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Evaluation of a Behavioral Audiometry Simulator for Teaching Visual Reinforcement Audiometry

Julie A. Durham*
James W. Thelin*
Robert A. Muenchen†
Christopher F. Halpin‡

Abstract

Eight audiology students with little or no visual reinforcement audiometry (VRA) experience each performed a VRA test on an infant. Four of the students received approximately 5 hours of behavioral audiometry simulator (BAS) training, and 1 week later, after the first VRA test, all eight students tested a second infant. Student performance was rated by three audiologists who were experienced in performing VRA with infants. The performance of the group that received BAS training improved significantly while the performance of the control group did not. Among the students who received BAS training, those who improved the most during stimulated testing also showed the greatest improvement in VRA with real infants.

Key Words: Behavioral audiometry simulator (BAS), computer workstation, pediatric audiology training, simulated infant tests, visual reinforcement audiometry (VRA)

In most audiology training programs, the student learns to perform behavioral audiometry with adults before attempting visual reinforcement audiometry (VRA) (Liden and Kankkunen, 1969) with infants and young children. The student is typically prepared to perform VRA with didactic instruction followed by familiarization with the VRA testing apparatus and reinforcement system. The student's first experiences in performing VRA are usually with infants suspected of having hearing loss. If the student examiner is not obtaining the necessary information and if the infant is losing interest, the supervisor is ethically bound to intervene and complete the test to ensure that a hearing loss does not go undetected. In this situation, the student becomes a passive observer while the practicum supervisor tests the infant.

To avoid compromising the interests of infants who may have hearing loss, practicum facilities could schedule infants with normal hearing for the beginning student to test. However, this method of instruction would be so expensive in terms of clinic time, space, and personnel that it is typically not feasible. The behavioral audiometry simulator (BAS) is a unique system developed to give the beginning student practical testing experience by using an infant recorded on an interactive videodisc (Halpin et al, 1988, 1991). The BAS requires active participation of the student in selecting and executing the VRA test protocol and in evaluating infant responses. The system permits the student to practice and learn with no consequences to a real infant.

The components of the BAS workstation, which are shown in Figure 1, are a personal computer, a videodisc player, a video monitor, and a custom-made audiometer console. The student sits at the controls of the BAS audiometer and views a video monitor with a 7-month-old boy sitting on his mother's lap in a typical VRA

*Department of Audiology and Speech Pathology; and †Computing Center; University of Tennessee, Knoxville, Tennessee; and ‡Massachusetts Eye and Ear Infirmary, Massachusetts

Reprint requests: James W. Thelin, Department of Audiology and Speech Pathology, University of Tennessee, 457 S. Stadium Hall, Knoxville, TN 37996

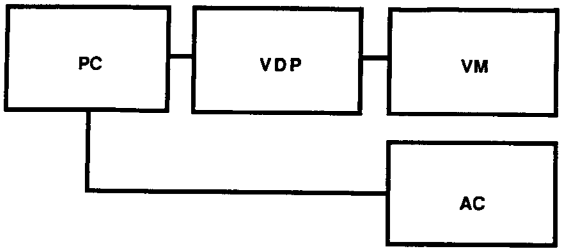

Figure 1 Components of the BAS workstation: personal computer (PC); videodisc player (VDP); video monitor (VM); and audiometer console (AC).

arrangement. When the student is operating the BAS system, the simulated infant responds to signals and visual reinforcement presented by the student using the audiometer console. Thus, actions taken by the student result in changes in the video images of the simulated infant being tested.

The BAS instructor has the option of selecting different infants for the student to test. As in VRA with real infants, the simulated infants differ in degree of hearing loss, cooperation, and response reliability. The student must condition the BAS infant to turn in response to a signal before the search for thresholds is undertaken. During a threshold search, the student is again required to make appropriate receptive state judgments before presenting test signals. Because the BAS infant provides both random and purposeful head turns during testing, the student is challenged to make accurate response judgments by learning to differentiate between false positive responses and true responses to signal presentations. After each stimulus-response-reinforcement sequence, if the student judges the response to be valid, the judgment is recorded by pressing a button on the audiometer console. The BAS computer gives the student an audible signal that the judgment was correct or incorrect.

The initial study on the effectiveness of BAS training was conducted by O'Neil et al (1991). They examined the performance of students in judging infant receptive state, in recognizing infant responses, and in obtaining accurate audiograms for the BAS infant. Twelve students with similar audiologic backgrounds were given an introductory lecture on VRA and then participated in 14 BAS training sessions of 15 minutes each—the approximate time an infant will cooperate (Thompson and Wilson, 1984). The students showed systematic improvement in all three skill areas. O'Neil et al (1991) found rapid improvement in the students' skills for 7 to 9 sessions. After the 9th training session, average performance plateaued. O'Neil et al concluded that by the 10th or 11th session, the students had developed skills that were ready to be introduced to the VRA evaluation with real infants.

The results of O'Neil et al (1991) demonstrate that BAS training improves the ability to test simulated infants using VRA. The present study extended their research to the testing of real infants, with the purpose of determining if BAS training improves the ability of students to perform VRA on real infants. This was accomplished by comparing the changes in test performance of students who received BAS training to those who did not. The test was conducted using real infants, and student performance was evaluated by audiologists skilled in VRA.

METHOD

Participants

In this study, the subjects were audiology students who each performed a VRA test on an infant listener and then a second VRA test on a different infant 1 week later. An audiologist who was skilled in testing infants served as the audiometric assistant for the testing. Three other audiologists who were skilled in VRA served as evaluators of student performance on VRA tests.

Student Examiners

The subjects were eight graduate students in the Master's program in audiology at the University of Tennessee, Knoxville. Originally, there were nine students, but one student was removed from the study (see section on Infant Listeners). The students had similar audiologic backgrounds; each student had completed at least one basic course in audiology, had clinical experience in audiologic testing of adults, and had very limited clinical experience testing infants.

Evaluators

Performance of students was evaluated by three audiologists who were experienced in testing infants with VRA. Each evaluator held a Master's degree in audiology and the Certificate of Clinical Competence in Audiology. The evaluators were selected because they did not know the students and had no knowledge of their audiologic skills. The evaluators were not aware of the design or purposes of the study. The evaluators rated student performance after each VRA test using the evaluation form shown in Table 1. The medians of the three evaluators' ratings were used in all tables and analyses. The median was chosen because of its immunity to influence by one extreme rating.

Table 1 Visual Reinforcement Audiometry Evaluation Form*

Components of VRA										
a) Use of the equipment	1	2	3	4	5	6	7	8	9	10
b) Procedures used to condition the infant	1	2	3	4	5	6	7	8	9	10
c) Ability to judge the infant's receptive state	1	2	3	4	5	6	7	8	9	10
d) Ability to identify the infant's responses	1	2	3	4	5	6	7	8	9	10
e) Procedures used to determine minimal response levels	1	2	3	4	5	6	7	8	9	10
f) Adaptation of test procedures based on the infant's ability to respond	1	2	3	4	5	6	7	8	9	10
g) Completeness of audiogram considering the infant's state	1	2	3	4	5	6	7	8	9	10
Overall evaluation of VRA performed with this infant	1	2	3	4	5	6	7	8	9	10
Cooperation of infant during testing	1	2	3	4	5	6	7	8	9	10
Cooperation of parent during testing	1	2	3	4	5	6	7	8	9	10

*The poorest performance was indicated by a rating of 1.

Audiometric Assistant

The audiometric assistant was an audiologist at the University of Tennessee Audiology Clinic who supervises the testing of infants and young children. The audiometric assistant had the same qualifications as the evaluators.

Infant Listeners

The initial group of infant listeners was comprised of 5 females and 13 males who ranged in age from 6 to 10 months. The data for two infant listeners were dropped from the study; this is discussed in the following paragraph. (For demographic data on infant listeners, refer to Table 2 in the Results section.) The infants were presumed to be normal-hearing infants on the basis of the following histories reported by parents: (1) no suspicion of hearing loss; (2) no history of ear disease; (3) no observed or reported ear anomalies; and (4) normal development. Though the purpose of this study was not to provide a clinical hearing evaluation of the infants, if the evaluators or the audiometric assistant suspected that an infant had a hearing problem, a screening audiometric evaluation was performed by a certified audiologist.

For each VRA test, the evaluators rated infant and parent cooperativeness using the ratings shown at the bottom of Table 1. Each of the parents participating in the study received a cooperativeness rating of 10. When infant cooperation was examined, it was found that 15 infants received a rating of 10 and 2 infants received a rating of 9. One infant in trial 1 was noticeably less cooperative than all other infants and received a rating of 7. Since only one student was required to test an uncooperative infant, the decision was made to exclude that student's data from the analysis of group effects. The data from the infant with the cooperativeness rating of 7 was excluded, along with the data from the infant the student tested in trial 2.

Apparatus

BAS System

The BAS was used to train students in the experimental group. The BAS workstation consisted of a personal computer (Samsung, Model AIC Turbo), a videodisc player (Sony Lasermax, Model 1450), a video monitor (Panasonic, Model CT 1382), and a custom-made audiometer console (Halpin et al, 1988). The console simulates a one-channel audiometer with standard audiometric controls and, in addition, a button for the student to indicate when an appropriate head-turning response had been obtained from the BAS infant.

VRA System for Testing Real Infants

VRA was conducted in a sound-treated suite with a control booth and a test booth (Industrial Acoustics, Serial No. 101528) at the University of Tennessee Audiology Clinic. Ambient noise levels in the sound-treated test booth were within permissible levels for ears not covered at 250, 500, 1000 Hz, and they exceeded permissible levels by 1.0 and 1.5 dB at 2000 and 4000 Hz, respectively (ANSI, 1977). A diagnostic audiometer (Madsen, Model OB 822) was used to generate pulsed and warbled pure-tone signals and deliver them to a loudspeaker (Grason-Stadler, Model 162-4). The arrangement of the test booth was similar to that which has been described in previous VRA studies (Moore et al, 1975; Wilson et al, 1976; Moore and Wilson, 1978; Thompson and Folsom, 1984). The infant listener sat on the parent's lap in a chair that was located in the center of the test booth. The reinforcement toy, an animated bear, was enclosed in a darkened, smoked-plastic box. The box was located on top of the loudspeaker at 45 degrees to the left of the infant's midline and at a distance of approximately 1 meter. The signal levels were within 5 dB of sound-field reference levels for frequency-specific stimuli presented at 45 degrees azimuth (ASHA, 1991). The audiometric assistant's chair was located approximately 0.3 meters to the infant's right side.

Procedure

Training for All Students

All students attended a 1-hour lecture on behavioral testing of infants using VRA given by a member of the University of Tennessee audiology faculty. This lecture included sections on the development of auditory behavior, behavioral test methods for infants, and expected minimum response levels for normal-hearing infants. Following the lecture, each student was given a written examination to evaluate understanding of the lecture material. If a student did not receive a perfect score on the examination, the material was reviewed until all of the examination questions were answered correctly. In addition to the lecture, each student was familiarized individually with the audiometric and VRA equipment that was used during the real infant testing. These sessions were conducted by the principal investigator, and each session lasted approximately 15 minutes. Each student was required to demonstrate proficiency in use of the audiometer and the VRA reinforcement system.

Trial 1: First VRA Evaluation

After the students completed the instructional sessions, each student performed VRA with one real infant in Trial 1. Each infant was tested only once to avoid confounding of effects associated with repeated measures. Trial 1 was conducted on a single day; infant listeners were scheduled at 30-minute intervals. Prior to testing, the audiometric assistant greeted the parent/guardian and the infant and explained the VRA test procedure. The audiometric assistant then escorted the infant and the parent into the test booth and prepared them for testing. The audiometric assistant remained in the test booth during the test and assisted by keeping the infant in an appropriate receptive state. The students communicated instructions to the audiometric assistant through a bone oscillator worn by the assistant. The students were expected to follow the test protocol taught in the lectures: they were to condition the infant listener and then attempt to establish minimum response levels in the soundfield at 250, 500, 1000, 2000, and 4000 Hz. Testing time was limited to 15 minutes. The three evaluators stood behind the student in the control booth during the VRA test procedure. At the end of each VRA test, each evaluator left the control booth without talking to one another or to the student, went to a separate room, and completed an independent evaluation (see Table 1) of the student's performance of VRA.

Assignment of Students into Control and Experimental Groups

After Trial 1, an overall VRA performance rating was determined for each student by taking the median of the scores from the three evaluators for the single rating item entitled "Overall evaluation of VRA performed with this infant." Using this rating, the students were ranked according to skill, grouped into pairs (first and second, third and fourth, etc.) and then randomly assigned from the pair to either the control or experimental group.

BAS Training Given to Experimental Subjects

The four experimental subjects participated in nine 30-minute BAS training sessions. The principal investigator instructed each student in the operation of the BAS and was present at all sessions to provide direction when technical mistakes were made.

In each session, the student was seated at the simulated audiometer console and viewed the BAS infant on the video monitor. The BAS infant was one of six preprogrammed infants selected at random by the principal investigator. The student was instructed that he or she would be required to condition and test the simulated infant. The students were given no information about the infant's hearing status or response behavior.

First, the student was required to condition the infant to give a head turn response toward the visual reinforcement. In this procedure, the student selected the frequency and level of the conditioning signal and judged the appropriateness of the infant's receptive state when conditioning the BAS infant. During conditioning, the signal was presented a fraction of a second before the reinforcement. Different BAS infants required different amounts of conditioning. If the student proceeded to the threshold search without having achieved appropriate conditioning, the infant would not respond systematically when signals were presented.

Second, the student performed threshold searches using pure-tone signals of different frequencies. The procedure for presenting signals was the same as that used in conditioning with the exception that reinforcement was given after an infant response. After the reinforcement, the student was required to determine if the response was valid. Following that, the BAS system compared the student's judgment with the judgment criteria programmed into the BAS system and then gave the student an audible signal to indicate if it agreed or disagreed with the student's judgment. The student was responsible for the strategy used to determine threshold and for decisions on the order and number of frequencies to be tested. The student recorded test results on a threshold audiogram. A 15-minute time limit was set for each test.

At the end of each training session, there was a short debriefing session during which the following aspects of student performance were discussed:

1. Percentage correct receptive state judgments made during the conditioning and threshold search phases of each session. (Conditioning phase results were collected by the principal investigator; threshold search phase results were computed from data tabulated by the BAS system.)
2. Percentage correct response judgments made during the threshold searches. (Results were computed from data tabulated by the BAS system.)
3. Number of correct thresholds obtained during each session. (Results obtained by comparing thresholds on the student's audiogram with threshold values for the preprogrammed BAS infant.)

If the student had any other questions about the training, they were answered by the principal investigator. BAS training for the four experimental subjects was completed in 1 week.

Trial 2: Second VRA Evaluation

One week after Trial 1, all students performed a second VRA evaluation with real infant listeners (Trial 2). The procedures in Trial 2 were the same as in Trial 1 with one exception: without the student's knowledge, loudspeaker output was attenuated by 15 dB for all signals so infant minimum response levels would be elevated from those obtained in Trial 1. This was done to disrupt any expectation that each student might have that the tasks in Trials 1 and 2 would be identical. After each VRA test in Trial 2, the student's performance was rated in the same manner by the same three evaluators.

RESULTS

Factors Related to Infant Listeners

The age and gender of each infant listener is shown in Table 2. An analysis of variance (ANOVA) was performed to determine if the ages of the infant listeners were different across groups or trials. Results indicated that the ages of the infant listeners were not different for the experimental and control groups ($F[1,12] = 0.13$, $p = .72$) or across trials ($F[1,12] = 3.26$, $p = .09$). The cooperativeness rating for each infant listener and parent is also shown in Table 2. The data for infant cooperativeness was analyzed in the same manner using ANOVA; the cooperativeness ratings were not significantly different for the experimental and control groups ($F[1,12] = 3.00$, $p = .10$) or across trials ($F[1,12] = 3.00$, $p = .10$).

Interevaluator Reliability

Interevaluator reliability was measured by obtaining an average of six correlations: three correlations were obtained between the ratings of pairs of evaluators (1 vs 2, 1 vs 3, and 2 vs 3) for each of the two trials. An interevaluator reliability correlation of .81 was obtained for overall VRA performance. This correlation indicates substantial agreement among the three evaluators for the overall VRA performance category.

Overall VRA Performance

The overall VRA performance ratings are shown in Figure 2 and Table 2 for individual students in the control and experimental groups. Each plotted datum is the overall VRA performance rating for each student for each trial. For the control group, two students' performances worsened from Trial 1 to Trial 2 and two students' performances improved. In contrast to the control group, the overall VRA performance ratings of all four experimental subjects improved from Trial 1 to Trial 2.

The effect of BAS training (i.e., the trial by group interaction) was found to be significant using ANOVA ($F[1,6] = 3.55$, $p = .05$). Changes in overall VRA performance were then determined for the control and experimental groups separately. A change score was computed for each subject by subtracting the Trial 1 overall VRA

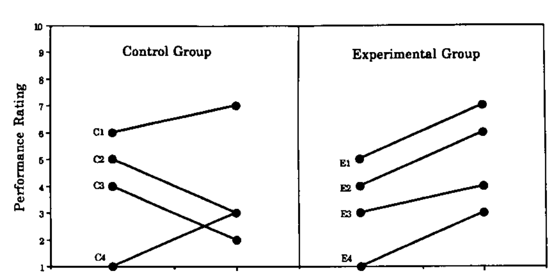

Figure 2 Overall VRA performance ratings for control (C1–C4) and experimental (E1–E4) subjects for Trials 1 and 2.

Table 2 Data on Infant Listeners, Parents, and Subject Performance

	Subjects							
	C1	*C2*	*C3*	*C4*	*E1*	*E2*	*E3*	*E4*
Trial 1								
Infant Listener								
Age (mos)	6	6	9	6	7	6	6	6
Gender	F	M	M	F	M	M	F	F
Cooperativeness rating	10	10	10	10	10	10	10	10
Parent								
Cooperativeness rating	10	10	10	10	10	10	10	10
Subject								
Overall VRA performance rating	6	5	4	1	5	4	3	1
Trial 2								
Infant Listener								
Age (mos)	9	9	7	6	7	8	6	10
Gender	M	M	M	M	M	M	F	M
Cooperativeness rating	10	9	10	9	10	10	10	10
Parent								
Cooperativeness rating	10	10	10	10	10	10	10	10
Subject								
Overall VRA performance rating	7	3	2	3	7	6	4	3

performance rating from the Trial 2 overall VRA performance rating. A paired, one-tailed t-test was used to determine if overall VRA performance for each group changed significantly from Trial 1 to Trial 2. The results are shown in Table 3 under the "Mean Change in Performance Ratings" for the overall VRA performance category along with the probability of the result. For the control group, the mean change in rating was negative (–0.25), indicating that performance in Trial 2 definitely did not increase from Trial 1 (t [3] = –0.24, p = .58). However, for the experimental group, there was a significant mean improvement in performance ratings from Trial 1 to Trial 2 of 1.75 points (t[3] = 7.00, p = .003).

Components of VRA

Though the primary purpose of this study was to show the effect of BAS training on the overall performance of VRA, the evaluators were given the opportunity to rate students on their ability to perform various aspects of VRA. For example, it was expected that a student might receive high ratings in use of the equipment but low ratings in identification of infant responses. Or, for example, the inability to identify infant responses might prevent the student from obtaining a complete audiogram for the infant.

The components of VRA (see Table 3) are listed from "a" to "g," and the changes in performance ratings are shown for the components of VRA in the same manner as they are shown for overall VRA performance. These results are shown for informational purposes only, because the sample size was insufficient to control the experiment-wise error rate using a multivariate analysis. For the control group, three of the changes were improvements in performance and four were decrements. For the experimental group, all seven changes in performance were improvements, and the improvements in each component category were all greater than for the control group. These results suggest that the components of VRA are learned simultaneously rather than individually.

Results of BAS Training on Experimental Group Subjects

The results were examined for the experimental subjects on the three BAS performance measures: (1) receptive state judgment; (2) infant response judgment; and (3) audiogram accuracy. These performance measures were similar but probably not identical to VRA component categories "c," "d," and "g," respectively. The results for these measures are shown in Figures 3, 4, and 5 for each training session for each experimental subject. The results of the present study were similar to those obtained by O'Neil et al (1991). Improvement was seen for all experimental subjects from training session 1 to training session 9 for each of the performance measures. Across the nine sessions, the mean percentage of correct receptive

Table 3 Mean Changes in Performance Ratings for Control and Experimental Groups for Overall VRA Performance and for Performance in Component Categories of VRA

VRA Performance Category	*Control Group* *Mean Change in Performance Rating (p)**		*Experimental Group* *Mean Change in Performance Rating (p)**	
Overall Evaluation of VRA Performed with This Infant	–0.25	(.58)	1.75	(.003)
Components of VRA				
a) Use of the equipment	0.25	(.31)	1.25	(.07)
b) Procedures used to condition the infant	1.25	(.19)	2.25	(.009)
c) Ability to judge the infant's receptive state	0.25	(.41)	1.75	(.003)
d) Ability to identify the infant's responses	–0.75	(.69)	1.00	(.12)
e) Procedures used to determine minimal response levels	–0.50	(.75)	1.75	(.003)
f) Adaptation of test procedures based on infant's ability to respond	–0.75	(.80)	0.75	(.10)
g) Completeness of audiogram considering the infant's state	–0.50	(.62)	1.25	(.04)

*The probability of each change, computed using a paired, one-tailed t-test (df = 3), is shown next to each change score.

state judgments increased from 61 percent to 85 percent. The mean percentage of correct response judgments increased from 62 percent to 88 percent. The mean number of thresholds obtained increased from 3.5 to 11 correct thresholds. As with VRA performance data, the BAS performance data indicate that learning does not occur for one skill at a time, but rather it occurs in several or many areas simultaneously. The BAS data also show that the learning occurs in small increments.

In Figures 3, 4, and 5, it can be seen that subject E3 showed less improvement after nine training sessions than the other three subjects. It is important to note that subject E3 also showed the least improvement in overall VRA performance from Trial 1 to Trial 2 (Fig. 2). These findings provide the first evidence that improved performance in simulated tests using the BAS may be an indicator of improved performance in VRA tests with real infants.

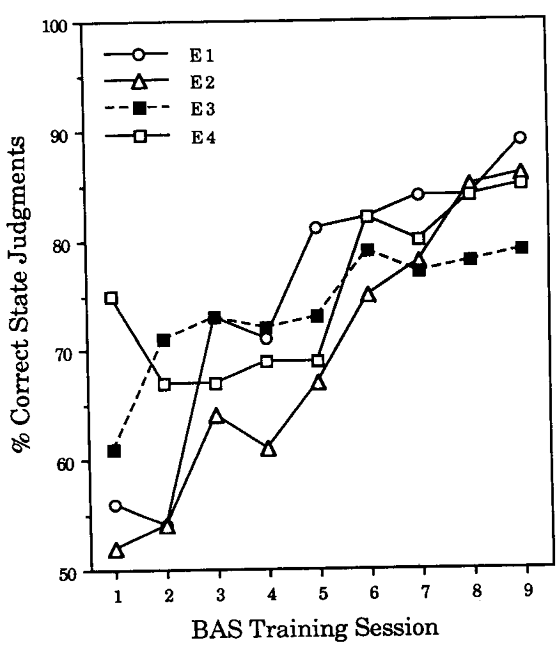

Figure 3 Percentage correct receptive state judgments made in each BAS training session by experimental subjects.

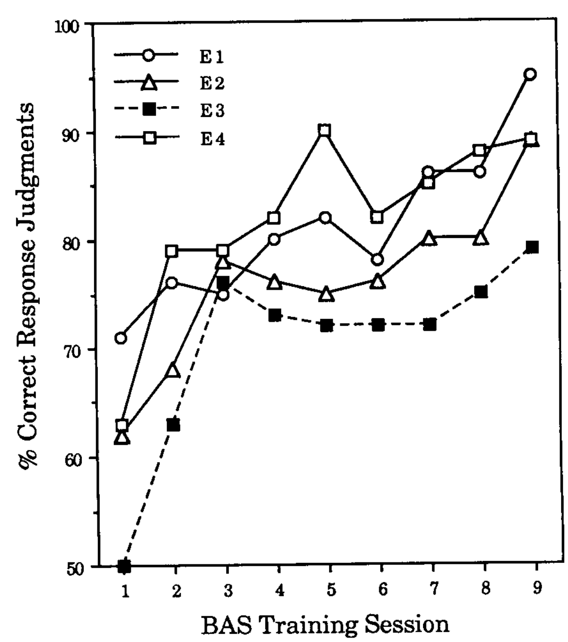

Figure 4 Percentage correct infant response judgments made in each BAS training session by experimental subjects.

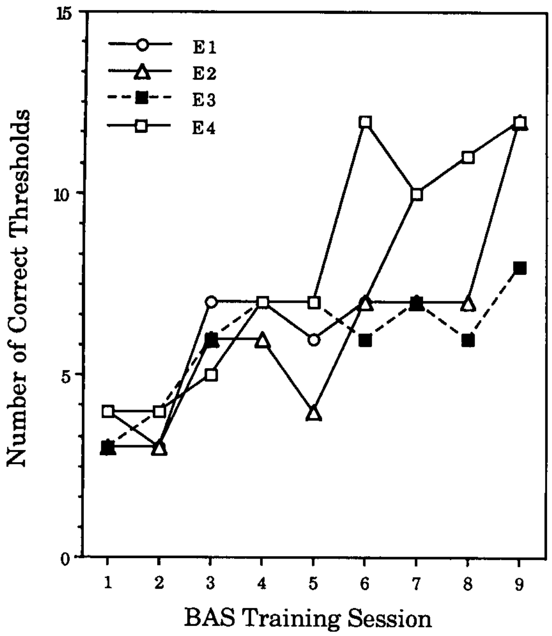

Figure 5 Number of correct thresholds obtained in each BAS training session by experimental subjects.

DISCUSSION

The use of real infants to teach VRA poses significant problems for any audiology training program. The BAS was developed to avoid those problems for beginning students by using a simulated VRA experience. The present study was conducted to determine if relevant VRA skills could be taught with the BAS. We found that VRA performance improved significantly for students who received BAS training, while VRA performance did not improve for students who did not receive BAS training. The evaluation of VRA performance was made by audiologists who had no knowledge of the BAS system or of the design of the study. In addition to the findings based on the evaluators' ratings, all four BAS-trained subjects told us anecdotally that the training experience increased their confidence in performing VRA.

It is important to note that the control and experimental subjects did not have equivalent training. Between Trials 1 and 2, the BAS-trained subjects performed nine simulated tests (over about 4½ hours), whereas the control subjects had no practical training experience. We considered having control subjects perform an alternate training experience, but there were no acceptable choices. It was inappropriate to have control subjects test nine real infants, because that was the approach we were trying to avoid. Also, we were unaware of any other training method that could be compared to the BAS training. Since students typically do not receive hands-on training before testing their first infant with VRA, the training given to the control subjects is typical of what is provided in audiology programs, and the results of the present study are representative of the gains that could be expected by adding BAS training to existing programs.

The results obtained for the experimental subjects on the simulated tests in BAS training reinforce the findings obtained in real VRA tests. In the present study, as well as in the study of O'Neil et al (1991), performance for all subjects improved systematically during BAS training in each of the three skill categories that were evaluated. In addition, the results indicate that the learning occurred in increments across the three skill categories over the nine training sessions. Thus, the results of the simulated and real VRA tests both provide evidence that the learning of VRA occurs in small steps simultaneously in many areas. This may be why the students in the present study were only able to state that training on the BAS increased their confidence in performing VRA tests and why they were unable to describe specific benefits of the training.

The implication of these findings is that VRA is complex to learn because the learning must take place in many areas at the same time. Though a practicum supervisor might point out specific areas in which a student needs improvement, it appears that success depends on the coordination of many skills. In learning VRA with real infants, the requirements of each test situation are often so different that the student is forced to modify test rules before they have really been learned. The BAS provides test situations with which the student becomes familiarized quickly, in which there are a smaller number of decisions to be made, and in which the infant operates in accordance with rigid rules. All of these features help make the initial attempts at performing VRA less overwhelming, because they allow the student to practice the systematic aspects of VRA without having concerns about the well-being of the infant and without the need to deal with exceptions before the rules are learned.

We have begun to use the BAS as part of the prepracticum training in the Master's program in audiology at the University of Tennessee. We anticipate that the use of the BAS will improve the training in pediatric audiology in several respects:

1. Students will have access to the BAS so that they may train at their convenience.
2. An instructor will be able to observe a student during one or more simulated tests as a means for confirming that the student has mastered the necessary skills or for identifying deficien-

cies that can be discussed while the student is testing or after the training session.

3. The BAS may serve as a framework for the discussion of VRA in didactic courses on audiometric technique and pediatric audiology.

Though the BAS was designed to train students to perform VRA, the system can also be used to study VRA. The BAS operates on a set of formal rules for the classification of infant behavior and for the evaluation of student action. These rules can be manipulated to create different forms of VRA tests and different simulated infants. In this respect, the BAS can serve as a framework for the discussion of the principles of VRA among audiologists who use different rules to perform VRA or who wish to test the consequences of changes in certain variables on the ability to learn or perform VRA. It is anticipated that the BAS will play a role in the development of the optimal forms of VRA procedures.

At present, only a small number of BAS systems have been manufactured. Inquiries regarding the acquisition of a BAS should be directed to Dr. Halpin at the Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, Massachusetts 02114.

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