instruction and one via an interpreter, and in both cases life-sized video projection was used. In the mediated instruction condition, the instructor was visible, but there was no audio. Lecture and interpreter were balanced over the testing sessions. The learning assessment tests were the same as those administered to students in Experiment 1.

Results and Discussion

Overall, interpreters performed equally well with the two lectures, $F(1, 27) = 3.41$, *ns*. Performance on the learning assessment tests varied across the three conditions, $F(2, 27) = 33.41$, $MSE = 238.57$, but did not interact with lecture. Most important, t tests revealed that the interpreters performed equally well regardless of whether they were receiving direct instruction (93%) or mediated (interpreted) instruction (90%). Only when the learning assessment tests were administered to interpreters without previous viewing of the lectures did performance differ (57%), and then scores were in the same range observed among deaf students who had seen the interpreted lectures in Experiment 1.

Further *t* tests indicated that interpreters who saw the lectures scored significantly higher than the deaf students in Experiment 1 across all conditions. Their scores did not differ reliably from those of the hearing students in Experiment 1, perhaps because of ceiling effects.

These results indicate both that the interpretations provided to students in Experiment 1 were fully comprehensible to skilled signers and that there is no a priori impairment to learning when students receive an interpretation of the lecture rather than receiving the lecture directly from the instructor. It could be argued that the present results still indicate a bias against deaf college students, who probably are not as skilled in their signing as certified interpreters. Such a position nevertheless calls into question an essential premise of mainstream/inclusive education for deaf students: that an interpreted education is comparable to the direct instruction received by hearing students. There are alternative explanations, however, for results indicating that deaf students do not learn as much in interpreted college lectures as their hearing peers. One of these alternatives was considered in Experiment 3.

Experiment 3

Visual acuity varies dramatically across the visual field, with high-resolution vision available only in the central fovea. Eye movements allow humans to shift their gaze rapidly and without conscious effort, giving the illusion of a large, high-resolution field of view. These frequent eye movements provide an external marker of visual attention, but indirect methods of monitoring such as verbal reports and posttests intended to infer attention are often unreliable and can change the behavior one is attempting to understand. Thus, in Experiment 3, we made use of eye-tracking technology to analyze the effects of visual technologies (e.g., computer-generated PowerPoint displays) on learning among deaf and hearing students.

As noted earlier, studies conducted by Tiene (2000), Mayer and Morena (1998), and others have demonstrated beneficial effects on learning when (hearing) students receive redundant verbal and visual information simultaneously in different modalities. Mayer, Heiser, and Lonn (2001) clarified these findings by showing that because it requires splitting of visual attention, simultaneously presented text can "overpower" visual materials, resulting in reduced use of both sources of input (see also Mousavi et al., 1995).

Hegarty and Just (1989) used eye tracking to explore how novices and experts differentially attended to scientific drawings. Hearing students familiar with the topic of discussion attended to illustrations primarily when the text lacked detail, apparently obtaining information from the nonverbal source that was not available from the verbal source. Novices attended to the drawings far more often, using the figural information to establish a basic representation of the topic and then cross checking the illustrations and the text. Importantly, Narayanan and Hegarty (1998) found that less skilled readers were not as likely as more skilled readers to create visual mental representations of machines based on a text description, suggesting that the amount of information drawn from long-term memory by less-skilled readers may be limited and that which is available is "fragile." This precisely represents the situation of many deaf learners, who have both reading abilities below those of their hearing peers (Traxler, 2000) and weaker, more idiosyncratic interconnections among concepts in memory (McEvoy, Marschark, & Nelson, 1999).

It appears, then, that use of visual technologies in mainstream/inclusive classrooms is likely to deny deaf students access to the communication available to hearing peers because of their need to constantly shift visual attention between two or more sources of information. Research described earlier, however, indicated that deaf individuals who are skilled signers possess visuospatial skills that may offset the apparent challenge created by multiple visual displays in the classroom. In particular, the ability to more rapidly shift visual attention and a greater sensitivity for stimuli in the periphery may provide a means to compensate for what appears to be a barrier to educational access.

Experiment 3 examined this possibility by presenting lectures to deaf students who were skilled signers, deaf students who were relatively new to sign language, and hearing students who did not know sign language. Lectures included an instructor, a sign language interpreter, and a visual display. Both live and video-based versions of the lectures were presented, while students' visual gaze allocation was recorded with eye-tracking equipment. On the basis of existing research concerning visuospatial processing in deaf individuals, it was expected that patterns of gaze allocation would differ across the three groups of students. Of particular interest was the likelihood that skilled deaf signers would show a more adaptive pattern of visual attention allocation than the new signers. The inclusion of visual materials was expected to create more of a learning challenge for the new signers than the skilled signers because of their presumably less flexible visuospatial skills.

This experiment also provided another opportunity to examine the effects of live versus video-based sign language interpreting. In this case, opportunities for student-interpreter feedback in the live condition were optimized by the fact that students were tested either individually or in pairs. Experiment 3 thus provided a more sensitive comparison of live and video presentation conditions than did Experiment 1.

Method

Participants

Thirty-two RIT students participated as paid volunteers: 10 hearing students who did not know sign language, 11 deaf students who were skilled signers, and 11 deaf students who were relatively new signers. For the purposes of this study, it was deemed sufficient that the two groups of deaf students self-reported their sign language skills as placing them in one or the other categories and that these placements were confirmed by the observations of two highly experienced educational interpreters. Of the students in the skilled signer group, 10 had learned sign language at 5 years of age or younger, and 1 had learned at 9 years of age ($M = 2.8$ years, $SD = 2.8$). Of those in the less skilled group, 7 had recently begun to learn sign language in college, at 18 or 19 years of age, and 2 had learned as young teenagers. The 2 other students in this group both reported "learning" sign language at a young age but, given inconsistent use, described their skill in sign language as "fair" (full group $M = 14.9$ years, $SD = 6.4$). Pure tone hearing thresholds (better ear) among the deaf students ranged from 43 to 120 dB, with an overall mean of 98 dB, and there was no difference between the hearing thresholds of students in the skilled and new signer groups ($ts < 1$).

Materials and Equipment

Two hearing members of the RIT faculty were recruited to provide introductory-level lectures that included visual displays considered by the instructors to be "moderately important" for comprehension of their lectures. The instructors were unaware of the purpose of the study beyond knowing that it involved comparing the visual attention strategies of deaf and hearing students. One lecture focused on the development of the Internet and the other on granular physics. Each lecture was approximately 15 minutes long.

Two eye trackers were available for the study, which limited testing to one or two participants at a time. The live lectures thus had to be given multiple times by each instructor. To help ensure uniformity, a single, highly experienced interpreter interpreted all lectures. The instructors and the interpreter endeavored to keep the lectures as similar as possible, and the slide displays were always the same. After more than a dozen presentations of the same lecture, the instructors may have lost some of their initial spontaneity, but a subsequent analysis indicated no consistent or reliable differences in student learning across the multiple presentations.

The interpretations of the first two live presentations were digitally recorded, and in each case the second one was used for the video presentations. Ten pretest and 12 learning assessment questions were developed in collaboration with the instructors, as in Experiment 1, and the same communication questionnaire was employed.

Eye movement data were obtained via custom-built wearable eye trackers that monitored students' gaze direction throughout each lecture. Gaze direction was monitored by locating the position of the pupil center and the first-surface corneal reflection of a low-level infrared illuminator. The tracker has an accuracy of approximately 1 degree of visual angle in the central field and 2–3 degrees near the periphery; calibration was optimized in the regions including the instructor and interpreter. Students were free to move their heads during the lectures. As reported elsewhere (Bard, Fleury, & Paillard, 1992), there was wide between-subjects variability in head movements. The head movements were typically small and limited to gaze changes toward and away from the display region.

The primary components of the eye tracker are a pair of modified glasses and a video multiplexer unit. The glass frames shown in Figure 1 support an infrared illuminator and two miniature video cameras. A color camera is placed

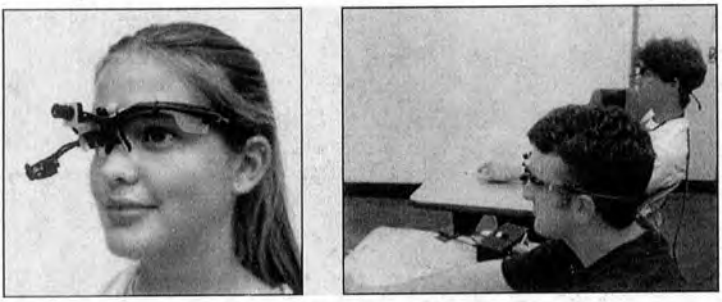

Figure 1. **Wearable eye tracker.**

above the observer's right eye to capture the view from his or her perspective, as illustrated in Figure 2. A miniature infrared camera placed below the line of sight views the right eye. The second component, the video multiplexer, combines the images from the two cameras and records them to a single videotape. The multiplexed videotape was analyzed off-line to determine where the student was looking. (A complete discussion of the wearable eye-tracking system and associated data analysis can be found in Babcock and Pelz [2004] and Pelz and Canosa [2001].)

The eye-tracking calibration procedure requires the students to maintain fixation on each of five points while the experimenter locates these points in the scene image. Off-line analysis allows a single video frame to be selected for each calibration point, in turn allowing more precise calibration while simplifying the calibration procedure for the students. The eye tracker provides a 60 Hz video sequence with a student's gaze point indicated with a white crosshair, as shown in Figure 2 for the live and video-based conditions.

Design and Procedure

Each student saw two lectures, one live and one via video. As much as possible given the schedules of instructors and students, condition and lecture were

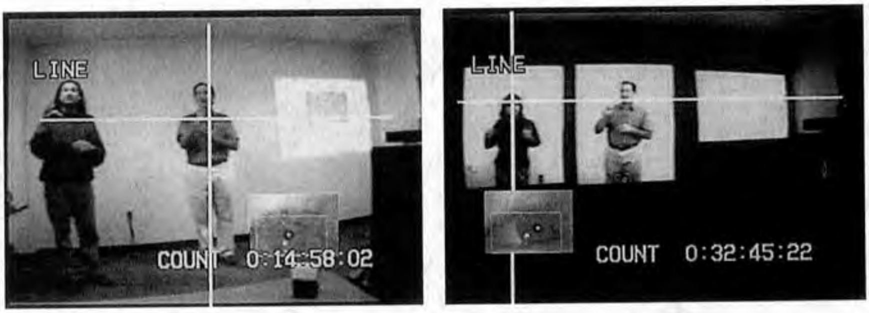

Figure 2. **Sample gaze records (live and video conditions).**

balanced across testing sessions. The complete design was thus a 3 (group: skilled deaf signers, less experienced deaf signers, or hearing nonsigners) × 2 (condition: live or video) × 2 (lecture type) design in which condition and lecture type were within-subject factors. As a means of optimizing fidelity for the video presentations, three digital video projectors were used to create life-sized images, and the projectors were mounted in brackets 90° from their normal orientation to provide "portrait" views (thus maximizing use of pixel density). The three digital videotapes were synchronized to ensure appropriate timing and standard presentation.

Students were tested in a mock classroom created for this project. The front wall of the room was painted with a special coating that optimized clarity for video projection. The three aligned video projection areas entirely filled the 6.7-m-long front wall of the room. Two students were scheduled for most testing sessions, although occasionally one student did not appear for testing; individual students were then scheduled to complete the balancing of cells for the design. Upon arrival, students completed pretests for both lectures and then were fitted with the eye tracker and underwent the calibration procedure as described.

After each lecture, students took the appropriate learning assessment test; they completed the communication questionnaire at the end of the session. A short break was provided between the two lectures while equipment was prepared.

Results and Discussion

Gaze Allocation Analyses

The videotaped record of each participant's gaze sequences was analyzed by identifying the gaze direction in each frame, as shown in Figure 3. For analysis, the scene was divided into three regions of interest (ROIs): the instructor, the interpreter, and the display (see Figure 4). Analysis of the videotape consisted of noting the time code and target region each time an individual's gaze shifted from one area of interest to another. Fixations outside the three defined areas of interest and periods during which the eye-track data were not reliable represented less than 2% of the total and were excluded from further analysis. The sequence of transitions and the total amount of time spent in each area of interest were recorded.

Total gaze duration. The first metric considered in evaluating gaze behavior was each student's distribution of total gaze duration in the instructor, interpreter, and display ROIs. Figure 5 shows the results of this analysis for hearing students, new signers, and skilled deaf signers. Hearing students spent the most time looking at the instructor, averaging 62%. Gaze was directed to the display 34% of the time and to the interpreter only 4% of the time. The deaf students' gaze patterns, overall, were reversed, with about 63% on the interpreter, 22% on the display, and 16% on the instructor.

Gaze duration analysis. Figure 5 indicates the total time students spent looking at the three ROIs but does not indicate the duration of the individual

Figure 3. **Crosshairs showing the student's gaze on the interpreter (a), display (b), and instructor (c).**

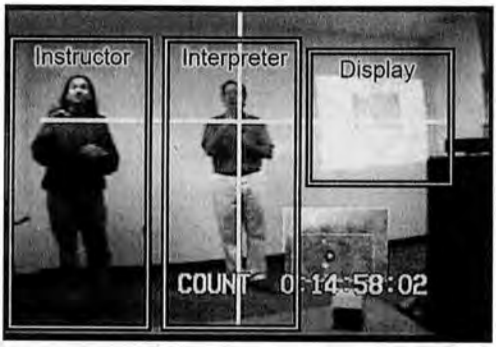

Figure 4. **Defined regions of interest in the analysis.**

gazes. Figure 6 shows that the mean duration of students' gaze at each ROI varied widely according to group. The hearing students, who spent 4% of their time looking at the interpreters, averaged gaze durations in that region of less than 1 second, whereas the new and skilled signers' mean gaze durations were much larger: 6.0 and 4.5 seconds, respectively. Hearing students' mean gaze duration on the instructor was more than 4 seconds; new and skilled signers' gazes to the instructor were much shorter: 2.4 and 1.6 seconds, respectively. There was less variation in gaze duration to the display; hearing students, new signers, and skilled signers all showed mean gaze durations of 2 to 3 seconds.

Gaze transition analysis. In addition to comparing mean and total gaze durations in each ROI, we computed the transition probabilities between each

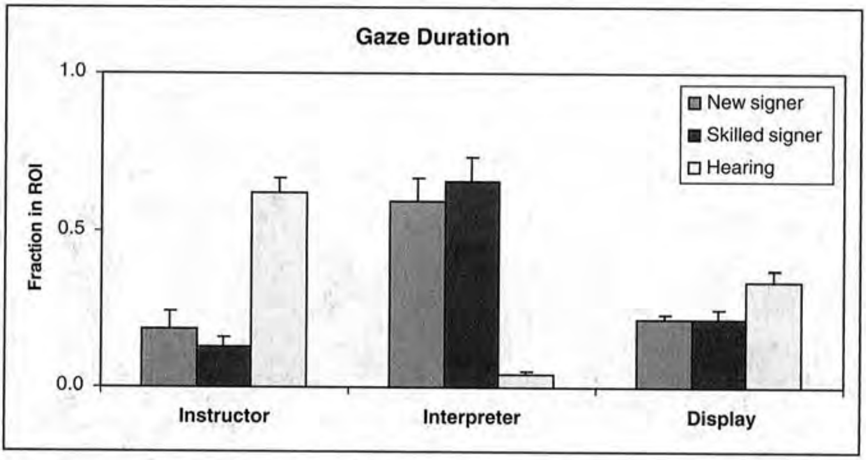

Figure 5. **Gaze durations in regions of interest: instructor, interpreter, and display (error bars represent 1 *SEM*).**

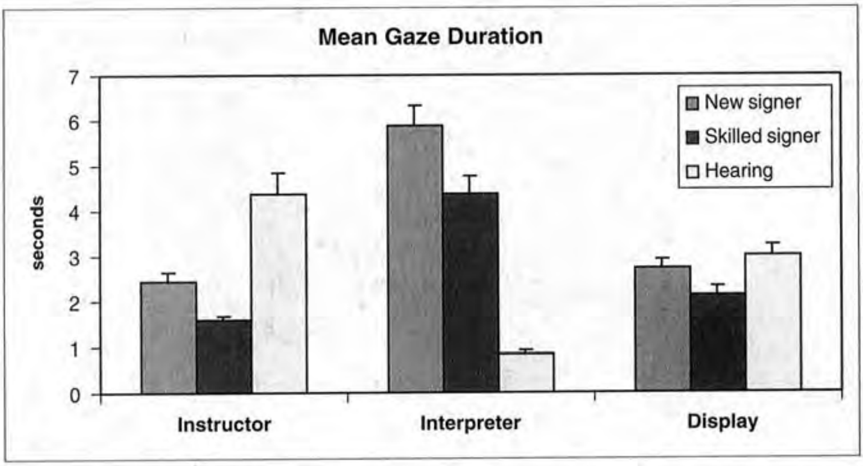

Figure 6. **Mean duration of gaze in each area: deaf new and skilled signers and hearing students (error bars represent 1 *SEM*).**

ROI for hearing students, new signers, and skilled signers. Figure 7 shows the probability of gaze shifts between regions for the three groups. As can be seen, new signers were more likely to shift their gaze from the instructor to the interpreter than from the interpreter to the display. The converse was true for shifts from the display: New signers were more likely to shift their gaze from the display to the interpreter than from the interpreter to the instructor. Hearing students were much more likely to shift their gaze from the display to the instructor than to the interpreter. Perhaps surprisingly, the new signers, skilled signers, and hearing students all had roughly equal probabilities of shifting

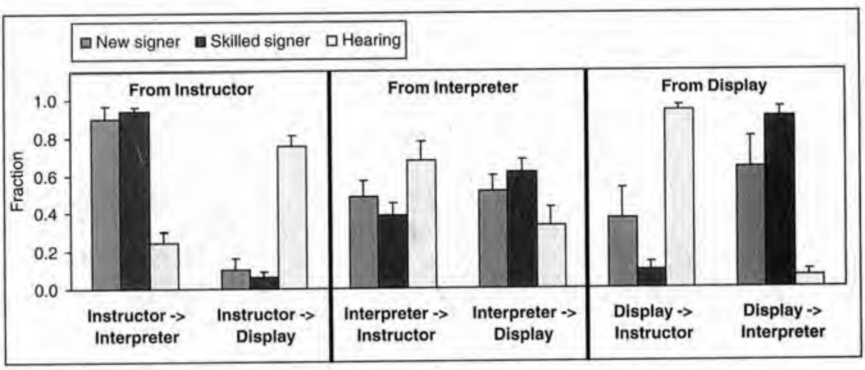

Figure 7. **Transition probabilities among new and skilled (deaf) signers and hearing students (error bars represent 1 *SEM*).**

their gaze from the interpreter to the instructor and shifting from the interpreter to the display. Recall, however, that the hearing students spent only a small fraction of their time looking at the interpreter, and their mean gaze duration on the interpreters was very short.

String comparisons. The transition metric just described considered only the immediate transition probability of moving from one ROI to the next in the sequence. A similarity metric for the full sequence of transitions making up the trial offered another opportunity to compare performances within and between hearing students, new signers, and skilled signers, as well as potential differences between live and video lecture presentations. This analysis involved representing the sequence of gazes during the lecture as a string. For example, the sequence "interpreter, display, interpreter, instructor" would be encoded as "IDIS," where I = interpreter, D = display, and S = instructor. Each gaze sequence "string" then can be compared with other strings by assessing a penalty for each insertion, deletion, and substitution that has to be made to make a pair of strings match. The result is known as the "Levenstein distance" (Kruskal, 1999). Two strings that match exactly have a score of 0 in that they require no insertions, deletions, or substitutions.

The Levenstein distance was generated for every sequence pair. These distances are shown within and between each of the three groups (hearing, new, and skilled signers) in Table 2 and Figure 8. The within-group Levenstein distances for hearing students (H/H), new signers (N/N), and skilled signers (S/S) were all approximately .5, indicating that the variability in gaze sequences within each of the groups was equal. The between-group variability was greater between hearing and deaf students, with distance metrics for hearing and new signers (H/N) and hearing and skilled signers (H/S) of approximately .75, indicating greater differences between the hearing and deaf students than within the groups. The variability between the new signers and skilled signers (N/S), on the other hand, was .5, a level of variability that was the same as that within each of the different groups.

The same string comparison analysis was used to compare the live and videotaped lecture presentations. In the case of each group of students, sequence string pairs were compared between live and videotaped lectures.

Table 2

Mean Levenstein Distance Within and Between Groups: Experiment 3

Comparison	Levenstein Distance	*SE*
Hearing (within group)	.50	.03
New signers (within group)	.52	.01
Skilled signers (within group)	.50	.01
Hearing: new signers	.73	.02
Hearing: skilled signers	.75	.01
New signers: skilled signers	.50	.01

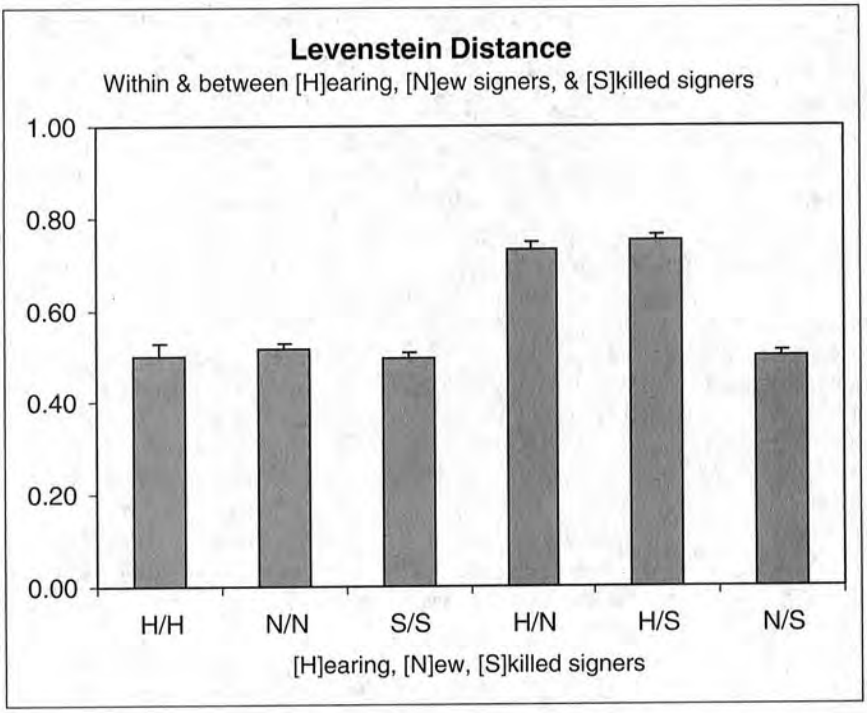

Figure 8. **Mean Levenstein distances within and between groups (error bars represent 1 *SEM*).**

Similar analyses of the string differences generated during the live and videotaped lectures showed no difference in the Levenstein metric (see Figure 9), indicating that presentation mode did not result in more within- or between-group variation.

Pretest and Learning Assessment Analyses

Preliminary analyses examined possible differences in pretest and learning assessment test scores as a function of lecture and condition presentation orders as well as the two lectures. Because these analyses did not yield significant main effects or interactions, subsequent analyses collapsed across order and lectures. Examination of Table 3 indicates that, on the pretest as well as the learning assessment tests, hearing students outperformed both their skilled signing deaf peers and those who were new signers, who did not appear to differ from each other. A 3 (group) × 2 (live versus video) analysis of variance of pretest scores revealed no differences among students in the live and video conditions, $F(1, 29) = 1.07$, $MSE = 0.28$. There was a reliable effect of group, $F(2, 29) = 4.42$, $MSE = 0.032$, but, contrary to appearances, post hoc tests revealed that only the difference between the skilled deaf signers and

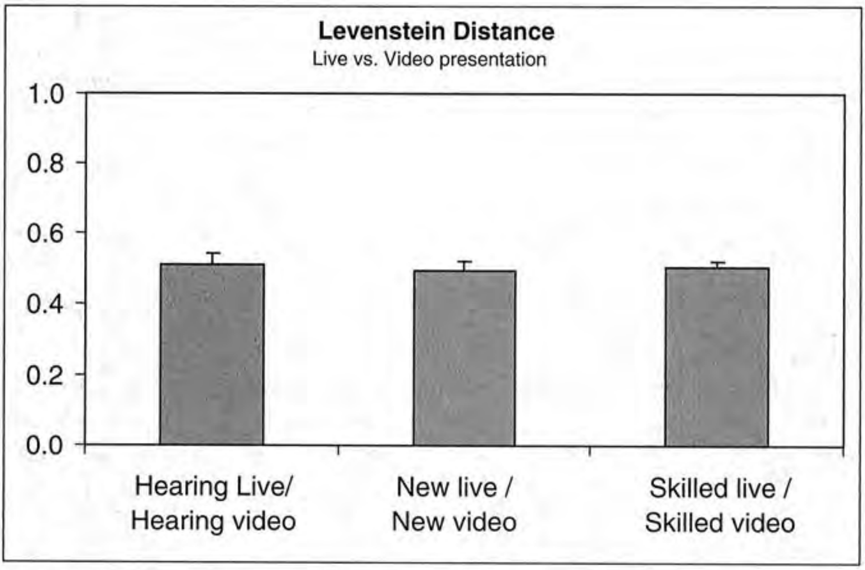

Figure 9. **Mean Levenstein distances for live and video conditions (error bars represent 1 *SEM*).**

hearing students was reliable. A similar analysis of learning assessment scores also yielded a reliable effect of group, $F(2, 29) = 8.15$, $MSE = 0.033$, with post hoc tests indicating that only the difference between new signers and hearing students was reliable. Perhaps most important, there was again no difference between live and video presentations, $F(1, 29) = 1.85$, $MSE = 0.017$, even

Table 3
Mean Pretest (Content Knowledge) and Postlecture Learning Assessment Performance (Proportion Correct): Experiment 3

	Condition			
	Live		Video	
Group	*M*	*SD*	*M*	*SD*
Pretest				
New signers	.71	.16	.67	.20
Skilled signers	.72	.13	.65	.25
Hearing students	.84	.12	.82	.14
Learning assessment				
New signers	.70	.18	.70	.18
Skilled signers	.80	.13	.72	.22
Hearing students	.94	.09	.90	.09

though deaf students were in a one-on-one or, at worst, two-on-one situation with the interpreter. In replicating the results of Experiment 1, this experiment clearly indicates that neither the availability of three-dimensional cues nor student-interpreter feedback is of major significance with regard to learning via sign language interpreting, at least within the context of the types of lectures used here.

Because there were no reliable differences between the skilled signing deaf students and the new signers, the two groups were combined and compared with the hearing students on both pretest and learning assessment scores. Analyses of variance indicated reliable effects of hearing status but not condition on both the pretests, $F(1, 30) = 9.11$, $MSE = 0.031$, and the learning assessments, $F(1, 30) = 14.93$, $MSE = 0.033$. As in Experiment 1, the pretest scores indicated that hearing students came into the classroom with more content knowledge on the lecture topics than their deaf peers, so an analysis of covariance was performed on learning assessment scores holding pretest scores constant. Hearing students still performed significantly better than deaf students when prior knowledge was thus controlled, $F(1, 28) = 4.32$, $MSE = 0.022$, with no effect of whether the presentation was live or via video.

As in Experiment 1, the relationship between prior content knowledge and learning was assessed by correlating pretest and learning assessment scores, here separately for the live and video conditions. The only reliable coefficient was that for pretest and learning by the skilled signers in the video condition, $r(10) = .74$. Once again, use of a cutoff score of .67 on the pretest eliminated the main effect of group in both the live and video presentation conditions. Analyses of learning assessment scores among the remaining students in the pool still yielded reliable main effects for both the live and video conditions, $F(1, 14) = 8.45$ and $F(1, 10) = 7.64$, respectively. These results lend further support to the suggestion that prior knowledge is not sufficient to explain the differences in learning among deaf and hearing students in the present experiments.

Multiple regression analyses including the variables listed in the Appendix as predictors and test scores as the dependent variable revealed that there were no significant predictors of either prior content knowledge (pretest) or learning via sign language interpreting (Fabich, 2005). Analyses of individual questions revealed no Hearing Status × Question interaction, indicating that interpreting did not differentially affect comprehension of particular test questions.

General Discussion

Given the complexity of the issues considered in this study and the methodologies required to examine them, the results are surprisingly simple to summarize. First, contrary to assumptions of interpreters and deaf students, the results of Experiments 1 and 3 indicate that comprehension of sign language—as indexed by amount learned from an interpreted lecture—is not affected by either the availability of three-dimensional visuospatial cues or student-interpreter feedback. In short, video-based interpreting appears to be just as effective as live interpreting in the college classroom. Results might vary in K–12 classrooms or community settings, but educational interpreting of college-level course material is in no way hindered by use of video-based delivery. This result augurs well for remote interpreting, the utility of increasingly popular video relay services, and the potential accessibility of distance learning among students who are deaf or hard of hearing. There are still issues to be addressed with regard to classroom communication, including student access to and participation in discussions, the appropriateness of video-based interpreting among school-aged children, and a greater possibility of eye fatigue on the part of viewers. At least in the case of eye fatigue, however, video recording could provide the opportunity for review of previously interpreted material or the possibility of rest breaks in the case of asynchronous presentation.

The second important finding from the present study is that despite demonstrations of enhanced visuospatial processing abilities on the part of skilled signers in carefully controlled laboratory demonstrations (e.g., Bavelier et al., 2001; Emmorey et al., 1993; Rettenback et al., 1999), these abilities do not appear to have any obvious effect on learning in the classroom. This conclusion is certainly preliminary, given that participants in the present experiments were not tested on their visuospatial abilities. Nevertheless, the lack of reliable differences—either in patterns of gaze duration and transitions or in learning from multiple visual displays between skilled and unskilled signers in Experiment 3—suggests that the real world may be too complex and information rich for there to be a simple bridge between the modest enhancements of visual abilities observed among skilled deaf and hearing signers. Alternatively, it might be that individuals with significant hearing losses, even if they are not skilled signers, have sufficient visual resources to deal with the learning situations involved here, and thus the benefits that accompany sign language skill are not of any incremental value. Indeed, the lack of a decrement to learning with video-based materials and previous demonstrations that deaf students equally comprehend various modes of sign language interpreting (Marschark et al., 2004, 2005a) lend support to this suggestion. This possibility has important applications with regard to the third key finding from our study.

As in previous studies comparing learning of deaf and hearing students over the past 30 years, the results of Experiments 1 and 3 indicate that deaf students take away less from classroom lectures presented via sign language interpreting than do their hearing classmates. The results of these and previous experiments, however, indicate that the locus of that difference is neither students' sign language skills nor, within certain limits, interpreters' skills. The present experiments, as well as those of Jacobs (1977), Livingston et al. (1994), Marschark et al. (2004), and others, involved highly skilled and experienced educational interpreters, but deaf students' performance on learning assessments was still relatively low. Marschark et al. (2005a) examined the effects of interpreters' familiarity with individual students' sign language skills and preferences as well as interpreter experience (5 years or less versus 10 years or more) and did not find reliable effects of either.

The results of Experiment 2, in which skilled interpreters viewed the lectures of Experiment 1 under both interpreted and direct instruction conditions, also bear on our conclusion that the challenge of learning through sign language interpreting does not reside in interpreter or student communication skills. The interpreters-as-learners in that experiment performed equally well under mediated and direct instruction conditions, casting doubt on the claim that mediated instruction is inherently inferior to direct instruction (see Marschark, Peterson, & Winston, 2005). Test scores were quite high (90%), also supporting the claim that use of video-based interpreting does not impede comprehension and learning. Future research should replicate this experiment with deaf students and interpreters who vary in their sign communication skills. However, the present experiments and those of Marschark et al. (2004, 2005a) failed to reveal any evidence that even deaf students of deaf parents, raised with ASL as their first language, learn significantly more from interpreted lectures than deaf students of hearing parents, who vary widely in when they learned to sign. In each of the previous studies, both mode of interpreting (ASL interpreting or English transliteration) and students' sign language skills/preferences were varied, but native users of ASL had no observable advantage.

At the very least, the consistent finding that deaf students learn less than their hearing peers in classes where they depend on sign language interpreting raises significant questions about the academic viability of mainstream education. In the United States and elsewhere, economic and sociopolitical expediencies have led to a headlong rush to educating deaf students in regular school classrooms with their hearing peers. Consistent with parents' desires to have their deaf children receive quality educations close to home (rather than in a more distant residential school), the move toward mainstream/inclusive education has implicitly assumed both that students with significant hearing losses can gain full access to communication and educational settings via sign language interpreting (or, in some cases, real-time text) and that the structures of instructional materials designed for hearing students in a "hearing" classroom are appropriate for the knowledge structure and learning styles of deaf students. The present experiments, and those reviewed earlier, indicate that the first of these two assumptions, at least, is untenable. Although the second assumption (related to "hearing" pedagogy among deaf students) is beyond the scope of the present discussion, a variety of indirect evidence suggests that it, too, may be unwarranted, and there is as yet no evidence to support it (see Marschark et al., 2005b).

The question of the appropriateness of instructional materials and methods designed for hearing students being applied to deaf students is relevant to the larger question of why it is that removing the obvious communication barrier in the mainstream classroom does not provide deaf children with sufficient access to learning at a level comparable to their hearing peers. Because of the tacit assumption of most parents, teachers, and educational administrators (and, perhaps, educational interpreters) that interpreting provides such access, only recently have serious questions been raised about the viability of interpreting or real-time text in the classroom. As a result, little research has explored this complex situation in any detail.

Another possible explanation of or contributor to deaf students' being at risk in mainstream classrooms is related to the "attentional multitasking" required when deaf students divide their attention between simultaneously provided visual communication from instructors or interpreters and visual display materials. Mayer and Morena (1998) emphasized that (hearing) students with relatively less content knowledge relating to a lecture—the situation of many deaf students—will benefit more from combined verbal and visual materials (see Rawson & Kintsch, 2002). Sequential presentation of verbal and visual materials, in contrast, increases cognitive load and reduces the utility of visual displays (Iding, 2000; Mousavi et al., 1995; see Johnson, 1991, for a related study involving sign language interpreting). Thus, while there is a preponderance of evidence that *concurrent,* multimodal information processing is advantageous in terms of learning, such information becomes functionally *consecutive* in the case of deaf students who have to alternate their attention to instructor/interpreter and visual materials, a situation known to impede learning.

Unfortunately, this situation is one in which deaf students are likely to be at an added disadvantage. Deaf students appear to have particular difficulty in linking successively encountered information over time in problem solving (Ottem, 1980), reading (Strassman, 1997), and studying college-level material (Richardson, MacLeod-Gallinger, Long, & McKee, 1999). This lack of automatic relational processing occurs in part because their conceptual knowledge is less strongly and richly interconnected than that of their hearing peers as assessed in verbal tasks (Marschark, Convertino, McEvoy, & Masteller, 2004; McEvoy et al., 1999), and Todman and Seedhouse (1994) obtained similar results in a nonverbal task.

Rawson and Kintsch (2002) demonstrated that background knowledge supports memory for textual materials by facilitating the organization of new information through existing, superordinate semantic links. Because this appears likely to be a significant issue among deaf learners, one might expect that sign language interpreters could help fill gaps in deaf students' knowledge and encourage the use of appropriate information-processing strategies in classroom settings. Interpreter training programs frequently do not teach future interpreters about the metacognitive or learning abilities of deaf students, however, and there is considerable ambivalence about allowing interpreters to engage in such activities (see Schick, 2005). An interpreting strategy of this sort also may preempt the instructional strategies of teachers who set up situations explicitly requiring students to go beyond the information given, thus fostering problem solving and learning.

Perhaps the most obvious possible explanation for results of the sort obtained here resides in the quality of academic preparation received by deaf students in K–12 classrooms. The findings indicating that deaf and hearing students differed significantly on content-specific pretests in both Experiments 1 and 2 (as in Marschark et al., 2004, 2005a) point to academic readiness as an important issue. Despite the faith placed in K–12 mainstream education by many parents and educators, we now know that the quality of interpreting in K–12 classrooms is variable and often poor (Jones, 2005; Jones et al., 1997; Schick et al., 1999). Regardless of whatever other factors might be at play, we cannot expect deaf students to be ready to graduate from high school, let alone be prepared for college, if they are years behind their hearing peers in language, reading, and mathematics achievement (e.g., Traxler, 2000). As long as the quality of interpreting provided to deaf children in K–12 classrooms is recognized as inferior and the educational system does not meet other academic and social needs of deaf students, there is little that can be done at the college level to make up for so much lost time (Harrington, 2000; Jones, 2005; Marschark et al., 2005b). This is not a new issue (Jacobs, 1977; Redden et al., 1978; Stewart & Kluwin, 1996), but it can no longer be ignored.

Finally, the present results offer a mixed message to educators of deaf students, or others with special needs, in mainstream/inclusive settings. Together with previous findings, the results of this study indicate that deaf students' knowledge and skills may leave them unable to benefit fully from education in mainstream classrooms, even with high-quality interpreting. Such differences should not be taken as deficiencies but as indicators that we require a better understanding of students' strengths and needs if we are to provide them with full access to academic opportunities. At the same time, this study suggests that contrary to assumptions and anecdotes, the use of video-based sign language interpreting and multiple visual information sources in the classroom does not present more of a challenge for deaf students than live classroom presentations. Just as recent research has demonstrated that mode of classroom interpreting (ASL interpretation or English transliteration) and the familiarity of students and interpreters are not as important as we thought they were, the present results offer direction for reallocating time and resources in the training of educational interpreters. As we continue to explore variables that influence deaf students' learning in mainstream/inclusive and other settings, studies of this sort offer a bridge between research and practice and the potential for making more effective and efficient use of resources, which in turn should help provide students of all ages with the quality education they deserve.

APPENDIX

Student Demographic and Communication Variables Examined: Experiments 1 and 3

Institutional Database Information

- ACT: English, mathematics, reasoning, natural science, and composite scores
- Michigan Test of English Language Proficiency
- California Reading Comprehension Test
- NTID reading, writing, and mathematics placement tests

- Pure tone threshold in each ear
- Age of hearing loss onset

Communication Questionnaire (Self-Report) Information

- Hearing aid and cochlear implant use
- Languages used in the home
- Age at initiation of sign learning
- Primary mode of communication preference (sign, speech, simultaneous communication)
- Sign communication preference (ASL, English-based sign)
- ASL production skills
- ASL receptive skills
- English-based sign production skills
- English-based sign receptive skills
- Simultaneous communication production skills
- Simultaneous communication receptive skills
- Age and grade of initiation of use of sign language interpreters

Notes

Preparation of this article and the research reported were supported by Grants REC-0207394 and REC-0307602 from the National Science Foundation and Grant 1R55DC00523801A1 from the National Institute on Deafness and Other Communication Disorders. Any opinions, findings, conclusions, or recommendations expressed are those of the authors and do not necessarily reflect the views of the National Science Foundation or the National Institutes of Health. We thank Doni LaRock and Gayle Macias for their interpreting excellence in these experiments and members of the NTID/RIT Department of Interpreting Services for their voluntary participation in Experiment 2. "Memorex" and "Live or Memorex?" are registered trademarks of the 3M Company.

[1]Although most research on interpreting has been done in English-speaking countries, "American Sign Language" and "English" are used generically to refer to natural sign languages and their corresponding vernaculars. *Interpreting,* as used here, thus refers to immediate transmission of productions from any natural sign language (e.g., ASL) via the spoken vernacular (e.g., English), and vice versa, and *transliteration* refers to transmission of a spoken language using the word order of that language while being strongly influenced by the natural sign vernacular (Registry of Interpreters for the Deaf, 2004).

[2]Unfortunately, different questions were used in the pretest and the learning assessment test, so gain scores could not be calculated. Gain scores have been used in subsequent experiments (still in preparation), and the results have been fully consistent with those reported here.

[3]We thank John T. E. Richardson for suggesting this possibility and the related analyses. Along the same lines, in a forthcoming study we explicitly examined the effects of prior knowledge of lecture content on the part of both students and interpreters. Prior content knowledge could affect deaf students' learning via interpreting through either reduction of the need to attend to simultaneously presented visual displays or scaffolding of relevant knowledge. However, neither of these factors had significant effects on learning in classrooms that involved multiple sources of visual information.

References

Aldersley, S. (2002). The courts and "least restrictive environment." *Journal of Deaf Studies and Deaf Education, 7,* 189–199.

Babcock, J., & Pelz, J. (2004). Building a lightweight eyetracking headgear. In *Proceedings of the Eye Tracking Research and Applications Symposium* (pp. 109–114). San Antonio, TX: ACM Press.

Baily, J., & Straub, S. (1992). Interpreting services. *Asha, 34,* 51–53.

Bard, C., Fleury, M., & Paillard, J. (1992). Different patterns in aiming accuracy for head-movers and non-head movers. In A. Berthoz, W. Graf, & P. P. Vidal (Eds.), *The head neck sensori-motor system* (pp. 582–586). New York: Oxford University Press.

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

Bernard, R. M., Abrami, P. C., Borokhovski, E., Wade, A., Wozney, L., Wallet, P. A., Fiset, M., & Huang, B. (2004). How does distance education compare with classroom instruction? A meta-analysis of the empirical literature. *Review of Educational Research, 74,* 379–439.

Braverman, B. B., & Hertzog, M. (1980). The effects of caption rate and language level on comprehension of a captioned video presentation. *American Annals of the Deaf, 125,* 943–948.

Chamberlain, C., & Mayberry, R. I. (1994, May). *Do the deaf "see" better? Effects of deafness on visuospatial skills.* Poster session presented at the TENNET V meetings, Montreal.

Cokely, D. (1990). The effectiveness of three means of communication in the college classroom. *Sign Language Studies, 69,* 415–439.

Cokely, D. (2005). Shifting positionality: A critical examination of the turning point in the relationship of interpreters and the deaf community. In M. Marschark, R. Peterson, & E. A. Winston (Eds.), *Interpreting and interpreter education: Directions for research and practice* (pp. 3–28). New York: Oxford University Press.

Dubow, S., Geer, S., & Strauss, K. (1992). *Legal rights: The guide for deaf and hard-of-hearing people* (4th ed.). Washington, DC: Gallaudet University Press.

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

Emmorey, K., & Kosslyn, S. (1996). Enhanced image generation abilities in deaf signers: A right hemisphere effect. *Brain and Cognition, 32,* 28–44.

Emmorey, K., Kosslyn, S., & Bellugi, U. (1993). Visual imagery and visual-spatial language: Enhanced imagery abilities in deaf and hearing ASL signers. *Cognition, 46,* 139–181.

Fabich, M. (2005). *A meta-analysis of demographic characteristics and learning by deaf students.* Unpublished master's thesis, Rochester Institute of Technology, Rochester, NY.

Fleischer, L. R. (1975). *Language interpretation under four interpreting conditions.* Unpublished doctoral dissertation, Brigham Young University, Provo, UT.

Gallaudet Research Institute. (2004). *Annual survey of deaf and hard of hearing children and youth, 2002–2003.* Washington, DC: Gallaudet University Press.

Gellevij, M., van der Meij, H., Jong, T. D., & Pieters, J. (2002). Multimodal versus unimodal instruction in a complex learning context. *Journal of Experimental Education, 70,* 215–239.

Harrington, F. (2000). Sign language interpreters and access for deaf students to university curricula: The ideal and the reality. In R. P. Roberts, S. E. Carr, D. Abraham, & A. Dufour (Eds.), *The critical link 2: Interpreters in the community* (pp. 219–273). Amsterdam: John Benjamins.

Hegarty, M., & Just, M. A. (1989). Understanding machines from text and diagrams. In H. Mandl & J. R. Stevens (Eds.), *Knowledge acquisition from text and pictures* (pp. 171–195). Amsterdam: Elsevier.

Iding, M. K. (2000). Is seeing believing? Features of effective multimedia for learning science. *International Journal of Instructional Media, 27,* 403–415.

Jacobs, L. R. (1977). The efficiency of interpreting input for processing lecture information by deaf college students. *Journal of Rehabilitation of the Deaf, 11,* 10–14.

Jensema, C., McCann, R., & Ramsey, S. (1996). Closed-captioned television presentation speed and vocabulary. *American Annals of the Deaf, 141,* 284–292.

Johnson, K. (1991). Miscommunication in interpreted classroom interaction. *Sign Language Studies, 70,* 1–34.

Jones, B. E. (2005). Competencies of K-12 educational interpreters: What we need versus what we have. In E. A. Winston (Ed.), *Educational interpreting: How it can succeed* (pp. 113–131). Washington, DC: Gallaudet University Press.

Jones, B. E., Clark, G., & Stoltz, D. (1997). Characteristics and practices of sign language interpreters in inclusive education programs. *Exceptional Children, 63,* 257–268.

Kluwin, T. N., & Stewart, D. A. (2000, Winter/Spring). Interpreting in schools: A look at research. *Odyssey,* pp. 15–17.

Kruskal, J. B. (1999). An overview of sequence comparison. In D. Sankoff & J. Kruskal (Eds.), *Time warps, string edits, and macromolecules: The theory and practice of sequence comparison* (pp. 1–44). Stanford, CA: Center for the Study of Language and Information.

Kurz, K. B. (2004). *A comparison of deaf children's learning in direct communication versus an interpreted environment.* Unpublished doctoral dissertation, University of Kansas, Lawrence.

Lang, H. G. (2002). Higher education for deaf students: Research priorities in the new millennium. *Journal of Deaf Studies and Deaf Education, 7,* 267–280.

Livingston, S. (1997). *Rethinking the education of deaf students.* Portsmouth, NH: Heinemann.

Livingston, S., Singer, B., & Abramson, T. (1994). A study to determine the effectiveness of two different kinds of interpreting. In *Proceedings of the Tenth National Convention of the Conference of Interpreter Trainers* (pp. 175–197). Sacramento, CA: Conference of Interpreter Trainers.

Loke, W. H., & Song, S. (1991). Central and peripheral visual processing in hearing and nonhearing individuals. *Bulletin of the Psychonomic Society, 29,* 437–440.

Marschark, M., Convertino, C., McEvoy, C., & Masteller, A. (2004). Organization and use of the mental lexicon by deaf and hearing individuals. *American Annals of the Deaf, 149,* 51–61.

Marschark, M., Lang, H. G., & Albertini, J. A. (2002). *Educating deaf students: From research to practice.* New York: Oxford University Press.

Marschark, M., Peterson, R., & Winston, E. A. (Eds.). (2005). *Interpreting and interpreter education: Directions for research and practice.* New York: Oxford University Press.

Marschark, M., Sapere, P., Convertino, C., & Seewagen, R. (2005a). Access to postsecondary education through sign language interpreting. *Journal of Deaf Studies and Deaf Education, 10,* 38–50.

Marschark, M., Sapere, P., Convertino, C., & Seewagen, R. (2005b). Educational interpreting: Access and outcomes. In M. Marschark, R. Peterson, & E. A. Winston (Eds.), *Sign language interpreting and interpreter education: Directions for research and practice* (pp. 57–83). New York: Oxford University Press.

Marschark, M., Sapere, P., Convertino, C., Seewagen, R. & Maltzan, H. (2004). Comprehension of sign language interpreting: Deciphering a complex task situation. *Sign Language Studies, 4,* 345–367.

Mayer, R. E. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81,* 240–246.

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93,* 187–198.

Mayer, R. E., & Morena, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90,* 312–320.

McEvoy, C., Marschark, M., & Nelson, D. L. (1999). Comparing the mental lexicons of deaf and hearing individuals. *Journal of Educational Psychology, 91,* 1–9.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87,* 319–334.

Murphy, H. J., & Fleischer, L. R. (1977). The effects of Ameslan versus Siglish upon test scores. *Journal of Rehabilitation of the Deaf, 11,* 15–18.

Myklebust, H. E. (1964). *The psychology of deafness* (2nd ed.). New York: Grune & Stratton.

Narayanan, N. H., & Hegarty, M. (1998). On designing comprehensible interactive hypermedia manuals. *International Journal of Human-Computer Studies, 48,* 267–301.

National Center for Education Statistics. (1999). *Integrated Postsecondary Education Data System, fall enrollment data file, fall 1997.* Retrieved April 20, 2005, from http://nces.ed.gov/Ipeds/ef9798/

National Center for Health Statistics. (2000). *Vital health statistics* (Series 10, No. 199). Retrieved April 20, 2005, from www.cdc.gov/nchswww/data/10_a199_1.pdf

National Technical Institute for the Deaf. (2004). *NTID vision 2010.* Rochester, NY: Author.

Neville, H. J. (1990). Intermodal competition and compensation in development: Evidence from studies of the visual system in congenitally deaf adults. *Annals of the New York Academy of Sciences, 608,* 71–91.

Neville, H. J., & Lawson, D. (1987). Attention to central and peripheral visual space in a movement detection task: An event-related potential and behavioral study. II. Congenitally deaf adults. *Brain Research, 405,* 268–283.

Ottem, E. (1980). An analysis of cognitive studies with deaf subjects. *American Annals of the Deaf, 125,* 564–575.

Paivio, A. (1971). *Imagery and verbal processes.* New York: Holt, Rinehart & Winston.

Paivio, A. (1986). *Mental representations: A dual coding approach.* New York: Oxford University Press.

Parton, B. S. (in press). Sign language recognition and translation: A multi-disciplined approach from the field of artificial intelligence. *Journal of Deaf Studies and Deaf Education.*

Pelz, J. B., & Canosa, R. L. (2001). Oculomotor behavior and perceptual strategies in complex tasks. *Vision Research, 41,* 3587–3596.

Power, D. J., & Hyde, M. B. (1997). Multisensory and unisensory approaches to communication with deaf children. *European Journal of Psychology and Education, 12,* 449–464.

Presno, C. (1997). Bruner's three forms of representation revisited: Action, pictures, and words for effective computer instruction. *Journal of Instructional Psychology, 24,* 112–118.

Proksch, J., & Bavelier, D. (2002). Changes in the spatial distribution of visual attention after early deafness. *Journal of Cognitive Neuroscience, 14,* 687–701.

Rawson, K. A., & Kintsch, W. (2002). How does background information improve memory for text? *Memory & Cognition, 30,* 768–778.

Redden, M. R., Davis, C. A., & Brown, J. W. (1978). *Science for handicapped students in higher education: Barriers, solutions, and recommendations.* Washington, DC: American Association for the Advancement of Science.

Registry of Interpreters for the Deaf. (2004). *Explanation of certificates*. Retrieved January 21, 2004, from http://www.rid.org/expl.html

Rettenback, R., Diller, G., & Sireteanu, R. (1999). Do deaf people see better? Texture segmentation and visual search compensate in adult but not in juvenile subjects. *Journal of Cognitive Neuroscience, 11*, 560–583.

Reynolds, H. N. (1993). Effects of foveal stimulation on peripheral visual processing and laterality in deaf and hearing subjects. *American Journal of Psychology, 106*, 523–540.

Richardson, J. T. E., MacLeod-Gallinger, J., Long, G. L., & McKee, B. G. (1999). Approaches to studying in deaf and hearing students in higher education. *Journal of Deaf Studies and Deaf Education, 5*, 156–173.

Schick, B. (2005). How might learning through an educational interpreter influence cognitive development? In E. Winston (Ed.), *Educational interpreting: The questions we should be asking* (pp. 73–87). Washington, DC: Gallaudet University Press.

Schick, B., Bolster, L., & Williams, K. (1999). Skill levels of educational interpreters working in public schools. *Journal of Deaf Studies and Deaf Education, 4*, 144–155.

Seal, B. C. (2004). *Best practices in educational interpreting* (2nd ed.). Boston: Allyn & Bacon.

Stewart, D. A., & Kluwin, T. N. (1996). The gap between guidelines, practice, and knowledge in interpreting services for deaf students. *Journal of Deaf Studies and Deaf Education, 1*, 29–39.

Strassman, B. (1997). Metacognition and reading in children who are deaf: A review of the research. *Journal of Deaf Studies and Deaf Education, 2*, 140–149.

Swisher, M. V. (1993). Perceptual and cognitive aspects of recognition of signs in peripheral vision. In M. Marschark & M. D. Clark (Eds.), *Psychological perspectives on deafness* (pp. 229–265). Hillsdale, NJ: Erlbaum.

Talbot, K. F. & Haude, R. H. (1993). The relationship between sign language skill and spatial visualization ability: Mental rotation of three-dimensional objects. *Perceptual and Motor Skills, 77*, 1387–1391.

Tharpe, A., Ashmead, D., & Rothpletz, A. (2002). Visual attention in children with normal hearing, children with hearing aids, and children with cochlear implants. *Journal of Speech, Hearing, and Language Research, 45*, 403–413.

Tiene, D. (2000). Sensory mode and information load: Examining the effects of timing on multisensory processing. *International Journal of Instructional Media, 27*, 183–198.

Todman, J., & Seedhouse, E. (1994). Visual-action code processing by deaf and hearing children. *Language and Cognitive Processes, 9*, 129–141.

Traxler, C. B. (2000). Measuring up to performance standards in reading and mathematics: Achievement of selected deaf and hard-of-hearing students in the national norming of the 9th Edition Stanford Achievement Test. *Journal of Deaf Studies and Deaf Education, 5*, 337–348.

Winston, E. A. (1994). An interpreted education: Inclusion or exclusion? In R. C. Johnson & O. P. Cohen (Eds.), *Implications and complications for deaf students of the full inclusion movement* (Gallaudet Research Institute Occasional Paper 94-2, pp. 55–62). Washington, DC: Gallaudet University Press.

Winston, E. A. (2005). Interpretability and accessibility of mainstream classrooms. In E. A. Winston (Ed.), *Educational interpreting: How it can succeed* (pp. 132–168). Washington, DC: Gallaudet University Press.

Manuscript received April 29, 2005
Revision received July 24, 2005
Accepted August 15, 2005