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Guttman Scale Analysis of Longitudinal Data: A Methodology and Drug Use Applications

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Abstract

Traditional Guttman scalogram analysis is limited to evaluating item order cross-sectionally. This paper describes a new methodology, Longitudinal Scalogram Analysis (LSA), that is a direct extension of cross-sectional scalogram analysis to longitudinal data. Example applications of the LSA method to drug use data are provided. The benefits of LSA relative to cross-sectional methods for drug use analysis are discussed. [Translations are provided in the International Abstracts section of this issue.]

Key Words. Drug use patterns; Guttman scale; Longitudinal scalogram analysis

Drug use involvement can be characterized in terms of initial experience and subsequent use. The initiation sequence for different drugs is fairly invariant: alcohol and/or cigarettes tend to be tried first, followed by cannabis, and then "harder" drugs (e.g., Adler and Kandel, 1981; Fisher, MacKinnon, Anglin, and Thompson,

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1987; Huba, 1983; Huba, Wingard, and Bentler, 1981; Single, Kandel, and Faust, 1974; Welte and Barnes, 1985). Patterns of subsequent drug use may differ from initiation patterns (Hays, Stacy, Widaman, DiMatteo, and Downey, 1986; Hays, Widaman, DiMatteo, and Stacy, 1987), although commonalities between initial and current use have been observed (Hays, 1984; Mills and Noyes, 1984; Windle, Barnes, and Welte, 1989).

Most studies of drug use have relied on cross-sectional data using Guttman (1944) scalogram analysis or structural equation simplex modeling (e.g., Huba et al., 1981) to draw inferences about sequences of involvement. Charting transitions into different stages of drug use has rarely been performed on longitudinal data (for an exception see Kandel, 1975; Kandel and Faust, 1975) and appropriate methods for evaluating these data have only recently become available (Collins, Cliff, and Dent, 1988). This paper summarizes the cross-sectional Guttman scalogram method that has been relied upon thus far and describes a longitudinal analysis method that is a direct extension of the cross-sectional procedure.

Cross-Sectional Guttman Scalogram Analysis

The Guttman scale model is straightforward and easy to interpret. If observed data fit a Guttman scale, then all persons with the same scale score (i.e., sum of endorsed items in the scale) have identical responses to each item in the scale. Table 1 presents the item response patterns expected for three levels of self-destructiveness hypothesized to form a Guttman scale: *low self-esteem, substance abuse,* and *suicide ideation* (Firestone and Seiden, 1987). Eight response patterns are possible, but only the four shown in Table 1 are consistent with a Guttman scale. In general, the number of possible response patterns is two raised to a power equal to the number of items, but the number of response patterns consistent with a Guttman scale equals the number of items plus one (Dotson and Summers, 1970; Schwartz, 1986).

Knowing that a respondent has experienced suicide ideation allows for the inference that the person is a substance abuser and has low self-esteem. Similarly, knowing that an individual is a substance abuser leads to the prediction that the person has low self-esteem. In contrast, knowing that a person has low self-esteem does not allow one to predict whether or not they are a substance abuser or whether they have experienced suicide ideation.

The degree to which data are consistent with a Guttman scale is determined by comparing observed patterns of data with the patterns predicted for a Guttman scale, and counting deviations from expected response patterns. The *coefficient of reproducibility* (CR) for Guttman scales is defined as the proportion of error (i.e., proportion of differences between observed and expected responses) subtracted from unity. A CR value of 0.90 or higher is considered acceptable. In addition, an index of reproducibility is typically computed by determining how well item

Table 1

Example of Pattern of Responding to Three Self-Destructiveness Items Fitting Perfectly a Cross-Sectional Guttman Scale

Low self-esteem	Substance abuse?	Suicide ideation?	Total score
No	No	No	0
Yes	No	No	1
Yes	Yes	No	2
Yes	Yes	Yes	3

Note. Pattern 1 represents an individual who has high self-esteem, has not abused substances, and has not experienced suicide ideation; pattern 2 depicts an individual who has low self-esteem only; pattern 3 reflects a person who has low self-esteem and has abused substances; pattern 4 represents someone who has low self-esteem, abused substances, and experienced suicide ideation.

modes reproduce the observed response patterns. (Differences between each observed item response and the modal response for that item across all respondents are summed to calculate errors.) This index, the *minimum marginal reproductibility* (MR), is used to calculate the *coefficient of scalability* (CS), defined as (CR – MR)/(1 – MR). A CS of 0.60 has been recommended as a minimum standard for acceptability (Menzel, 1953).

Although an inference about the order of drug use is often reasonable when high CR and CS values are obtained, circumstances in which such an inference is unwarranted have been noted (Schmeidler, 1985). Suppose, for example, that some individuals use marijuana but they have never tried any other drug. Further, suppose that alcohol use quickly leads to trying marijuana. In these circumstances, a substantial proportion of individuals will have initiated marijuana without trying alcohol and only a few persons will have tried alcohol *and not* marijuana. Cross-sectional Guttman scalogram analysis of these data might lead one to conclude erroneously that initiation to marijuana precedes experimentation with alcohol.

Longitudinal Scalogram Analysis

Traditional Guttman scalogram analysis is limited to evaluating item order cross-sectionally. We propose an extension of traditional scalogram analysis that incorporates the element of time, Longitudinal Scalogram Analysis (LSA). See Note 1. Table 2 presents patterns of responding for three items measured at three time points. As illustrated in Table 2, only one pattern of responses is longitudinally consistent with a total score of 0, 1, 8, or 9 "yes" answers. However, there are two different response patterns consistent with 2 or 7 affirmative answers and three

Table 2

Example of Pattern of Responding to Three Self-Destructiveness Items Fitting Perfectly a Three-Wave Longitudinal Guttman Scale

A1	B1	C1	A2	B2	C2	A3	B3	C3	Total score
No	No	No	No	No	No	No	No	No	0
No	No	No	No	No	No	Yes	No	No	1
No	No	No	Yes	No	No	Yes	No	No	2
No	No	No	No	No	No	Yes	Yes	No	2
No	No	No	Yes	No	No	Yes	Yes	No	3
No	No	No	No	No	No	Yes	Yes	Yes	3
Yes	No	No	Yes	No	No	Yes	No	No	3
No	No	No	Yes	Yes	No	Yes	Yes	No	4
No	No	No	Yes	No	No	Yes	Yes	Yes	4
Yes	No	No	Yes	No	No	Yes	Yes	No	4
No	No	No	Yes	Yes	No	Yes	Yes	Yes	5
Yes	No	No	Yes	Yes	No	Yes	Yes	No	5
Yes	No	No	Yes	No	No	Yes	Yes	Yes	5
No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	6
Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	6
Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	6
Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	7
Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	7
Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

Note. Key for letters on column headings is as follows: A = Low self-esteem, B = Substance abuse, C = Suicide ideation. Numbers represent wave (time point) of data collection.

different response patterns consistent with a total of 3, 4, 5, or 6 affirmative answers. For example, a total score of 2 may be obtained by reporting low self-esteem at time 2 and time 3 *or* by reporting low self-esteem and substance abuse at time 3. Because the same total score may be associated with multiple Guttman response patterns, the calculation of reproducibility and scalability is not as straightforward for longitudinal as it is for cross-sectional data.

With longitudinal data, the expected pattern against which observed scores are compared cannot be determined solely on the basis of the total score across items.

Table 3

Comparing Example Pattern to Patterns Consistent with a Longitudinal Guttman Scale: Three Items, Three Waves, and a Total Score of 5

Item scores at 3 time points				
Time 1: items 1 2 3	Time 2: items 1 2 3	Time 3: items 1 2 3	Difference between patterns	Pattern
0 0 1	1 1 1	1 0 0	—	Example pattern
0 0 0	1 1 0	1 1 1	4	Longitudinally consistent pattern 1
1 0 0	1 1 0	1 1 0	4	Longitudinally consistent pattern 2
1 0 0	1 0 0	1 1 1	6	Longitudinally consistent pattern 3

Note. 0 = not passed, 1 = passed. Item 1 = Low self-esteem, Item 2 = Substance abuse, Item 3 = Suicide ideation.

However, identification of all longitudinal patterns that are consistent with the Guttman model and yield the total score observed for an individual can be used to select the pattern (i.e., "expected pattern") that is *minimally different* from observed score pattern. Table 3 provides an example of selecting the expected pattern for an individual with a total score of 5 and observed score pattern of 001 111 100 for the self-destructiveness scale discussed earlier (see Table 2). These observed scores represent a person who reported suicide ideation at time 1, low self-esteem, substance abuse and suicide ideation at time 2, and low self-esteem at time 3. The minimum difference between the observed pattern and the three patterns consistent with a longitudinal Guttman scale and yielding the same total score is 4. This difference is observed for two of the three patterns; thus, either of these patterns can serve as the expected pattern (i.e., they are equivalent for the purpose of computing scalogram errors). See Note 2.

Once the expected pattern has been determined, longitudinal coefficients of reproducibility (LCR) and scalability (LCS) can be computed as in cross-sectional Guttman scalogram analysis. Subtracting the proportion of errors from unity yields LCR. LCS is defined as the difference between LCR and the reproducibility of items from their modes (LMR), divided by LMR subtracted from unity: LCS = (LCR − LMR)/(1 − LMR).

Applications of Longitudinal Scalogram Analysis

Kandel and Faust (1975) Data. Kandel and Faust (1975) provided cross-tabulations of drug use stages at the end of the senior year by use reported during a subsequent 5–9 month time interval for 872 public secondary school students. Applying the LSA methodology to these data allows an evaluation of the hypothesis that cumulative drug use reported at the end of high school continues as current use during a time span immediately following high school. These two waves of data were analyzed using the LSA.EXE microcomputer program we developed (Hays and Ellickson, 1990).

About 95% of the sample reported drug use that was cross-sectionally consistent (i.e., had no errors) at both time points with a seven-level Guttman scale: nonuse, use of legal drugs, cannabis, pills, psychedelics, cocaine, and heroin. We restricted the LSA analysis to these respondents ($n = 791$), because complete information about response patterns was not discernible in the original article for the rest of the sample. The data for this subsample (see Table 4) supports the hypothesized longitudinal Guttman scale, although there were some relapses (i.e., items not passed at time 2 that were passed at time 1) and these are reflected in the less than perfect longitudinal scalogram coefficients (LCR = 0.97, LCS = 0.72). Cross-sectional Guttman scale analysis of the two waves of data is insensitive to these relapses (i.e., CS = 1.0 at both time points), because it ignores the dimension of time.

Examination of the longitudinal scaling errors reveals that the majority involve two types: persons who reported (1) having tried legal drugs but abstained after high school; and (2) having tried legal drugs and cannabis, but abstained from cannabis after high school.

Hypothetical Drug Abuse Data. A hypothetical data set is given in Table 5 to illustrate how LSA might be useful for studying transition stages for addicts in drug abuse treatment. This example represents a situation in which addicts learn techniques to resist pressures to use drugs as part of a treatment program (e.g., Hawkins, Catalano, Gillmore, and Wells, 1989). Ability to resist drugs is measured at three time points: at entry into treatment, midpoint of treatment, and at exit from the treatment program. Three levels of resistance are assessed: *low, medium*, and *high* situational pressures to use drugs. In the low pressure situation, the addict is in the company of a drug-free support group. The medium pressure situation involves coming home after a frustrating day of work. The high pressure situation refers to attendance at a party where drug use is encouraged.

The hypothetical data in Table 5 are consistent with a longitudinal Guttman scale (LCR = 1.00, LCS = 1.00). They also represent circumstances that a drug treatment program manager would probably view favorably. The six addicts in the example are unable to resist prodrug pressures in any situation upon entry into treatment (designated as 0's at time 1). At time 2, resistance increases for all addicts, to varying degrees. Three addicts are able to resist drugs in the low pressure situation only, two are able to resist in the low and medium pressure situations, and one is able to resist in all situations. At exit from treatment, further increases in ability to resist are observed for half the addicts while resistance ability for the

Table 4

Response Patterns for 791 Respondents from Kandel and Faust (1975)

Time 1: items						Time 2: items						
1	2	3	4	5	6	1	2	3	4	5	6	Frequency
0	0	0	0	0	0	0	0	0	0	0	0	36
0	0	0	0	0	0	1	0	0	0	0	0	22
0	0	0	0	0	0	1	1	0	0	0	0	3
0	0	0	0	0	0	1	1	1	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	33*
1	0	0	0	0	0	1	0	0	0	0	0	345
1	0	0	0	0	0	1	1	0	0	0	0	76
1	0	0	0	0	0	1	1	1	0	0	0	5
1	1	0	0	0	0	1	0	0	0	0	0	35*
1	1	0	0	0	0	1	1	0	0	0	0	106
1	1	0	0	0	0	1	1	1	0	0	0	13
1	1	0	0	0	0	1	1	1	1	0	0	5
1	1	0	0	0	0	1	1	1	1	1	0	2
1	1	1	0	0	0	1	0	0	0	0	0	8*
1	1	1	0	0	0	1	1	0	0	0	0	12*
1	1	1	0	0	0	1	1	1	0	0	0	20
1	1	1	0	0	0	1	1	1	1	0	0	5
1	1	1	0	0	0	1	1	1	1	1	0	2
1	1	1	0	0	0	1	1	1	1	1	1	2
1	1	1	1	0	0	1	0	0	0	0	0	8*
1	1	1	1	0	0	1	1	0	0	0	0	13*
1	1	1	1	0	0	1	1	1	0	0	0	10*
1	1	1	1	0	0	1	1	1	1	0	0	8
1	1	1	1	0	0	1	1	1	1	1	0	9
1	1	1	1	1	0	1	1	0	0	0	0	2*
1	1	1	1	1	0	1	1	1	0	0	0	3*
1	1	1	1	1	0	1	1	1	1	0	0	3*
1	1	1	1	1	0	1	0	0	0	0	0	1*
1	1	1	1	1	0	1	1	0	0	0	0	1*
1	1	1	1	1	0	1	1	1	0	0	0	2*
Total												791

Note. 0 = not passed, 1 = passed. Items are legal drugs, cannabis, pills, psychedelics, cocaine, and heroin. Asterisks denote patterns with longitudinal relapses (i.e., items failed at time 2 but passed at time 1).

Table 5

Hypothetical Data for Six Addicts in Drug Abuse Treatment

Time 1			Time 2			Time 3		
Low	Medium	High	Low	Medium	High	Low	Medium	High
0	0	0	1	0	0	1	0	0
0	0	0	1	0	0	1	1	0
0	0	0	1	0	0	1	1	1
0	0	0	1	1	0	1	1	0
0	0	0	1	1	0	1	1	1
0	0	0	1	1	1	1	1	1

Note. Time 1 = entry into drug abuse treatment, Time 2 = midpoint of treatment, Time 3 = exit from treatment program. Three levels of pressure situations are defined: low, medium, high. 0 = unable to resist drugs, 1 = able to resist drugs.

Table 6

Hypothetical Data Illustrating An Absence of Longitudinal Transitions

Time 1			Time 2		
Low	Medium	High	Low	Medium	High
0	0	0	0	0	0
1	0	0	1	0	0
1	1	0	1	1	0
1	1	1	1	1	1
1	0	1	1	0	1
0	1	1	0	1	1

Note. Time 1 = entry into drug abuse treatment, Time 2 = midpoint of treatment. Three levels of pressure situations are defined: low, medium, high. 0 = unable to resist drugs, 1 = able to resist drugs.

other half has stabilized at the level detected at the midpoint of treatment. Monitoring an addict's position along the ability to resist drugs dimension would be useful for targeting treatment efforts.

No Longitudinal Transitions Data. In the special case where no longitudinal transitions occur (i.e., the cross-sectional hierarchy among items contains all the information, as in the example shown in Table 6), the LCS index is *not* simply the average of the cross-sectional scalability coefficients. In general, the LCS value will exceed the average of the CS values because longitudinal data offers greater flexibility in identifying target response patterns that minimize scalability errors. For example, LCS = 0.62 for the data shown in Table 6 while CS = 0.50 for both waves of data.

DISCUSSION AND FUTURE RESEARCH

Previous studies of drug use sequences have used cross-sectional Guttman scalogram analysis to examine development over time. These analyses do not "demonstrate that these levels of involvement are actually *stages* in a developmental sequence of transitions into greater drug use" (Donovan and Jessor, 1983, p. 550) or permit a direct inference about the temporal order of drug use (Fleming, Leventhal, Glynn, and Ershler, 1989). Demarcating stages or levels of drug use involvement requires an analytic model that is appropriate for dynamic processes.

The LSA analysis procedure incorporates the dynamic nature of longitudinal data. Unlike cross-sectional models of behavior, which require cross-sectional item variance, the LSA method evaluates consistency across individuals in transitions along a hypothesized hierarchy of behavior. Because transitions over time are explicitly modeled, the LSA method accurately reflects longitudinal drug use processes. Future research using LSA or other longitudinal analytic methods is needed to establish true development sequences of drug use.

Additional work is also needed to understand the mechanisms that generate stages of drug use involvement. For example, some researchers have hypothesized a causal chain, beginning with alcohol use, leading to marijuana use, and ending with hard drug use (O'Donnell and Clayton, 1982). Subsequent work by Kandel and Adler (1982) revealed that the effects of alcohol use on marijuana use were mediated entirely by attitudes toward marijuana. Further mapping of any variables intervening in the explanatory chain should be a priority.

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NOTES

1. Collins et al. (1988) have developed an alternative longitudinal scaling method, the Longitudinal Guttman Simplex (LGS). The LGS method differs from the approach described here in two important respects: (1) the LGS scaling coefficient, CL, is derived by classifying and counting order relations (responses to pairs of items at two time points) in terms of the number of adherences and deviations from model axioms (Collins and Cliff, 1985); (2) adequate guidelines for interpreting CL have not yet been published.
2. As an alternative to narrowing down the potential expected patterns based on the respondent's total score, each individual's item scores can be compared with *all* longitudinally consistent patterns to identify the pattern that is least different. This alternative procedure is much more computationally intensive and will yield scaling coefficients (reproducibility and scalability) that are as large or larger than those obtained from the standard method. It is also less consistent with scoring used for cross-sectional Guttman scalogram analysis and more likely than the first method to yield estimates of scalability that are too high.

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