Determining Missing Data Rules for Patient-Reported Outcomes: Alpha-If-Item-Deleted

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BACKGROUND

- Instrument developers must establish scoring algorithms, including rules for handling missing data.
- Often, instrument developers use arbitrary rules of thumb when creating scoring guidelines for missing data.
- Patient-reported outcomes research commonly uses the "50% rule," which indicates that an overall or subscale score can only be computed if at least half of the items of the instrument or subscale are nonmissing.
- The arbitrary application of missingness rules without regard for item properties can lead to scores with inadequate reliability.
- Cronbach's alpha is considered a lower bound estimate for reliability, and while other methods exist, this approach has been commonplace in instrument development for the last half century.[1,2,3]
- One simple approach for empirically determining the maximum tolerable number of missing item-level responses is a stepwise alpha-if-item-deleted method described by Mitchell and Bradley.[4]

OBJECTIVE

- To compare the reliability of scores based on the alpha-if-item-deleted method's missing data rule to the reliability of scores based on the rule proposed by the instrument developer.

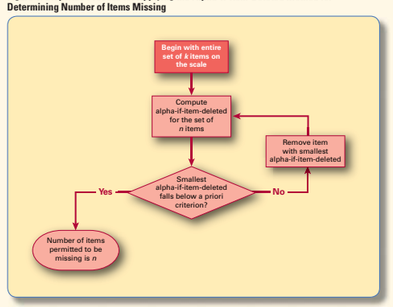
METHOD

- Using Cronbach's alpha[5] to compute reliability of a *k*-item scale:

$$\alpha = \left(\frac{k}{k-1}\right)\left[1 - \frac{\Sigma_i^k V(Y_i)}{V(\Sigma_i^k Y_i)}\right]$$

- We computed alpha three times for each instrument:
  1. All items on the scale to identify the upper-bound of alpha for this scale score when no data are missing.
  2. Only the number of items permitted to be missing according to the developer's guidelines, where the items excluded were those with the largest contribution to alpha (i.e., lowest alpha-if-item-deleted values).
  3. Only the number of items permitted to be missing according to the alpha-if-item-deleted approach (Figure 1), also basing exclusion criteria on the largest contribution to alpha.
- Stepwise alpha-if-item-deleted method:[4]
  - Cronbach's alpha is calculated sequentially as items are excluded from the item set one at a time.
  - The order in which items are removed from the item set is based on the magnitude of alpha-if-item-deleted, where the item with the smallest alpha-if-item-deleted (i.e., the item with the greatest contribution to the alpha) is removed at each step.
  - When the smallest alpha-if-item-deleted for a set of items falls below an a priori identified threshold (e.g., 0.70), the number of items considered at that step is determined to be the minimum number of items needed to calculate a reliable scale score for an individual.
  - In the present study, we used an alpha of 0.70, the minimum recommended by Streiner and Norman[6] for group-level comparisons. The alpha for the stepwise method should usually be just above 0.70 because the removal of one additional item would drop alpha below this standard of 0.70.

Figure 1. Stepwise Process for Applying the Alpha-If-Item-Deleted Method for Determining Number of Items Missing



- Table 1 illustrates the stepwise alpha-if-item-deleted method for the 9-item hypothetical Example Questionnaire (ExQ).
  - ExQ items were removed in successive steps beginning with the item with the smallest alpha-if-item-deleted (i.e., the item that contributes the most to alpha), until the alpha of the remaining items fell below the threshold of 0.70.

  Step 1: Shows the alpha for the full 9-item scale (0.87) and the alpha-if-item-deleted for each of the 9 ExQ items.
  - Item 7 had the smallest alpha-if-item-deleted (0.84), so it was removed.

  Step 2: The alpha for the 8 remaining items was 0.84 (the alpha-if-item-deleted for the excluded item at the previous step).
  - Item 5 had the lowest alpha-if-item-deleted (0.79) so it was removed.

  Step 3: The remaining 7 items had an alpha of 0.79.
  - Item 3 had the smallest alpha-if-item-deleted (0.73) so it was removed.

  Step 4: The remaining 6 items had an alpha of 0.73.
  - Item 2 had the smallest alpha-if-item-deleted (0.65) so it was removed.
- The deletion of Item 2 in Step 4 drops the overall alpha for the remaining items below the 0.70 threshold (0.65); thus, the minimum number of nonmissing responses from the 9-item ExQ is 6 (the number of items considered at the last step when overall alpha is greater than the threshold).

Table 1. Sequential Alpha-If-Item-Deleted for the ExQ Items at Each Step

Item	Alpha-If-Item-Deleted			
	Step 1	Step 2	Step 3	Step 4
1	0.88	0.85	0.79	0.74
2	0.85	0.81	0.74	0.65
3	0.84	0.80	0.73	—
4	0.85	0.82	0.75	0.67
5	0.83	0.79	—	—
6	0.86	0.82	0.76	0.69
7	0.84	—	—	—
8	0.86	0.83	0.76	0.70
9	0.88	0.85	0.79	0.71
Total alpha	0.87	0.84	0.79	0.73

RESULTS

- A total of 6 datasets were analyzed, including 9 different instruments for a total of 34 different subscales (Table 2).
- Instruments: Brief Pain Inventory-Short Form (BPI-SF),[7] Center for Epidemiological Studies Depression Scale (CES-D),[8] Irritable Bowel Syndrome Quality of Life Questionnaire (IBS-QOL)[9] Medical Outcomes Study Cognitive Questionnaire (MOS-Cog)[10] Medical Outcomes Study Sleep Scale (MOS-Sleep),[11] Paediatric Asthma Caregiver's Quality of Life Questionnaire (PACQLQ)[12] Patient Assessment of Constipation Quality of Life questionnaire (PAC-QOL),[13] Patient Assessment of Constipation Symptoms Questionnaire (PAC-SYM),[14,15] Medical Outcomes Study Short Form–36 (SF-36).[16]

Scenario 1

- Alphas computed using the developer's guidelines were greater than alphas computed using the stepwise rule.
- This result indicated that the developer's guidelines were conservative and reliable scores could be calculated using fewer items (i.e., in the presence of more missing data).
- Alphas computed using the developer's guidelines were smaller than the corresponding alphas computed using the full item set, but still very satisfactory.
- Instruments: BPI-SF Impact of Pain on Daily Function; CES-D; PACQLQ Overall and Emotional Functioning; PAC-QOL Overall, Worries and Concerns, and Psychosocial Discomfort; PAC-SYM Overall.

Scenario 2

- Alphas computed using the developer's guidelines were smaller than alphas computed using the stepwise rule (and much smaller than alphas computed using the full item set).
- This result indicated that the developer's guidelines were too liberal (i.e., allowed too many missing data) and scores calculated with the recommended allowable number of items missing did not meet our reliability threshold.
- Instruments: BPI-SF Severity of Pain; IBS-QOL Mental Health and Sleep; MOS-Sleep Sleep Disturbance, Daytime Somnolence, 6-item Sleep Problems Index, and 9-item Sleep Problems Index; PACQLQ Activity Limitations; PAC-QOL Satisfaction; PAC-SYM Abdominal Symptoms and Rectal Symptoms; SF-36 Vitality and General Health Perceptions.

Scenario 3

- The developer's guidelines and the stepwise alpha-if-item-deleted method guidelines were the same.
- Instruments: IBS-QOL Emotional Health, Physical Function, Physical Role, Diet, Sexual Relations, and Social Role; MOS-Cog; PAC-QOL Physical Discomfort; PAC-SYM Stool; SF-36 Physical Functioning, Role Limitations due to Physical Health, General Mental Health.

Table 2. Comparison of Alphas and Number of Allowable Items Based on Developer's Guidelines and the Stepwise Alpha-if-Item-Deleted Rule

Scale	Number of Items	Alpha for Full-Scale	Developer's Guidelines		Alpha-If-Item-Deleted Rule	
			Number of Nonmissing Items Required	Alpha	Number of Nonmissing Items Required	Alpha
BPI-SF (n = 150)						
Severity of Pain	4	0.83	2	0.65	3	0.77
Impact of Pain on Daily Function	7	0.94	5	0.91	2	0.71
CES-D (n = 850)	20	0.91	19	0.90	9	0.73
IBS-QOL (n = 250)						
Emotional Health	4	0.90	2	0.77	2	0.77
Mental Health	4	0.86	2	0.62	3	0.79
Sleep	3	0.82	2	0.67	3	0.82
Physical Function	3	0.90	2	0.78	2	0.78
Physical Role	4	0.93	2	0.84	2	0.84
Diet	3	0.77	2	0.63	3	0.77
Sexual Relations	3	0.89	2	0.80	2	0.80
Social Role	4	0.90	2	0.79	2	0.79
MOS-Cog (n = 500)	6	0.89	3	0.76	3	0.76
MOS-Sleep (n = 950)						
Sleep Disturbance	4	0.77	1	-	4	0.77
Daytime Somnolence	3	0.75	1	-	3	0.75
6-item Sleep Problems Index	6	0.75	1	-	6	0.75
9-item Sleep Problems Index	9	0.83	1	-	6	0.71
PACQLQ (n = 200)						
Activity Limitations	4	0.86	2	0.63	3	0.79
Emotional Functioning	9	0.89	5	0.78	4	0.73
Overall	13	0.91	7	0.81	5	0.73
PAC-QOL (n = 650)						
Worries and Concerns	11	0.95	6	0.82	4	0.75
Physical Discomfort	4	0.86	2	0.72	2	0.72
Psychosocial Discomfort	8	0.92	4	0.81	3	0.75
Satisfaction	5	0.85	3	0.62	4	0.79
Overall	28	0.96	14	0.88	7	0.74
PAC-SYM (n = 650)						
Abdominal	4	0.86	2	0.66	3	0.77
Rectal	3	0.82	2	0.66	3	0.82
Stool	5	0.87	3	0.75	3	0.75
Overall	12	0.91	6	0.79	5	0.74
SF-36 (n = 150)						
Physical Functioning	10	0.89	5	0.74	5	0.74
Role Limitations due to Physical Health	4	0.93	2	0.85	2	0.85
General Mental Health	5	0.89	3	0.78	3	0.78
Role Limitations due to Emotional Problems	3	0.94	2	0.87	2	0.87
Vitality	4	0.83	2	0.56	3	0.76
General Health	5	0.81	3	0.61	4	0.74

Note: Rows highlighted in yellow signify Scenario 1. Rows highlighted in red signify Scenario 2. Rows highlighted in green signify Scenario 3. Only subscales with 3 or more items are presented.

- Rules of thumb cannot be applied blindly across scales because they don't account for scale properties (e.g., overall reliability, strength of individual items).
- Even within the same instrument, the application of the same rule (e.g., the 50% rule) may be too conservative for some subscales and too liberal for others. For example:
  - BPI-SF Impact of Pain on Daily Function (conservative) vs. BPI-SF Severity of Pain (liberal)
  - PACQLQ Overall and Emotional Functioning (conservative) vs. PACQLQ Activity Limitations (liberal)
  - PAC-QOL Overall, Worries and Concerns, and Psychosocial (conservative) vs. PAC-QOL Satisfaction (liberal)
  - PAC-SYM Overall (conservative) vs. PAC-SYM Abdominal Symptoms and Rectal Symptoms (liberal).
- Overall alphas are larger for scales where the developer guidelines are too conservative rather than too liberal. In most cases, the overall alpha for scales with conservative developer guidelines is greater than 0.90, and there's more room for alpha to decrease with item deletion before going below 0.70 (Table 2).

DISCUSSION AND CONCLUSIONS

- It is important to consider the reliability of the scale and the effect of item-level missing data on scale reliability.
- The application of the 50% rule and other rules of thumb may be too liberal for some subscales and too conservative for other subscales within the same instrument because item and instrument properties are not carefully considered.
  - When too many missing data are allowed, the available data are insufficient and scores are less reliable than expected using the overall scale. At minimum, the resulting score is full of error, and excluding scores with such error can increase the signal to noise ratio when considering study results.
  - When the developer's rule unnecessarily restricts meaningful missing item-level data, missing score values will be assigned to individuals where reliable scores could be calculated given even larger amounts of missing data. The reliability of the resulting score may be greater than 0.70.
- Calculation of reliable subscale scores when missing data are present is desirable because it provides information at the individual level and increases power at the study level.
- When the alpha-if-item-deleted method is applied, it is known that all scores calculated with a reduced item set when item responses are missing, no matter which items are missing, will meet a certain reliability level.

LIMITATIONS

- There are a number of methods available for assessing reliability that consider levels of reliability across the range of scale scores (e.g., standard error of measurement in item response theory).
  - This stepwise Cronbach's alpha-based method is presented as the most common and straightforward method to consider when scoring scales with missing data, although researchers are encouraged to consider reliability as calculated through model-based scoring algorithms.
- The stepwise alpha-if-item-deleted method can lead to the deletion of items whose removal entails a loss of composite reliability, despite an improvement in alpha.[17,18]
  - This method should be considered a first step for determining the number of items that can be missing from a subscale score, and resulting alphas should be considered a lower bound for reliability.
- Missing data scoring guidelines, especially the methods examined here, do not consider the content validity of the scale.
  - Allowing for a certain number of missing items can lead to scale scores that no longer measure the full spectrum of the intended construct.

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Presented at: ISPOR 15th Annual International Meeting
May 15-19, 2010
Atlanta, GA, United States