A general measure of organization in free recall for variable unit size and internal sequential consistency*

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A general procedure that can be applied to any type of free recall data for the quantitative measurement of subjective organization intertrial repetitions (ITRs) is described. The procedure makes it possible to examine any unit size with any type of internal consistency criterion. The application of this procedure and the corresponding expected value formula to four distinct data measurement cases is described, and several applied subjective organization measures are discussed. In addition, the relationship of clustering as a special case of subjective organization is demonstrated.

Measures of intertrial subjective organization have been criticized for their inability to reflect higher order units of organization (e.g., Mandler, 1967; Postman, 1971). The two basic measures that have been proposed (Tulving, 1962; Bousfield & Bousfield, 1966) test for the repetition of pairwise contingencies across free recall trials. Although the measures differ with respect to the value of subjective organization finally determined, their results are highly correlated (Puff & Hyson, 1967). It is possible, however, to analyze free recall protocols also for higher order units of organization and to compare these observed higher order units with values expected by chance. The present paper describes a general procedure applicable to the quantitative measurement of organizational units of any size and with any type of internal consistency, of which the Bousfield and Bousfield ITR measure becomes a special case.

COMPUTATION OF OBSERVED UNITS

In order to determine the number of units of Size X that are present, the criteria for defining a subjective organization unit must be stated. There are three possible ways of defining a subjective organization unit: unidirectionally, bidirectionally, and unordered, and these are a function of internal consistency. The following example illustrates each of these

criteria and the procedure for obtaining observed subjective organization units. In a 10-item list (A-J), Items A-F are recalled in that order on Trial t , whereas on Trial $t + 1$ Items BACDFHI are sequentially recalled. In the Tulving (1962) and Bousfield and Bousfield (1966) measures of subjective organization, units of Size 2 are defined in a unidirectional fashion. In the example, since Items A and B occur sequentially on Trial t , the first possible subjective organization unit is AB. If A and B occur in the same sequential order on $t + 1$, then there is one observed intertrial repetition [$O(ITR)$]. Similarly, B and C form a second subjective organization unit on t and if they also occur in the same sequential order on $t + 1$ then there is a second $O(ITR)$. A and B can also be considered as a unit on $t + 1$ if they occur in either a AB or BA sequence, and in this case the unit of Size 2 is defined as having bidirectional properties (e.g., Gorfein, Blair, & Rowland, 1968). If t is now examined for units of Size 3, the first possible triplet is ABC. If the unit is defined unidirectionally, then only in the case where ABC occur in the same sequential order on $t + 1$ will there be an $O(ITR)$. If, however, the unit is defined as having bidirectional properties, then ABC or CBA would be considered an $O(ITR)$ on $t + 1$. The third possibility is that the unit is defined according to any of the $3!$ ways in which these items can be sequentially combined. In this case there would be six possible sequential orderings of ABC, which would yield an $O(ITR)$ on $t + 1$. Thus there are three possible criteria for defining an $O(ITR)$ of the unit of Size X . If it is defined unidirectionally, then there is only one possible sequential ordering of the X items that will provide an $O(ITR)$. Defining the unit bidirectionally yields two possible

sequences that will provide an $O(ITR)$, whereas defining it to include all possible ordered combinations of the X items yields $X!$ possible sequences that will represent an $O(ITR)$.

The following notational system will be used in the remainder of this paper: U refers to the unidirectional criterion, B the bidirectional criterion, and S the unordered criterion. Thus $O(ITR_{U/2})$ refers to an observed unidirectional intertrial repetition for Unit Size 2. For general statements, the symbol $O(ITR_{\alpha/X})$ will be used.

To determine the number of $O(ITR_{\alpha/X})$ for unit sizes from 2 to M (number of items recalled on t), a matrix of position values is generated. The columns represent each of the items within the list, whereas the rows represent each individual trial. Each recalled item is assigned a value which can vary from 1 to L (the number of items within the entire list). All nonrecalled items are assigned the value of zero. The value of a particular cell thus represents the recall position of that item for that particular trial. The following is the matrix for the previously presented example. To determine the number of $O(ITR_{\alpha/X})$ for units of Size 2, a sequential search in Row t is initiated.

Item	A	B	C	D	E	F	G	H	I	J
t	1	2	3	4	5	6	0	0	0	0
$t + 1$	2	1	3	4	0	5	0	6	7	0

This search starts by finding that item with Position 1 on t , which is Item A, and then finding the item with Position 2, which is B. Having found these two items, which comprise the first sequential pair on t , the search now finds the $t + 1$ values for these items which are 2 and 1, respectively. There is a relatively simple procedure which uses these $t + 1$ values to determine if an $O(ITR_{\alpha/X})$ has occurred. Initially, the $t + 1$ position values for the items in the unit are converted into values of P_i , where P_i equals the $t + 1$ position for the i^{th} item in the unit, and i refers to an item's sequential position within the unit on Trial t and thus ranges between values of 1 and X . For the sequential unit AB in the example, the i values are 1 and 2, respectively, and $P_1 = 2$, $P_2 = 1$. There are two restrictions that determine if an $O(ITR_{\alpha/X})$ has occurred: (1) no P_i value can equal zero, and (2) the absolute value of the largest difference between any two P_i values must be less than X . If either or both of these restrictions are not met, then no $O(ITR_{\alpha/X})$ has occurred for that particular unit of Size X . If, however, both restrictions are met, there are three steps for determining which type

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Table 1
Individual S Free Recall Protocols

Recall Position	S 1		S 2		S 3	
	t	t+1	t	t+1	t	t+1
1	A	C	A	H	A	J
2	B	B	B	I	B	L
3	C	A	C	J	C	I
4	D	P	D	K	D	K
5	E	E	E	L	E	H
6	F	G	F	M	F	M
7	G	F	G	N	G	N
8	H	H	H	D	H	E
9	I	I	I	E	I	F
10	J	M	J	F	J	D
11	K	K	K	R	K	R
12	L	L	L	O	L	O
13		R		B		B
14		N		A		A
15		O		P		P

(or types) of $O(ITR_{\alpha/X})$ has occurred.

(1) If each value obtained for the difference $P_{i+1} - P_i$ (where i ranges from 1 to $X-1$) is positive, then an $O(ITR_{\alpha/X})$ has occurred for all three ordering criteria (unidirectional, bidirectional, and unordered).

(2) If 1 is not satisfied, then a check is made of each $P_{i+1} - P_i$ value to determine if they are all negative. If so, an $O(ITR_{\alpha/X})$ has occurred for the bidirectional and unordered criteria only.

(3) If neither 1 nor 2 is satisfied, then only an unordered $O(ITR_{\alpha/X})$ has occurred.

Thus it is possible in one search of the unit size X to determine $O(ITR_{\alpha/X})$ values for all three ordering criteria simultaneously. The following illustrates the application of these steps to the sequential units AB, CD, and ABCD in the preceding example. For the unit AB, both restrictions are met, since both P_i values are not zero and the absolute value of the difference between them is 1, which is less than $X(2)$. The $P_{i+1} - P_i$ difference is negative; thus Step 1 is not satisfied. This difference does, however, satisfy Step 2; thus a bidirectional $O(ITR_{\alpha/X})$ has occurred. It should be noted that for units of Size 2, bidirectional and unordered are identical. For the next sequential unit of Size 2 (which is BC), the i values are 1 and 2, respectively, with $P_1 = 1$ and $P_2 = 3$. The application of the position restrictions yields no $O(ITR_{\alpha/X})$ for any of the three ordering possibilities. For the unit CD and i values are again 1 and 2 and $P_1 = 3$ and $P_2 = 4$ so that both restrictions are fulfilled. The value of $P_{i+1} - P_i$ is positive; thus Step 1 is fulfilled and an $O(ITR_{\alpha/X})$ has occurred for the unidirectional, bidirectional, and unordered criteria. For the larger unit, ABCD, which is composed of these three smaller units, the i values are 1, 2, 3, and 4, respectively, and $P_1 = 2$, $P_2 = 1$,

$P_3 = 3$, and $P_4 = 4$. Both restrictions are met since no P_i value is 0, and the absolute value of the largest difference between any two P_i values ($P_4 - P_2 = 3$) is smaller than $X(4)$. The values of $P_{i+1} - P_i$ ($-1, 2, 1$) are not all positive; thus Step 1 is not fulfilled. They are also not all negative; thus Step 2 is also not fulfilled. Therefore, an $O(ITR_{\alpha/X})$ has occurred only for the unordered criteria. This example illustrates that an unordered higher order unit can be formed from three units, one of which is bidirectionally and a second unidirectionally reproduced on $t+1$, with the third not appearing at all on $t+1$.

If t and $t+1$ are now examined for the next unit of Size 2 (which is DE), the $t+1$ positions are 4 and 0, respectively, and $P_1 = 4$ and $P_2 = 0$. The application of the position restrictions yields no $O(ITR_{\alpha/X})$ for any of the three ordering possibilities. The data for t and $t+1$ can now be examined for the next subjective organization unit of Size 2, and this will continue until all sequential

pairings from t have been examined. Once this is accomplished, we have the number of total $O(ITR_{\alpha/2})$ for all three ordering possibilities for Unit Size 2. The data can then be examined for all sequential units of Size 3 using the same search and test procedure. Similarly, this can be done for all unit sizes up to M . With this technique (which is most easily accomplished by computer searching routines), it is possible to assess the number of $O(ITR_{\alpha/X})$ for each unit size and obtain different values for the three possible ordering criteria of subjective organization units.

EXPECTED VALUES

The procedure previously described provides a method of determining the number of $O(ITR_{\alpha/X})$ for any unit size. A chance expected value can also be determined for the different unit sizes. The rationale for determining expected values of higher order units is based upon the assumption of limited availability of items and is similar to that developed by Bousfield and Bousfield (1966). The following is the general equation for computing the expected number of intertrial repetitions for a unit of Size X .¹

$E(ITR_{\alpha/X})$

$$= \frac{(N - X + 1)! (A)(M - X + 1 - R)}{N!} \quad (1)$$

Where M = number of items recalled on Trial t ; N = number of items recalled on Trial $t+1$; X = size of the subjective organization unit; R = number of units of Size X from Trial t that have one or more items not recalled on $t+1$; and A = variable parameter dependent upon the specific order within the subjective

Table 2
Observed ITRs as a Function of Data Cases, Unit Ordering Criteria, and Unit Size

	S 1				S 2				S 3			
	2	3	4	5	2	3	4	5	2	3	4	5
Case 1												
uni	2	0	0	0	6	4	2	1	1	0	0	0
bi	5	1	0	0	7	4	2	1	2	0	0	0
unord	5	3	2	1	7	4	2	1	2	1	1	1
Case 2												
uni	2	0	0	0	6	4	2	1	1	0	0	0
bi	5	1	0	0	7	4	2	1	2	0	0	0
unord	5	3	2	1	7	4	2	1	2	1	1	1
Case 3												
uni	2	0	0	0	6	4	2	1	1	0	0	0
bi	5	1	0	0	7	4	2	1	2	0	0	0
unord	5	3	2	1	7	4	2	1	2	1	1	1
Case 4												
uni	3	2	1	0	6	4	2	1	1	0	0	0
bi	6	3	1	0	7	4	2	1	3	1	0	0
unord	6	5	4	2	7	4	3	2	3	3	3	3

Table 3
Individual Item Frequency of Occurrence in Observed Unordered Units

S 1					S 2					S 3				
2	3	4	5		2	3	4	5		2	3	4	5	
E		1	1	1	H	1	1	1	1	H				1
F	1	2	2	1	I	2	2	2	1	I		1	1	
G	1	2	2	1	J	2	3	2	1	J		1	1	
H	1	1	2	1	K	2	2	2	1	K		1	1	
I	1		1	1	L	1	1	1	1	L		1	1	
A	1	1			D	1	1			D			1	
B	2	1			E	2	1			E	1	1		
C	1	1			F	1	1			F	1	1		
K	1				A	1				A	1			
L	1				B	1				B	1			
D					C					C				
J					G					G				

organization unit ($A = 1$ for unidirectional units, $A = 2$ for bidirectional units, and $A = X!$ for unordered units).

In the previously presented example, $M = 6$, $N = 7$, and (for units of Size 2) $X = 2$. If the formula is applied, then $R = 2$ since Item E was not recalled on $t + 1$ and appears in two units of Size 2 on Trial t . For the unidirectional case, $E(ITR_{U/2}) = .428$ and for bidirectional pairs $E(ITR_{B/2}) = .856$.² For units of Size 3, $R = 2$ since Item E appears in two triplets. For unidirectional triplets $E(ITR_{U/3}) = .048$, for bidirectional triplets $E(ITR_{B/3}) = .096$, and for unordered triplets $E(ITR_{S/3}) = .288$.

There are four different cases where measures of subjective organization can be applied. These cases involve modifications of the data to deal with certain options concerning the measurement of $O(ITR_{\alpha/X})$. Table 1 presents three sets of data which illustrate the application of these cases. In all three sets of data, $M = 12$, $N = 15$, and there are two items from t that are not recalled on $t + 1$. For S-1 and S-3, there are higher order units of organization, but this organization is not a function of the carryover of unidirectional units, while S-2 has the same higher order units, but their organization is very highly unidirectional.

Case 1

This case corresponds to the general application of subjective organization to free recall data. The items from t and $t + 1$ are examined without any modification of the data. The unidirectional observed scores in Table 2 show small amounts of organization for all unit sizes for S-1 and S-3, while S-2 shows unidirectional organization within all unit sizes. The bidirectional analysis again shows the superiority of S-2 to both S-1 and S-3, and also the superiority of S-1 to S-3 for units of Sizes 2 and 3. In the unordered analysis, all three Ss show equal amounts of organization for units of

Size 5 and there are increasing differences between the three Ss with respect to decreasing unit sizes.

This analysis of the differences in organization between Ss is made more readily understandable by breaking down the list structure into independent units. This is accomplished by making a frequency count of the number of times an item from Trial t appears in an observed unit of Size X [$O(ITR_{\alpha/X})$] on $t + 1$. Table 3 is the frequency count for the unordered analysis. By grouping together those items that appear in a unit of at most Size X ($X = 2, 3$, etc.), it is possible to derive the independent units within the list. For the unordered criterion, Table 3 shows all three Ss with the same independent unordered units: one each of Sizes 2, 3, and 5. The frequency table also shows the organization within these independent units. The frequency profiles correspond to the between-Ss differences in the observed scores for the unordered analysis. This type of table can also be applied to the unidirectional and bidirectional data.

One further index that is generally useful for providing a gross measure of sequential consistency is a ratio of observed unidirectional ITRs [$O(ITR_{U/X})$] to observed unordered ITRs [$O(ITR_{S/X})$] for a particular unit size. The value obtained in this ratio is the proportion of $O(ITR_{S/X})$ that are a function of sequential ordering, with a value of 1 indicating complete sequential consistency and a value of 0 indicating the lack of any sequential consistency. Careful examination of all three analyses (observed scores, frequency table, and unidirectional-unordered ratio) provides a more complete profile of individual-S organization and between-S differences in organization. It is possible to abstract the independent units of organization, the subunits, and the consistency of serial ordering within all these units.

Case 2

This case involves a modification of

the data from Trial $t + 1$ by eliminating from this trial newly recalled items. This case deals with the problem of whether or not a unit of Size X is still an observed unit on $t + 1$ if new items have been added to this unit making it part of a new higher order unit. For S-1 one pairwise unit on t was KL. If on $t + 1$ the recall output was KML, where M is a newly recalled item, then the elimination of M would show the original unit preserved. It is an empirical question whether or not one wishes to consider the unit as preserved in this case and whether such a modification of the data is required. Under this modification, the $O(ITR_{\alpha/X})$ can either remain the same or increase. If the expected-value formula is applied to this case, then N must be decreased by the number of deleted items, so that under this condition the expected value will increase relative to that determined for Case 1.

Case 3

This is a modification of the data where items from t not recalled on $t + 1$ are eliminated from the list. This case deals with the question of whether or not an item that is not recalled on $t + 1$ should be included as part of a subjective organization unit on Trial t . For S-1 recall on t was ABCDE, but D was not recalled on $t + 1$. The elimination of D reduces M and increases the number of usable units for all X values. The usable pairs now become AB, BC, CE, the usable triplets are ABC, BCE, and the usable quadruplet is now ABCE. The elimination of items such as D will increase the number of usable units (those now capable of being examined on $t + 1$), with this value increasing more rapidly the larger the unit size. If the expected value formula is applied, R will equal zero and M is reduced. The expected values can increase or remain the same relative to Case 1, and the increase will be greater for larger size units since $(M - X + 1 - R)$ increases by a larger factor for these units. The $O(ITR_{\alpha/X})$ can remain constant or increase as in Case 2.

Case 4

This last modification is the combination of Cases 2 and 3. It has all the same properties as these cases independently since $O(ITR_{\alpha/X})$ can remain constant or increase. With respect to expected values, these can only increase as in Case 2 since N is reduced. R is equal to zero and M is also reduced.

The frequency table and the unidirectional-unordered ratio should also be applied to Cases 2, 3, and 4. Thus, in all four cases, a complete profile of organization can be

determined. In the computation of $O(ITR_{\alpha/X})$ for Cases 2-4, a slight modification of the matrix is necessary to use the search procedure previously described. If an item is deleted from either t or $t + 1$, then for each deleted item a value of 1 must be subtracted from the position values for all items that sequentially followed the deleted item on that trial. This collapses all of the positions so that they now correspond to the new value of M or N .

SUBJECTIVE ORGANIZATION MEASURES

Applying the procedure for obtaining $O(ITR_{\alpha/X})$ to individual S free-recall protocols provides a means of deriving an overall profile of all the observed units of organization that occur within two successive trials. Within the matrix of position values, it is also possible to compare nonadjacent trials to evaluate the consistency of organization over a series of trials. There are several ways in which the $O(ITR_{\alpha/X})$ values obtained for adjacent and nonadjacent trials can be used in different applied subjective organization measures. The following are four different subjective organization measures that can be used.

$$RR'_{\alpha/X} = \frac{O(ITR_{\alpha/X})}{\text{MAX}(ITR_{\alpha/X})} \quad (2)$$

$$DEV_{\alpha/X} = O(ITR_{\alpha/X}) - E(ITR_{\alpha/X}) \quad (3)$$

$$ARC'_{\alpha/X} = \frac{O(ITR_{\alpha/X}) - E(ITR_{\alpha/X})}{\text{MAX}(ITR_{\alpha/X}) - E(ITR_{\alpha/X})} \quad (4)$$

$$SCR'_{\alpha/X} = \frac{O(ITR_{\alpha/X})}{\text{MAX}(ITR_{\alpha/X})} - \frac{E(ITR_{\alpha/X})}{\text{MAX}(ITR_{\alpha/X})} \quad (5)$$

where $\text{MAX}(ITR_{\alpha/X}) = M - X + 1 - R$.

Equation 2 is similar to the ratio used by Tulving (1962) for pairwise subjective organization and that used in determining clustering values for categorized word lists. This ratio has the unfortunate property that if S fails to recall most of the items from t on $t + 1$ the $\text{MAX}(ITR_{\alpha/X})$ value will be low and the ratio may be spuriously high since very little organization is carried over to Trial $t + 1$. One way to correct for this is to make $\text{MAX}(ITR_{\alpha/X}) = M - X + 1$. Under this modification, all possible groupings of Size X on Trial t are considered. Equation 3 is the deviation measure proposed by Bousfield and Bousfield (1966). It suffers from the lack of an

Table 4
Correlation Values of Subjective Organization Measures as a Function of Unit Ordering Criteria

		RR''	DEV	ARC'	ARC''	SCR'
Unordered	RR'	.295	.330	.997	.388	.982
	RR''		.995	.278	.993	.166
	DEV			.319	.999	.217
	ARC'				.377	.991
	ARC''					.275
Bidirectional	RR'	.786	.782	.997	.809	.992
	RR''		.995	.771	.994	.718
	DEV			.774	.999	.723
	ARC'				.802	.996
	ARC''					.753
Unidirectional	RR'	.758	.763	.999	.809	.998
	RR''		.996	.749	.992	.728
	DEV			.761	.998	.741
	ARC'				.803	.999
	ARC''					.785

upper boundary and difficulty in comparing different unit sizes, since the number of possible observable units decreases as unit size increases. A correction for the latter problem is to divide the deviation score by the standard deviation of the expected value producing a Z score. However, the calculation of the standard deviation is a complicated procedure for subjective organization scores (although not with E -determined clustering scores, see Hudson & Dunn, 1969). Equation 4 is a modification proposed by Roenker, Thompson, and Brown (1971) for clustering scores, while Eq. 5 is a similar modification proposed by Fagan (1968) for subjective organization scores. Both measures have the property that linear increases in the $O(ITR_{\alpha/X})$ values will be reflected by linear increases in the score obtained. In addition, the positive range for the ARC' score is 0 to +1, representing chance to maximum values. However, both measures have the same property as Eq. 2, and the score obtained may be unnecessarily inflated. All four measures have certain desirable and certain undesirable properties. Table 4 is the correlation matrix for these measures applied to the observed data for Case 1. In this table, RR'' and ARC'' are RR' and ARC' with $\text{MAX}(ITR_{\alpha/X}) = M - X + 1$. The values in the table were obtained by comparing the measures across Unit Sizes 2-5 for all three sets of data from Table 1. For the unordered unit criterion, there are two distinct sets of three measures, with each set having high intercorrelations. ARC' , DEV , and RR'' correlate very highly, while ARC' , SCR' , and RR' are also very highly correlated. However, the correlations between any members of these two subsets are low. The latter result is a function of the differences between measures with respect to the subjective organization scores obtained

within a S for the different unit sizes. For ARC'' , DEV , and RR'' , the scores obtained within S s tend to decrease as unit size increases, while for ARC' , SCR' , and RR' , these tend to increase with increases in unit size. A similar pattern of results is also apparent for the bidirectional and unidirectional unit criteria. However, for these criteria, the correlation values are artificially raised because of a few scores which differ markedly from zero on both measures, even though most scores are at or near zero (and thus normally should reduce the size of the correlation). In general, however, the results are the same. It would appear then that all six measures provide comparable results when compared at only one unit size and the differences between the measures is with respect to their treatment of different unit sizes. This result is a function of the differences between the measures in the treatment or weighting of $O(ITR_{\alpha/X})$ or in the $\text{MAX}(ITR_{\alpha/X})$ value employed. The measure that is probably best suited to between- S comparisons is the ARC' (or ARC'') score since it will provide an equivalent range statistic across all S s regardless of amount of recall.

CLUSTERING

The manner in which clustering is normally scored can be viewed as representative of a case of bidirectional pairwise subjective organization, where the subjective organization units that are examined are the E -defined relationships within the list. In this sense, each separate E -defined category becomes the list from Trial t and S 's recall becomes the list from Trial $t + 1$. Thus, by taking into account the number of possible pair sequences within the list categories that will provide an $O(ITR_{\alpha/X})$, the general equation for $E(ITR_{\alpha/X})$ can be modified to handle clustering examples. The following

illustrates this relationship. On Trial K a S recalls the following sequentially ordered items: $A_1-A_3-A_5-B_1-B_3-A_6-C_1-C_2-C_3$. If the E-defined list has six items in each of the three recalled categories, then each category represents a list of six items from Trial K-1. If Category A has six members, then there are $\binom{6}{2}$ possible pairings that will provide an $O(ITR_{\alpha/X})$. However, since only four items from Category A were recalled, there are $\binom{4}{2}$ possible usable pairings for Category A. Similarly, there are $\binom{2}{2}$ for B and $\binom{3}{2}$ for Category C. These combinations yield the number of usable units of Size 2 within each category. Equation 1 can now be written:

$$E(ITR_{B/2}) = \frac{(N-X+1)! (2) \binom{M_i}{2}}{N!} \quad (6)$$

where M_i equals the number of items recalled from Category i . This equation will provide the number of expected bidirectional pairwise ITRs within a specific category. To obtain $E(ITR_{B/2})$ for the entire list, Eq. 6 must be summed over all categories:

$$E(ITR_{B/2}) = \sum_{i=1}^C \frac{(N-X+1)! (2) \binom{M_i}{2}}{N!} \quad (7)$$

where C equals the number of categories recalled on Trial K. Since $X = 2$

$$E(ITR_{B/2}) = \sum_{i=1}^C \frac{(N-1)! (2) \binom{M_i}{2}}{(N)! (2)! (M_i-2)!} \quad (7a)$$

$$= \frac{1}{N} \sum_{i=1}^C M_i(M_i-1) \quad (7b)$$

$$= \frac{\sum_{i=1}^C M_i^2}{N} - \frac{\sum_{i=1}^C M_i}{N} \quad (7c)$$

$$= \frac{\sum_{i=1}^C M_i^2}{N} - 1 \quad (7d)$$

Equation 7d is the same as the Bousfield and Bousfield (1966) equation for computing expected values of clustering. Thus, category clustering can be interpreted as a special case of bidirectional pairwise subjective organization where the usable subjective organization units are the E-defined relationships within the list. The general equation for computing $E(ITR_{\alpha/X})$ can be appropriately modified to demonstrate this relationship.

One frequent criticism of E-defined clustering is the inability to differentiate the E units from the S units (Tulving, 1968). It is possible,

however, to compare clustering analyses with subjective organization analyses of the same free recall data using the techniques described in this paper. In this way, higher order subjective organization units can be determined and related to the E-defined structure of the list. In addition, it is important to determine if the organization within the E units is variable or unidirectional and if it involves subunits reflecting a hierarchical organization. The latter questions can only be answered by applying the type of subjective organization analysis described under Case 1. The use of observed ITR values (or their transformation into one of the four subjective organization measures previously presented) for different unit sizes, the frequency table, and the unidirectional-unordered ratio will provide the data necessary to answer these questions. With the subjective organization analysis of higher order units, categories can be dealt with as unordered higher order units and the transitional relationships between categories can be examined. By combining normal clustering data with subjective organization analyses, a more unified description of the relationships within E-structured lists is obtained. It is also possible to more directly relate cuing variables to their ability to influence individual S organization.

SUMMARY

A general method for obtaining observed values for higher order subjective organization units has been described. The equation for computing the corresponding chance-expected values has also been provided. The general applicability of both these procedures has been demonstrated under four possible cases in which the data can be viewed in slightly different formats. In addition, several applied formulae for the use of observed and expected ITR values in subjective organization measures have been presented along with their intercorrelation. Finally, the relationship of clustering as a special case of subjective organization has been demonstrated and the general usefulness of subjective organization analysis of higher order units within E-defined lists has been explained. The three techniques described in Case 1 for assessing units of organization within free recall data make it possible to obtain complete profiles of individual S organization, as well as differences between and within Ss in organization across free recall trials. It should be noted that the measurement of subjective organization according to different unit sizes and ordering

criteria has its most efficient application when both variables are treated as repeated measures within the normal experimental treatments. The repeated-measures type of statistical analysis yields the greatest amount of information about the relationship of organizational variables and treatment variables, since all unit sizes are represented and differences between treatment variables with respect to the amount of organization are reflected by pooled measures across all unit sizes and/or across all ordering criteria. In addition, the interactions of treatment variables with either or both unit size and ordering criteria become a particularly meaningful indication of different patterns of organization as a function of different values of the treatment variable.

REFERENCES

- BOUSFIELD, A. K., & BOUSFIELD, W. A. Measurement of clustering and of sequential constancies in repeated free recall. *Psychological Reports*, 1966, 19, 935-942.
- FAGAN, J. F. Measuring verbal recall. II: The ITR score expressed as a ratio. *Psychonomic Science*, 1968, 11, 205.
- GORFEIN, D. S., BLAIR, C., & ROWLAND, C. The generality of free-recall: I. Subjective organization as an ability factor. *Psychonomic Science*, 1968, 11, 279-280.
- HUDSON, R. L., & DUNN, J. E. A major modification of the Bousfield (1966) measure of category clustering. *Behavior Research Methods & Instrumentation*, 1969, 1, 110-111.
- MANDLER, G. Organization and memory. In K. W. Spence and J. T. Spence (Eds.), *The psychology of learning and motivation*. New York: Academic Press, 1967.
- POSTMAN, L. A pragmatic view of organization theory. Paper presented at University of Pittsburgh conference on organization and memory, March 1971.
- PUFF, C. R., & HYSON, S. P. An empirical comparison of two measures of intertrial organization in free recall. *Psychonomic Science*, 1967, 9, 329-330.
- ROENKER, D. L., THOMPSON, C. P., & BROWN, S. C. A comparison of measures for the estimation of clustering in free recall. *Psychological Bulletin*, in press.
- TULVING, E. Subjective organization in free recall of "unrelated" words. *Psychological Review*, 1962, 69, 344-354.
- TULVING, E. Theoretical issues in free recall. In T. R. Dixon and D. L. Horton (Eds.), *Verbal behavior and general behavior theory*. Englewood Cliffs, N.J.: Prentice-Hall, 1968.

NOTES

1. Equation 1 is composed of three parts, each derived on the basis of combinatorial chance computations. The first part of the equation, $(N-X+1)!/N!$, gives the proportion of the total possible sequences ($N!$) that can have one unidirectional ITR of a unit of Size X . Only one possible sequence of X items will yield a unidirectional ITR (assuming that all X items are recalled on both trials), leaving $N-X$ items with which this one sequence can be combined to produce an ITR. Considering this one Size X unit as one additional "item" gives $(N-X+1)!$ "items" and $(N-X+1)!$ possible sequences that will produce a unidirectional ITR of a unit of Size X .

The second part (A) of Eq. 1 reflects the

ordering criterion chosen, equaling 1 for unidirectional, 2 for bidirectional, and $X!$ for unordered ITR criterion. Thus the value of A represents the number of possible sequences within the unit of Size X that can be combined with the $N - X$ remaining items to yield an observed ITR, depending upon the criterion chosen.

The third part $(M - X + 1 - R)$ of Eq. 1 gives the number of units of Size X on Trial t that also are found on Trial $t + 1$, eliminating from consideration all cases where one or more items are recalled on t but not $t + 1$. Thus the product of the first two parts of Eq. 1 represents the expected

value for one unit of Size X , while the third part $(M - X + 1 - R)$ gives the total possible number of such units.

2. The expected values derived from Eq. 1 differ from those obtained from the Bousfield & Bousfield (1966) equation (and the revision of that equation by Gorfein, Blair, & Rowland, 1968, for bidirectional pairs). This difference in expected values is due to a mathematical averaging problem in the latter two equations. These equations treat a nonrecalled item (one recalled on t but not on $t + 1$) as only eliminating one pair from the analysis, and the value

obtained under these formulae is the average expected value for the cases where one or two pairs are eliminated by the failure to recall an item on $t + 1$. Therefore, the average expected value that is derived is not the exact value for the particular recall sequence being examined. This problem is more serious when several items are not recalled on $t + 1$ since the average expected value deviates more significantly from the actual expected value. Equation 5, however, does not have the problem since the expected value is appropriate to the particular recall sequence under examination.