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Early Indicators of Hearing Conservation Program Performance

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Abstract

Retrospective analysis of initial audiograms from 21 hearing conservation programs (HCPs) revealed several statistical protocols capable of identifying HCPs of known performance. American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA) protocols clearly identified 3 HCPs known to have demonstrated excellent overall programs. ANSI and OSHA outcomes appeared equivalent in ability to provide early warnings of potentially unacceptable HCP practices.

Key Words: American National Standards Institute (ANSI), audiometric variability, baseline audiogram, hearing conservation program (HCP), Occupational Safety and Health Administration (OSHA), standard deviation of difference threshold, standard threshold shifts (STS)

Early indicators of industrial hearing conservation program (HCP) performance are necessary to prevent or minimize occupational hearing loss. Early warnings are necessary if HCP managers are to take corrective steps to improve audiometric testing programs or strengthen ineffective hearing protection, training, or noise control programs. Early positive feedback may also be used to reinforce effective HCP practices.

Over the past decade, attention has been focused upon audiometric data to provide assessments of HCP effectiveness. Several analysis approaches that may provide timely evidence of program performance have been identified.

Potential Early Indicators

Variability Indices

The American National Standards Institute (ANSI) has recently released a draft standard providing statistical protocols for judging the effectiveness of hearing conservation programs (ANSI, 1991). ANSI protocols measure year-to-year audiometric variability, suggesting that excessive audiometric variability may identify either inadequate audiometric testing procedures or inadequate hearing protection programs. If poor quality audiometric testing can be ruled out as a contributor to excessive audiometric variability, then audiometric data are thought to be contaminated by temporary threshold shift (TTS), thus questioning the effectiveness of hearing protection programs. ANSI recommends three protocols for assessing HCP effectiveness:

1. **Percent worse sequential (%Ws):** The percent of audiograms demonstrating a 15-dB change for the worse at any test frequency (500–6000 Hz) in either ear.
2. **Percent better or worse sequential (%BWs):** The percent of audiograms with 15-dB changes for the better or worse at any test frequency (500–6000 Hz) in either ear.
3. **Standard deviation of threshold shifts:** Computed from binaurally averaged audiometric frequencies at 0.5, 1, 2, 3, 4, and 6 kHz and grouped frequency combinations of 0.5–3 kHz, 2–4 kHz, and 3–6 kHz.

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Criterion ranges of acceptable, marginal, and unacceptable levels of audiometric variability are published in the draft standard for trial use, comment, and criticism (ANSI, 1991).

Shift Indices

Learning effects have been associated with "improving" audiometric thresholds for low noise-exposed and well-protected populations with little previous audiometric experience (Royster and Royster, 1986a). Improvements in mean hearing levels of 1 dB per year over the first 4 years of testing have been observed in HCPs exhibiting good hearing protection programs. These "improvements" are thought to reflect increased audiometric sophistication of test subjects (Royster and Royster, 1982).

OSHA Standard Threshold Shift

Federal noise regulations promulgated by the Occupational Safety and Health Administration (OSHA, 1983) specify that baseline and annual audiograms be obtained from employees who are occupationally exposed to noise at or above 85 dB(A) for a time-weighted average of 8 hours. Each annual audiogram is compared to baseline (i.e., initial audiogram) to monitor potential changes in hearing level due to noise exposure. An average audiometric change in either ear of 10 dB or greater at 2, 3, and 4 kHz is defined as a standard threshold shift (STS). If comparison of an annual to baseline audiogram reveals STS, employees must be notified in writing and counselled in proper use of hearing protection devices (HPDs). Use of HPDs is mandatory for employees subsequent to STS. Also, if employees were using HPDs prior to the STS event, then HPDs affording greater attenuation must be provided, if necessary. Employers may retest within 30 days to confirm STS, and corrections for presbycusis may be utilized in calculating STS.

Regulatory pressures cause many HCPs to track OSHA STS rates for compliance purposes. Consequently, use of OSHA STS rates for assessing HCP performance is fairly widespread. Yet proponents of ANSI S12.13 (1991) protocols state that OSHA STS is not as sensitive to HCP performance as measures of audiometric variability. They contend that reliance upon OSHA STS may allow preventable hearing loss to develop before high STS rates signal the need for corrective action (Royster and Royster, 1991).

The purpose of this investigation was to examine the first two chronologic audiograms from a group of HCPs to determine what statistical indices might serve as early indicators of HCP performance. A secondary purpose of this investigation was to specifically examine the efficacy of OSHA STS for early detection of unacceptable HCP performance. The project was undertaken with the assumption that a minimum of two serial audiograms is necessary to estimate HCP effectiveness.

METHOD

Audiometric Data

Audiometric data were originally compiled by Royster and Royster (1986b) and served as the basis for variability indices appearing in Draft ANSI Standard "Evaluating the Effectiveness of Hearing Conservation Programs" (ANSI, 1991). Data consist of serial audiograms from 22 HCPs representing 15,297 employees with a minimum of four audiograms and 3,958 employees with a minimum of eight audiograms. Data are anonymous as to employer and employee name and include such demographic information as employee sex, age, race, and noise exposure classification. The entire database contains over 140,000 audiograms and is reported to be the largest public domain database of its kind (ANSI, 1991). The database is available in magnetic format from the National Technical Information Service, Springfield, Virginia.

Of the 22 HCPs, 4 programs familiar to ANSI investigators were judged to be either low noise-exposed or to demonstrate excellent HCP practices. These 4 HCPs were classified as "controls" by ANSI investigators. Because less was known about the practices of the remaining 18 HCPs, they were simply classified by ANSI investigators as "noncontrol" groups. In control HCPs, measures of audiometric variability were similar between low noise-exposed and well-protected populations. Additionally, control HCPs were found to exhibit markedly less year-to-year audiometric variability than noncontrol HCPs (ANSI, 1991). ANSI classifications of "control" and "noncontrol" were maintained during this investigation to characterize overall HCP performance.

Selection of Audiometric Records

A total of 27,047 employees demonstrated a minimum of two audiograms. Of this total, 3,245 represented control HCPs and 23,802 represented noncontrol HCPs. Selection of audiometric records was limited to only those employees whose second chronologic audiogram fell within a time window of 6 to 18 months subsequent to their original (first) audiogram. This selection process reduced the total database to 13,283 employees from 21 HCPs: 1,761 from 3 controls HCPs and 11,522 from 18 noncontrols HCPs. One control HCP (number 6) was excluded because no second audiograms fell within 6 to 18 months subsequent to first audiograms. Mean elapsed time between tests 1 and 2 for control and noncontrol HCPs was 1.03 and 1.02 years, respectively. This difference was not statistically significant ($p > .05$).

No other selection criteria were employed. HCPs were not examined for demographic or noise exposure differences.

Data Analysis

Twenty statistical outcomes were calculated to compare tests 1 and 2 for control versus noncontrol HCPs.

Variability Indices

Standard deviations of test 1 to test 2 threshold shifts were computed for binaurally averaged audiometric frequencies of 0.5, 1, 2, 3, 4, and 6 kHz and also for binaurally averaged frequency combinations of 0.5, 1, 2, and 3 kHz; 2, 3, and 4 kHz; and 3, 4, and 6 kHz. Also, %Ws criteria were applied to each HCP by determining percentages of cases where a retest audiogram demonstrated a 15-dB or greater shift for the worse at any frequency (0.5, 1, 2, 3, 4, or 6 kHz) in either ear (ANSI, 1991).

Mean Binaural Shift Indices

Mean binaural audiometric shifts were also calculated between tests 1 and 2 for the same nine single and multiple audiometric frequency combinations as standard deviation of difference protocols (above) to identify possible learning effects. Shifts were calculated by subtracting audiogram 2 threshold values from audiogram 1 values; therefore, negative shifts indicated worsening hearing levels, while positive shifts indicated hearing level "improvements" from test 1 to test 2.

OSHA STS

Mean shifts of 10 dB or greater in either ear at 2, 3, and 4 kHz were classified as STS. Only hearing level declines were considered, and age correction factors were not employed in calculation of these shifts (OSHA, 1983). Rates of STS (percent) were calculated for each HCP by dividing the number of STS occurrences by the total number of test 1 to test 2 comparisons.

Mean outcomes were determined for control ($n = 3$) and noncontrol ($n = 18$) HCPs for each statistical index. Because HCP assessment protocols differed in criterion shift frequencies and shift magnitudes, outcomes were normalized to Z-scores for comparison purposes. Medians, quartile ranges, and 95 percent confidence intervals for normalized outcome values were compared to identify potentially useful HCP assessment protocols.

RESULTS

Statistical outcomes for mean binaural shifts from baseline for 21 HCPs are summarized in Table 1. Each row in Table 1 represents a single HCP, with HCP identifiers corresponding to original Royster and Royster (1986b) classifications. Column 2 indicates HCP classification group as control (C) or noncontrol (N). Column 3 indicates sample size for each HCP. The remaining columns summarize outcomes for single- and multiple-frequency shifts. Mean and standard deviation outcomes for control, noncontrol, and all HCPs are summarized below each column. ANSI and OSHA outcomes are similarly summarized in Table 2.

No clear pattern of results emerged for mean binaural shift calculations (Table 1). An approximately equal number of control and noncontrol HCPs demonstrated mean hearing level "improvements" (positive shifts) and declines (negative shifts).

Mean outcomes for ANSI and OSHA protocols, however, clearly differentiated control from noncontrol HCPs (Table 2). Control HCPs demonstrated markedly less audiometric variability than noncontrol HCPs for each ANSI standard deviation protocol. Mean ANSI %Ws outcomes were 14.0 percent and 33.8 percent for control versus noncontrol HCPs, respectively. Mean OSHA STS rates were 3.7 percent and 12.1 percent for control versus noncontrol HCPs.

Figure 1 provides notched box-and-whisker plots summarizing normalized outcomes of mean binaural shifts for control versus noncontrol HCPs. Abscissa values in Figure 1 denote binaural shift frequency criteria, and ordinate values depict normalized (i.e., Z-score) outcomes.

Each notched box-and-whisker plot ordinally summarizes Z-score distributions for con-

Table 1 Summary of Mean Binaural Shifts from Baseline to First Annual Audiogram for 21 HCPs

			Mean Binaural Shift Outcome (kHz)								
HCP	*Group**	*n*	*0.5*	*1*	*2*	*3*	*4*	*6*	*0.5123*	*234*	*346*
1	C	100	2.2	0.8	1.7	–0.3	1.1	–2.1	1.1	0.8	–0.4
2	C	1305	–0.3	–0.8	–1.2	–0.6	–0.8	–1.1	–0.7	–0.8	–0.8
5	C	356	0.5	0.3	0.1	0.1	–0.2	0.5	0.3	0.0	0.1
3	N	91	0.7	–0.3	–0.8	–1.1	–1.5	–1.4	–0.4	–1.1	–1.3
4	N	1304	0.7	0.6	1.0	1.5	0.5	1.3	0.9	1.0	1.1
7	N	2315	2.8	1.8	1.5	2.6	1.3	2.6	2.2	1.8	2.2
8	N	635	–0.2	–0.8	–0.3	–2.4	–2.1	–3.0	–0.9	–1.6	–2.5
9	N	143	–4.7	–7.7	–5.7	–4.6	–2.8	–3.6	–5.7	–4.4	–3.7
10	N	1010	1.0	1.3	0.8	0.9	0.2	0.3	1.0	0.6	0.5
11	N	325	1.9	1.7	0.4	–0.5	–0.5	–0.1	0.9	–0.2	–0.3
12	N	323	0.8	0.6	0.2	1.3	–0.7	–0.3	0.7	0.2	0.1
13	N	155	–0.2	1.2	1.4	3.5	1.1	1.3	1.5	2.0	2.0
14	N	221	2.4	1.6	1.4	2.7	0.1	3.5	2.0	1.4	2.1
15	N	216	0.3	0.4	–0.2	6.4	–0.5	1.5	1.7	1.9	2.5
16	N	611	0.1	0.3	0.0	4.1	0.1	–0.3	1.1	1.4	1.3
17A	N	533	0.2	0.6	0.1	0.1	0.0	–0.3	0.2	0.0	–0.1
17D	N	145	–0.5	0.6	0.9	1.5	1.0	1.3	0.6	1.1	1.2
17E	N	96	0.9	–1.0	–0.9	–1.3	–1.1	–3.9	–0.6	–1.1	–2.1
17F	N	2081	0.6	0.5	0.3	–0.6	–0.1	–0.6	0.2	–0.1	–0.4
17I	N	1122	1.1	0.5	0.6	–0.7	–0.6	–0.3	0.4	–0.3	–0.5
18	N	196	0.9	0.3	–0.3	–0.7	–1.1	2.2	0.1	–0.7	0.1
Controls		M	0.8	0.1	0.2	–0.3	0.0	–0.9	0.2	0.0	–0.4
		SD	1.0	0.7	1.2	0.3	0.8	1.1	0.7	0.7	0.4
Noncontrols		M	0.5	0.1	0.0	0.7	–0.4	0.0	0.3	0.1	0.1
		SD	1.5	2.0	1.6	2.5	1.1	2.0	1.7	1.5	1.7
All		M	0.5	0.1	0.0	0.6	–0.3	–0.1	0.3	0.1	0.1
		SD	1.5	1.9	1.5	2.4	1.0	1.9	1.6	1.4	1.6

*C = control; N = noncontrol.

trol (n = 3) and noncontrol (n = 18) HCPs, where widths of each box are proportional to square roots of each sample size. Middle horizontal lines in each box-and-whisker plot depict median Z-scores, while top and bottom horizontal lines indicate upper and lower quartile Z-scores, respectively. Notches extend from medians in each plot to approximate 95 percent confidence intervals surrounding each median Z-score. Vertical "whiskers" extend from some box-and-whisker plots to indicate broad Z-score distributions, and extreme outlier Z-score values are depicted by individual data points. In Figure 1, these notches, whiskers, and outlier data points are more clearly visible for noncontrol HCPs.

Overlapping box plots for control and noncontrol HCPs in Figure 1 clearly indicate failure of binaural mean shift protocols to distinguish HCP performance. Overlapping quartile ranges and confidence intervals at each frequency criterion confirm that positive and negative threshold shifts from baseline were as likely to occur in either control or noncontrol HCPs.

Figures 2 and 3 indicate a clear distinction between control and noncontrol HCPs by stan-

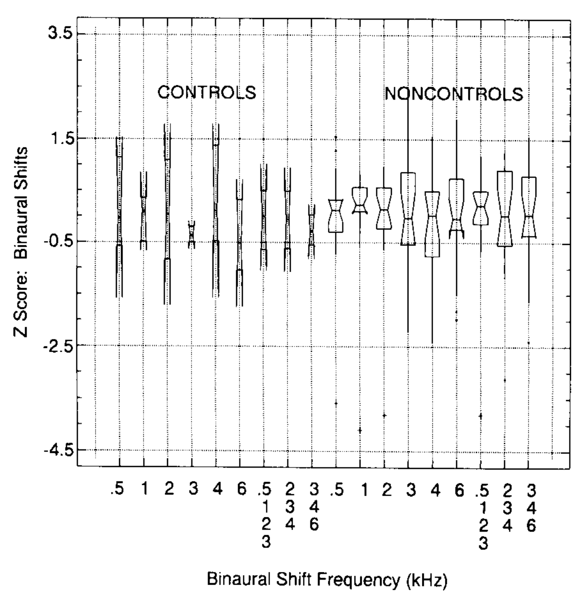

Figure 1 Notched box-and-whisker plots of normalized binaural shift outcomes for control and noncontrol HCPs.

Table 2 Summary of ANSI S12.13 and OSHA STS Outcomes for 21 HCPs

			ANSI S12.13 HCP Assessment Protocols										*OSHA*
			Standard Deviations of Binaural Shifts (kHz)									*%Ws*	*STS (%)*
HCP	*Group*	*n*	*0.5*	*1*	*2*	*3*	*4*	*6*	*0.5123*	*234*	*346*	*ANY*	*234*
1	C	100	3.8	3.9	3.8	2.0	5.8	8.1	2.5	2.8	4.4	14.0	3.0
2	C	1305	5.3	5.0	4.8	5.9	6.2	7.6	4.0	4.8	5.2	19.8	5.7
5	C	356	4.5	3.4	3.5	3.5	4.4	5.6	2.7	3.1	3.4	8.1	2.5
3	N	91	5.8	5.1	5.7	6.8	7.0	9.4	4.7	5.5	6.3	35.2	15.4
4	N	1304	7.5	6.2	6.1	7.0	7.7	8.2	5.6	6.0	6.2	28.6	9.1
7	N	2315	8.9	7.1	7.0	13.8	8.3	14.4	6.8	7.4	10.0	23.2	6.5
8	N	635	11.8	12.1	12.6	11.7	13.8	15.8	9.5	10.7	11.8	51.0	19.1
9	N	143	6.5	8.8	8.2	7.2	7.1	8.7	6.4	6.4	5.8	72.0	28.0
10	N	1010	6.5	5.4	5.4	5.9	6.5	8.6	4.6	5.0	5.5	29.4	7.7
11	N	325	6.7	5.7	5.4	6.5	8.0	9.9	4.7	5.2	6.0	28.6	10.8
12	N	323	7.5	5.7	5.7	8.8	7.9	9.5	5.5	6.3	7.0	27.6	9.6
13	N	155	8.4	7.3	7.4	9.8	6.6	9.4	6.6	6.4	6.4	21.9	7.7
14	N	221	6.5	5.4	7.0	8.1	7.2	9.6	5.5	6.4	6.7	21.3	5.4
15	N	216	6.9	6.3	5.3	10.5	7.2	10.3	5.2	5.7	7.0	24.1	5.6
16	N	611	6.3	5.9	6.5	11.1	8.4	10.4	6.0	7.1	8.0	25.7	9.7
17A	N	533	9.7	10.0	11.0	11.9	11.8	13.1	9.5	10.8	11.1	43.5	19.5
17D	N	145	9.0	6.9	7.0	6.8	7.7	10.3	6.1	6.1	7.0	35.9	9.7
17E	N	96	6.7	5.4	4.9	5.9	7.0	8.0	4.5	5.3	5.8	41.7	10.4
17F	N	2081	8.9	7.8	8.4	10.0	10.4	11.9	7.5	8.7	9.5	42.7	18.7
17I	N	1122	8.9	8.4	9.3	10.4	11.1	12.6	8.0	9.3	10.2	42.7	20.2
18	N	196	4.0	3.4	4.0	4.2	3.9	6.8	2.9	3.1	3.5	13.8	4.6
Controls		M	4.5	4.1	4.0	3.8	5.5	7.1	3.1	3.6	4.3	14.0	3.7
		SD	0.6	0.7	0.6	1.6	0.8	1.1	0.7	0.9	0.7	4.7	1.4
Noncontrols		M	7.6	6.8	7.1	8.7	8.2	10.4	6.1	6.7	7.4	33.8	12.1
		SD	1.7	2.0	2.1	2.5	2.2	2.3	1.7	1.9	2.1	13.3	6.3
All		M	7.1	6.4	6.6	8.0	7.8	9.9	5.7	6.3	7.0	31.0	10.9
		SD	1.9	2.1	2.3	2.9	2.3	2.4	1.9	2.1	2.3	14.2	6.6

*C = control; N = noncontrol.

dard deviation of difference, %Ws, and STS protocols. Each standard deviation of difference protocol (Figure 2) clearly reveals markedly less year-to-year audiometric variability for control versus noncontrol HCPs. Results for binaurally averaged audiometric frequencies of 0.5–3 kHz appear to provide the clearest distinction, while 6-kHz results appear to provide the poorest separation of HCP groups. Figure 3 reveals excellent and essentially identical performance for ANSI %Ws and OSHA STS protocols.

DISCUSSION

These results confirm reports in ANSI S12.13 (1991) that year-to-year audiometric variability distinguishes control versus noncontrol HCPs for the 21 programs examined. Furthermore, ANSI outcomes clearly distinguished HCP performance from the first two chronologic audiograms, indicating utility for HCP managers as "early warnings" of unacceptable HCP performance.

However, contrary to reports in ANSI S12.13 (1991), this study also demonstrates OSHA STS rates to clearly distinguish between control and noncontrol HCPs from the first two serial hearing tests. These results do not confirm ANSI S12.13 reports that variability outcomes provide more timely evidence of HCP performance than "...simply tallying OSHA STSs..." (ANSI, 1991, p. 15).

Larger HCP performance ranges for ANSI %Ws outcomes over OSHA STS outcomes in this investigation are attributed to differences in shift criteria. More annual audiograms will be flagged for single frequency shifts of 15 dB at any frequency in either ear (ANSI %Ws) than for OSHA STS shifts of 10 dB averaged over 2, 3, and 4 kHz in either ear (Dobie, 1983; Gasaway, 1985; Lane et al, 1985; Simpson et al, 1992). Relative differences in control versus noncontrol HCP performance as indicated by ANSI %Ws and OSHA STS outcomes were identical. This is indicated by raw outcomes from Table 2 and more clearly by normalized outcomes in Figure 3.

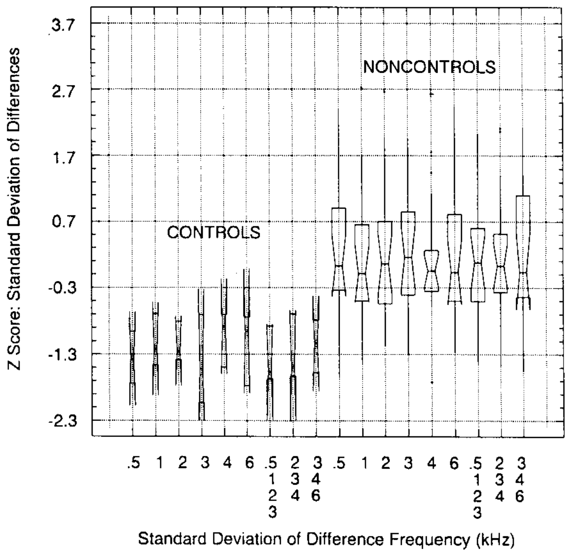

Figure 2 Notched box-and-whisker plots of normalized standard deviation of difference threshold outcomes for control and noncontrol HCPs.

No clear advantages emerged in favor of ANSI %Ws, OSHA STS, or ANSI standard deviation of difference protocols as a single "best" early indicator of HCP performance. ANSI %Ws and OSHA STS differ from standard deviation of difference protocols, as neither %Ws nor STS directly accounts for audiometric reliability. It seems reasonable to speculate that both %Ws and STS outcomes directly reflect hearing protector program integrity and indirectly reflect audiometric testing program integrity. TTS will directly inflate both outcomes, while unacceptable testing procedures such as poor instructions or ambient noise at baseline may cause threshold "improvements" at second audiograms. ANSI standard deviation protocols may be more sensitive to "improvements" and therefore merit continued investigation. ANSI S12.13 (1991) offers an additional %BWs protocol more analogous to standard deviation methods. This protocol determines the percent of retest audiograms demonstrating either positive or negative 15-dB shifts in either ear. This protocol was not examined in this investigation because it is not recommended over the first 4 HCP years, when learning effects may artificially inflate %BWs outcomes in acceptable HCPs (ANSI, 1991).

Mean hearing shifts per se did not distinguish control from noncontrol HCP performance; however, calculation of mean hearing threshold levels over time for a constant employee population is recommended by ANSI S12.13 to rule out systematic hearing shifts attributable to fluctuations in audiometer calibration (ANSI, 1991). This is an important consideration for HCP managers, as even calibration fluctuations within tolerances specified by ANSI S3.6 (ANSI, 1989) may be enough to impose artifact on statistical protocols intended for industrial audiometric data. Tracking mean HTLs over time should therefore be encouraged.

Results from this investigation apply only to audiograms 1 and 2 and should not be applied in "mature" programs to assess audiograms 3 or greater. ANSI S12.13 (1991) provides more rigorous criteria to analyze audiograms 5 or greater to allow for increased test-taking sophistication in employee populations. Readers should consult Royster and Royster (1986c) for comparative data on annual rates of OSHA STS covering 8 years of HCP performance. Results of this investigation, however, do apply to newly hired populations or groups of existing employees newly included in the HCP.

Future attempts to identify valid indicators of HCP effectiveness should consider both variability outcomes and shift criteria such as ANSI %Ws and OSHA STS. It may be difficult to directly compare the relative effectiveness of two HCPs unless they demonstrate comparable levels of audiometric reliability. Investigators should examine the homogeneity of variance between samples before application of certain statistical tests; likewise, comparable levels of audiometric reliability are likely necessary between two HCPs before shift criteria can be used to determine relative effectiveness levels.

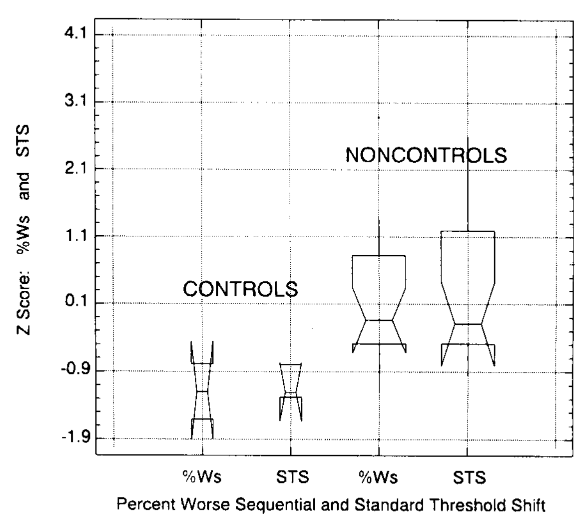

Figure 3 Notched box-and-whisker plots of normalized %Ws and STS outcomes for control and noncontrol HCPs.

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