

Beside hearing screenings are routinely conducted by speech and language pathologists for brain injury survivors during rehabilitation. Cognitive deficits resulting from brain injury, however, may interfere with obtaining estimates of auditory thresholds. Poor comprehension or attention deficits often compromise patient abilities to follow procedural instructions. This article describes the effects of jointly applying behavioral methods and psychophysical methods to improve two severely brain-injured survivors' attending and reporting on auditory test stimuli presentation. Treatment consisted of stimulus control training that involved differentially reinforcing responding in the presence and absence of an auditory test tone. Subsequent hearing screenings were conducted with novel auditory test tones and a common titration procedure. Results showed that prior stimulus control training improved attending and reporting such that hearing screenings were conducted and estimates of auditory thresholds were obtained.

When Instructions Fail

The Effects of Stimulus Control Training on Brain Injury Survivors' Attending and Reporting During Hearing Screenings

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Diffuse brain injury resulting from stroke or head trauma may produce disorientation, inattention, aphasia, or hearing losses that compromise instruction following. Speech and language therapists routinely conduct brief hearing screenings to assess for hearing loss before pursuing formal audiological testing, especially when audiological services (e.g., rural subacute skilled nursing facilities) are not readily available. Instructions are primarily used during hearing screenings to establish patient responding to auditory test stimuli. A common problem, however, is that brain injury survivors may be unable to consistently follow instructions. Consequently, estimates of auditory thresholds may be difficult to obtain during screenings. This article describes the application of a stimulus control training proce-



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ture that originates in the stimulus control literature to facilitate patient attending and responding during hearing screenings. For an overview of stimulus control see Dinsmoor (1995a, 1995b).

The difficulties associated with conducting hearing screenings with brain injury survivors unable to follow instructions parallels the difficulties faced by psychologists studying nonhuman animal auditory systems and audiologists conducting hearing screenings with children. Fortunately, a variety of operant methods are available in the nonhuman animal literature on stimulus control that may help rehabilitation professionals overcome some of the assessment challenges presented by brain injury survivors. The methods combine psychophysical methods, such as titration methods (Harrison & Turnock, 1975; Hendricks, 1966; Maurissen, 1988; Mosokowitz & Kitzes, 1966), which are also common methods in clinical audiology, and principles and methods characteristic of behavioral approaches (Atkinson, 1958; Bekesey, 1947; Gourevitch & Hack, 1966; Gourevitch, Hack, & Hawkins, 1960; Harrison, 1984; Harrison, Abelson, & Fisher, 1960; Hunter, 1914; Stebbins, Green, & Miller, 1966). Similarly, the application of reinforcement principles form the core of numerous clinical audiology procedures developed for assessing children, such as conditioned play audiometry (Olsen, 1994), tangible reinforcement operant conditioning audiology (Wilson & Richardson, 1991), and visual reinforcement operant conditioning audiology (Thompson, Thompson, & Vethivelu, 1989). However, unlike nonhuman animal studies, verbal instructions often remain an essential component of procedures used to prepare children for testing and maintaining responding during testing. A notable exception is a study by Woolcock and Alferink (1982) that employed reinforcement and errorless discrimination training procedures.

NONHUMAN ANIMAL MODEL

One characteristic common between nonhuman animal stimulus control experiments and human hearing screenings is a focus on the integrity of functional relations between environmental stimuli and behavior. An experiment by Harrison (1984) provides a model for developing clinical procedures devoted to improving hearing screen-

ing performances of brain injury survivors unable to consistently follow instructions. Harrison's experimental procedure is based on the go right, go left successive method developed by Hunter (1914) to study auditory stimulus control. Harrison used a test chamber that contained two levers mounted on one wall and speakers mounted to the left side and right side of the two levers. Monkeys were trained to press both levers under a 45-second variable interval reinforcement schedule that delivered liquid, on average, every 45 seconds following a bar press. Stimulus control training used a 45-decibel sound pressure level (SPL) (wide band noise bursts) stimulus presented randomly through the left or right speaker. The stimulus remained on until a bar press occurred. If the auditory stimulus was presented to the left speaker and a left bar press occurred, the response was reinforced. Similarly, if the auditory stimulus was presented to the right speaker and a right bar press occurred, the response was reinforced. All other bar presses terminated the stimulus and were not reinforced. Results showed that stimulus control over responding progressed from 50% accuracy (chance) on each bar to more than 90% accuracy. Thus, two three-term relations or contingencies were established:

S+1 (left 45-dB stimulus): R1 (left bar press): Reinforcement (liquid)

S+2 (right 45-dB stimulus): R2 (right bar press): Reinforcement (liquid).

Harrison's (1984) experiment illustrates a procedure for studying stimulus control relations with nonhuman animals, and it demonstrates how differential reinforcement may establish and maintain two three-term contingencies. Similarly, speech therapists are also concerned with stimulus control relations. Hearing screenings investigate how systematic changes in auditory stimuli along a dimension (e.g., hertz [Hz], decibels [dB]) exert functional changes over behavior along a dimension (e.g., rate, latency, probability) with the goal of determining auditory thresholds. Although Harrison's procedure employed differential reinforcement as the mechanism to establish functional relations, speech therapists often rely on instructions as the mechanism to establish and maintain functional relations. Inconsistent or absent responding during screenings may represent a failure in instructions as the mechanism for establishing functional relations.

The nonhuman animal stimulus control literature suggests that differential reinforcement may serve as an alternative mechanism under such circumstances.

STIMULUS CONTROL TRAINING

Harrison's (1984) experimental procedure may be adapted to facilitate the development of basic functional relations between auditory test stimuli and behavior when instructions fail. To improve patient attending to relevant test stimuli and reporting during hearing screenings, elements of Harrison's procedure may be useful for developing a stimulus control training procedure for use before screenings. These elements include using several auditory stimuli, correlating stimuli with reinforcement, and requiring several distinct responses.

Overall, training would focus on establishing several basic three-term contingencies. In particular, training would need to focus on establishing control by stimuli above and below threshold to prepare for screenings that involve responding to stimuli that lie above and below threshold. For example, a patient would learn to emit one response in the presence of an auditory stimulus and a separate response in the absence of an auditory stimulus. This would require employing two compound stimuli. One compound stimulus (S+1) would consist of a light stimulus paired with an audible test stimulus (an auditory tone that lies well above threshold). A target response (R1) would be reinforced in the presence of the compound stimulus (S+1). The second compound stimulus (S+2) would consist of a light stimulus paired with no stimulus tone, which may be viewed as a simple stimulus. A second, separate response (R2) would be reinforced in the presence of the compound stimulus (S+2). Modeling Harrison's procedure, the stimulus control training procedure would focus on establishing the following three-term contingencies:

S+1 (light + 70-dB, 4,000-Hz tone): R1 (tone present): Reinforcement

S+2 (light + no tone): R2 (tone absent): Reinforcement.

In one sense, the contingencies form two extremes or anchors of a psychometric function. That is, S+1 serves as a stimulus that lies well above threshold and S+2 serves as a stimulus that lies below threshold.

Such a procedure may serve as a first step toward conducting hearing screenings that involve presenting many stimuli that lie above and below threshold.

There are also noteworthy reasons for applying reinforcement and employing two responses during training and subsequent hearing screenings. The application of reinforcement has been shown to maintain high levels of attending to relevant environmental stimuli (Dinsmoor, 1995a) and is common to cognitive and behavioral treatments in rehabilitation (e.g., Parente & Herrmann, 1996). By requiring responding to both the presence and absence of auditory test stimuli, the negative influences of cognitive impairments on responding may be minimized. Specifically, if responding is required for stimuli below threshold and responding fails to occur, the trial provides no meaningful data. Without the required response following the presentation of auditory stimuli (i.e., stimuli that lie below threshold), it may be difficult for the clinician to ascertain whether stimuli were below threshold or poor attending compromised detection.

In the present study, two brain injury survivors exhibiting severe cognitive impairments and hearing loss learned to discriminate the presence and absence of an auditory stimulus through stimulus control training. Subsequent hearing screenings were conducted using a titration procedure common to animal psychophysical studies and clinical audiology. Screening involved presenting a variety of novel compound stimuli. Based on responding to stimuli, decibel levels increased or decreased on the following trial. The decibel level associated with relatively equal percentages of each response (i.e., 50% tone absent and 50% tone present) provided an estimate of the auditory threshold.

METHOD

PARTICIPANTS

Patient 1 (S1) was a 65-year-old White male who survived a cerebral vascular accident. Axial-computed tomography images of the brain showed edema of the right cerebral hemisphere with effacement

of the sulci and a mild mass effect compressing the lateral ventricles. The patient ranged from 5 to 6 on the Rancho Los Amigos cognitive scale. Because of severe impairments, the patient could not complete a brief neurocognitive behavioral examination. Evaluation by a speech and language pathologist noted decreased cognition, verbal apraxia, and expressive and receptive language deficits. During initial screening, S1 was reasonably attentive and cooperative but did not comprehend verbal or written instructions. Consequently, S1 could not participate in a hearing screening.

Patient 2 (S2) was a 49-year-old White male who survived a severe closed-head injury. Axial-computed tomography images of the brain suggest diffuse axonal shearing and injury to the right frontoparietal region. The patient ranged from 4 to 5 on the Rancho Los Amigos cognitive scale. Because of severe impairments, the patient could not complete a brief neurocognitive behavioral examination. Evaluation by a speech and language pathologist noted significant processing delays, poor following of instruction, disorientation, and severe attentional deficits. During initial screening, S2 was inattentive, unable to consistently follow verbal or written instructions, withheld responding, and often stated hearing a test tone during and between trials (false alarms [FAs]—see below).

APPARATUS

A MAICO MA27 audiometer, 14 × 17 × 7 inches, was used to present a warbling tone ($\pm 5\%$; 5 Hz rate) stimulus to participants through headphones. A common handheld flashlight provided a light stimulus.

PROCEDURE

Stimulus control training. All auditory test stimuli were presented through headphones. The clinician sat facing S1 with the flashlight, and the operator of the audiometric equipment remained seated behind S1. A coffee cup and a red and white poker chip were placed on a small table in front of S1. For S2, the tester sat facing S2 with the flashlight and with the audiometric equipment hidden from view.

Figure 1 outlines the discrete trial procedure employed. A trial began with the presentation of one of two compound stimuli. The stimuli consisted of a compound light, 70-decibel 4000-Hz-tone stimulus and a compound light, no-tone stimulus. Each compound stimulus was presented for 3 seconds, and stimuli were presented in a random order, with equal frequency. Initially, hand-over-hand assistance and modeling were required to establish target responses to stimuli. Responding for S1, shown in Figure 1, consisted of placing a red poker chip in a cup (S2 waved his arms above his head and nodded "yes") following the presentation of the compound light, 70-decibel, 4000-Hz-tone stimulus. Responding for S1 also consisted of placing a white poker chip in a cup (S2 shook his head "no") following the presentation of the compound light, no-tone stimulus. Correct responses were reinforced (S+). All incorrect responses were not reinforced (S-). Reinforcers consisted of verbal praise, cheers, smiles, and handshakes. Each auditory channel was trained individually.

Hearing screenings. A titration procedure was employed to obtain estimates of auditory thresholds. Within sessions, the decibel level of a probe tone (range 5 to 65 dB) decreased 5 decibels on the trial following a participant's response that indicated detection of the probe tone, and it increased 5 decibels on the trial following the participant's response that indicated nondetection of the probe tone. Figure 2 outlines the screening procedure. The outline for S1 (different from S2's by response type—see above) shows that probe stimuli (range 5 to 65 dB) paired with a light were presented for 3 seconds. All target responses were reinforced (S+). The same procedure was employed with S2 with the addition of catch trials presented randomly during testing ($p = .50$). Catch trials consisted of presenting the compound light, no-tone stimulus. All correct catch trial responses were reinforced.

Frequencies of 500, 1000, and 8000 Hz were manipulated between sessions. Sessions ended if responding appeared stable during the first 10 trials or, during sessions, responding stabilized for approximately 5 trials.

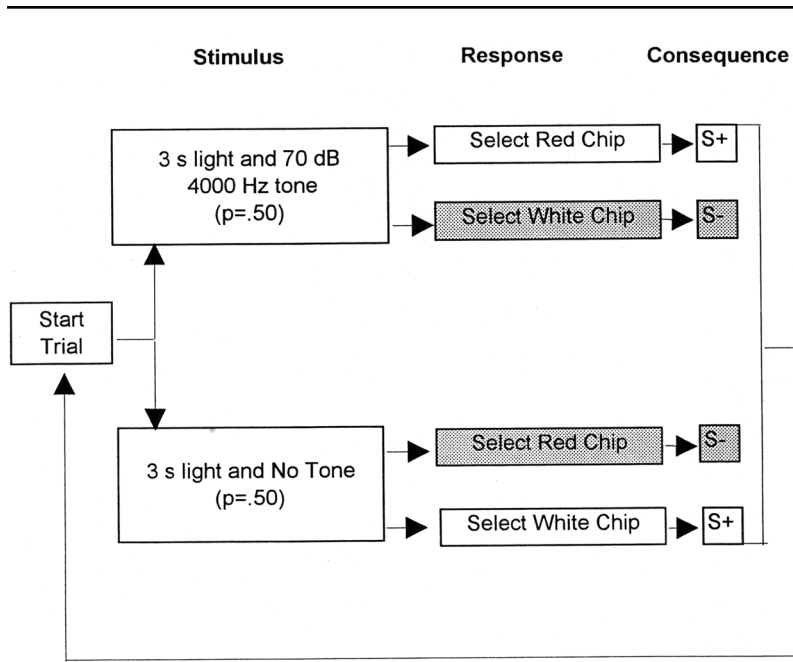


Figure 1. Temporal order of events for a stimulus control training trial.

NOTE: Following stimulus presentation, a correct response (shaded white) was reinforced (S+) and an incorrect response (shaded gray) was not reinforced (S-).

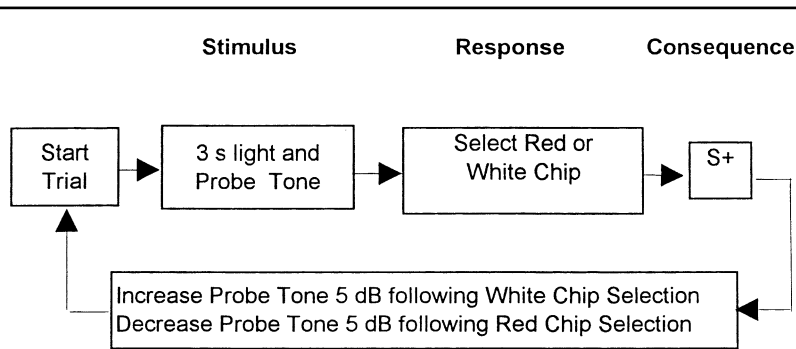


Figure 2. Temporal order of events for a screening trial with titration.

NOTE: Following stimulus presentation, all target responses were reinforced (S+) and the decibel level was titrated based on responding.

RESULTS

Stimulus control training. Figure 3 shows responding under titration for S2 at 4000 and 8000 Hz before stimulus control training. Left auditory channel responding at 4000 Hz shows stability near 50 dB, whereas right auditory channel responding steadily increased and then decreased to 20 dB. On catch trials 24 and 25, the compound light, no-tone stimulus was presented, and FAs occurred. Erratic responding was also observed at 8000 Hz. On catch trials 6 through 14, numerous FAs occurred.

During stimulus control training, participants were required to emit 15 consecutive correct responses for each auditory channel before receiving a hearing screening. Results showed that both S1 and S2 met the training criterion for each channel within 25 trials.

Hearing screenings. Stimulus control training for S1 successfully established consistent responding and enabled the speech therapist to conduct a hearing screening. During the screening, responding under titration produced stable functions and provided threshold estimates. Figure 4 shows the titrated dB level by trial for S1 at 500, 1000, 4000, and 8000 Hz and means taken from the last five titrated trials. In general, responding was maintained under titration, and estimates of auditory thresholds were obtained. Mean decibel levels suggest hearing losses in the left and right auditory channels at high frequencies (4000 and 8000 Hz).

Figure 5 shows responding under titration for S2 at 500, 1000, 4000, and 8000 Hz following stimulus control training and means taken from the last five titrated trials. No false alarms occurred on catch trials. In general, responding to auditory test stimuli under titration was more consistent after stimulus control training. Data show orderly declines in decibel levels to thresholds for both auditory channels and across all frequencies tested. Mean dB levels suggest hearing losses in the right auditory channel and losses at high frequencies (4000 and 8000 Hz) in the left auditory channel.

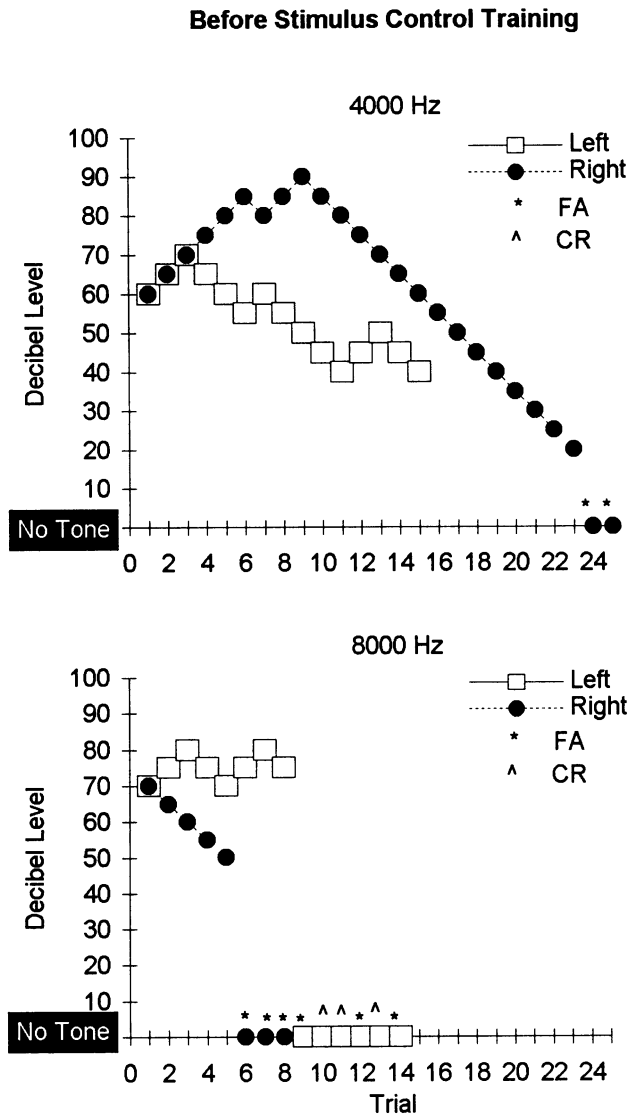


Figure 3. Results of responding under titrating decibel levels within sessions for Patient 2 prior to stimulus control training.
 NOTE: FA = false alarm. CR = correct rejection.

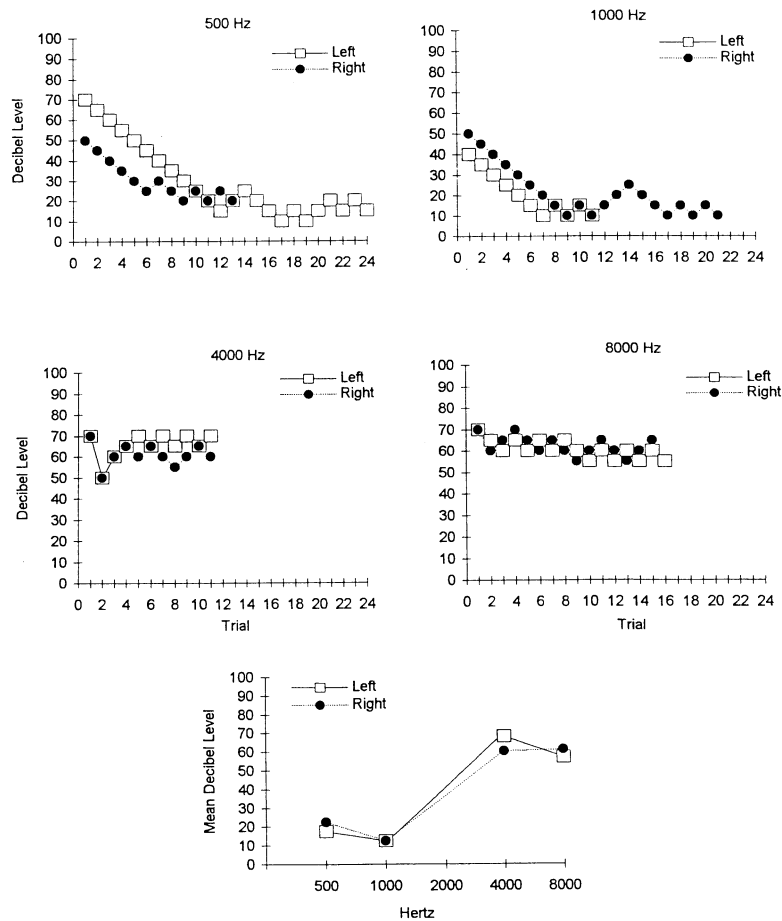


Figure 4. Results of responding under titrating decibel levels within sessions for Patient 1 after stimulus control training.

NOTE: Four test conditions (500, 1000, 4000, and 8000 Hz) and the mean decibel level from each test condition (bottom graph) are presented.

DISCUSSION

A stimulus control training procedure, based on methods used to study stimulus control with nonhuman animals, was employed to improve two brain injury survivors' attending and reporting during

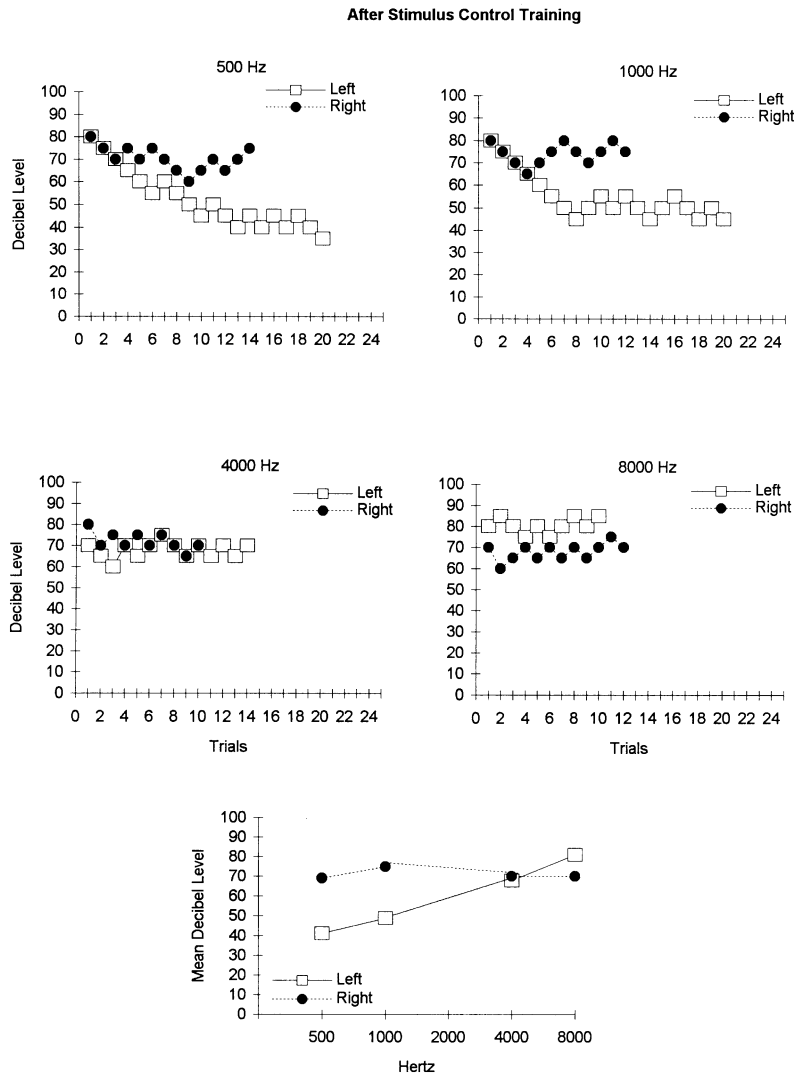


Figure 5. Results of responding under titrating decibel levels within sessions for Patient 2 after stimulus control training.

NOTE: Four test conditions (500, 1000, 4000, and 8000 Hz) and the mean decibel level from each test condition (bottom graph) are presented.

hearing screenings. The stimulus control training procedure involved differential reinforcement of responding in the presence and absence of an auditory stimulus. Following the establishment of two basic three-term contingencies, screenings were conducted that involved titrating dB level within sessions to obtain estimates of auditory thresholds. Means taken from stable titration functions suggested the presence of hearing losses for both patients. In general, the intervention was successful in preparing patients, who displayed significant cognitive impairments that prevented assessment, for a common hearing screening procedure by a speech therapist.

Modeling the stimulus control training procedure after methods common to nonhuman animal research (Harrison, 1984) facilitated auditory stimulus control over patient responding. In the present study, compound stimuli that may be viewed as anchors or endpoints of a psychometric function were employed to prepare patients for hearing screenings that involved responding to stimuli above and below threshold. In essence, patients learned to functionally communicate the perceived presence and perceived absence of auditory test stimuli to the clinician. The rapid response acquisition during training and response maintenance during screenings appears clinically significant given the severity of the patients' deficits. Some clinicians might question the validity of the auditory thresholds obtained. Such questions, however, are related to the application of the titration procedure. The purpose of the study was to demonstrate that training could improve patient attending and reporting such that hearing screenings could be conducted rather than to demonstrate the validity of thresholds obtained using a titration procedure.

The application of a two-response procedure, which is a modification of the go right, go left successive method, also appears critical to both training and screening. During stimulus control training, it was possible to establish two distinct three-term contingencies and assess the integrity of stimulus control over responding before conducting the more complex hearing screenings. During screenings, it was possible to observe alternating patterns of subjective detection and subjective nondetection in each titrated function near threshold. Overall, employing two responses increased our confidence of the integrity of functional relations as well as the auditory threshold estimates obtained.

The data also provided the rehabilitation team with preliminary information about patients' potential hearing deficits until formal audiological testing results were obtained.

Future research on the application of stimulus control methods with brain injury survivors might focus on identifying variables that affect application, such as type of injury, length of coma, or type of cognitive impairments. At a broad level, research must also examine the effects of reinforcement on cognitive and behavioral impairments (e.g., Schlund, 1999). In this regard, laboratory research may illuminate the extent to which survivors are able to report, anticipate, and respond appropriately to consequences. Given the growing recognition of the effectiveness of behavioral principles and methods in rehabilitation, basic and clinical research is needed that outlines how behavior-environment relations may be differentially affected by brain injury.

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