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ABBREVIATIONS:

IMPROVING OPERATOR PERFORMANCE ON BATTLEFIELD AUTOMATED SYSTEMS

S. L. Ehrenreich and Theodora A. Porcu

HUMAN FACTORS TECHNICAL AREA

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One way to improve performance on abbreviations is to inform operators of the rules used to generate the abbreviations. This was tested in a series of rating, encoding and decoding experiments which compared the benefits of truncation versus contraction and fixed versus variable length abbreviations. In addition, the advisability of representing common suffixes (ING, ED, S) in abbreviations was tested along with a system for dealing with the problem of a simple rule generating the same abbreviation for more than one word. Based upon the results of these experiments, guidelines for generating abbreviations are presented.

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IMPROVING OPERATOR PERFORMANCE ON

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Human Factors in Training and
Operational Effectiveness

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FOREWORD

The Human Factors Technical Area is concerned with improving man/machine systems to acquire, transmit, process, disseminate, and utilize information from the increasingly complex battlefield. The research is focused on the interface problems and interactions within command and control centers and is concerned with such areas as user-oriented systems, software development, information management, staff operations and procedures, decision support, and systems integration and utilization.

One area of special research interest involves the design and evaluation of procedures to increase efficiency and accuracy of user-computer interactions. Advances in user-approachable systems would reduce errors, increase input rates, and provide for well-structured outputs to help realize the potential benefits of automation for command and control applications. The present research evaluated the potential benefit of generating abbreviations in a systematic manner and informing operators about the system. It is part of a continuing effort to provide the command staff with efficient vocabularies, message structures, and "natural" language elements for interacting with battlefield automated systems. Such research provides techniques and methods which can be incorporated into plans for Army-wide automated systems.

As a result of this research project, guidelines for improved "user-oriented" abbreviations will be available to the designers of battlefield automated systems. This will improve the performance of the system and eliminate a simple but potent source of operator frustration and system error. Together with other human factors projects designed to improve the operator-computer interface, the working environment for the soldier/operator will be tremendously improved.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

ABBREVIATIONS: IMPROVING OPERATOR PERFORMANCE ON BATTLEFIELD AUTOMATED SYSTEMS

BRIEF

Requirements:

To improve the design of abbreviations so that they are easy to remember and to use. Poor abbreviation performance can usually be attributed to the absence of a systematic relationship between words and their abbreviations. This forces people to rely upon rote memory in order to perform the task. That is, they have to learn every abbreviation as well as its association to a word. But if the abbreviations are generated by a simple rule which people understand, then the memory load is greatly reduced.

Procedure:

Three experiments were performed to investigate: (1) people's subjective rating of abbreviations; (2) their ability to encode words; and (3) their ability to decode abbreviations. In the last two experiments, participants were told the rule used to generate the abbreviations.

Each experiment considered four variables: abbreviation technique (truncation or contraction), abbreviation length (fixed or variable), the effect of incorporating endings (ING, ED, and S) into abbreviations, and the effect of intermixing abbreviations which were generated by an abbreviation rule with those which were not (deviants).

Findings:

Rating Experiment. Subjective ratings of abbreviations found contraction abbreviations to be slightly preferred over truncation abbreviations. On the other hand, there was no preference as to abbreviation length. Also, participants had no preference regarding whether or not an ending was incorporated into an abbreviation. As for abbreviations formed by a rule, they were rated higher than abbreviations generated in an unsystematic manner.

Encoding Experiment. When participants knew the abbreviation rules, truncation abbreviations were easier to produce than contraction abbreviations. In addition, it did not matter if the abbreviations were fixed or variable in length. But performance was poorer when endings had to be incorporated into abbreviations. As for terms whose abbreviations were deviant, their presence did not affect the encoding of terms which followed a rule. However, terms having deviant abbreviations were marked with an asterisk. Finally, the encoding of terms whose abbreviations followed a rule was superior to the encoding of terms whose abbreviations did not.

Decoding Experiment. When participants knew the abbreviation rules, there were no major differences in the ability to decode abbreviations generated by the truncation and contraction techniques. Truncation, however, was superior in the presence of abbreviations which did not follow a rule. Also, the spelling of a word decoded from a truncation abbreviation was more likely to be correct than one decoded from a contraction abbreviation. As for abbreviation length, variable length abbreviations were decoded more often than fixed length ones but the former were also longer and that probably accounts for the difference. With regard to the method used for incorporating endings into abbreviations, it did result in making those endings easier to decode. Finally, rule generated abbreviations were decoded more often than were deviant abbreviations.

Utilization of Findings:

These experiments are the last in a series of experiments designed to determine what are good abbreviations for use on battlefield automated systems. As a result of this series of experiments, a final report is being prepared to present system designers with recommended techniques for generating abbreviations. However, an interim set of guidelines is presented at the end of this report.

ABBREVIATIONS: IMPROVING OPERATOR PERFORMANCE ON BATTLEFIELD AUTOMATED SYSTEMS

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ABBREVIATIONS: IMPROVING OPERATOR PERFORMANCE ON BATTLEFIELD AUTOMATED SYSTEMS

INTRODUCTION

Abbreviations are universally employed to expedite data entry and reduce the space (field) occupied by a message. However, when abbreviations are hard to remember, work slows, errors increase, and operators become frustrated. Although these problems are undesirable under any circumstances, poor abbreviations can be more than an inconvenience in battlefield automated systems. Figure 1 shows a screen display proposed for the Tactical Operating System (TOS), a prototype command and control system of the 1960's and 1970's. As is readily apparent, an operator could neither enter nor extract information from the TOS data base without a good grasp of the abbreviations used on the system. And given that the operator of such a battlefield automated system might be under fire, on double shift, or a recent replacement, the probability is high that he will fail to remember some of the abbreviations. (More discussion of data entry on battlefield automated systems can be found in Alderman, Ehrenreich, and Bindewald, 1980).

This report represents part of a research program undertaken to discover how abbreviations should be constructed. The remainder of the program is presented in Moses and Potash (1979) and Moses, Mendez, and Ehrenreich (in preparation). Together, the research presented in these reports are the basis for developing guidelines for better operator-oriented abbreviations. Some guidelines appear in this report, but a last report (Ehrenreich, in preparation) will present the information in a form suitable for direct application by Army system designers.

BACKGROUND

All abbreviation techniques are not equally effective and a number of factors must be weighed in selecting among them. If abbreviations are used primarily to facilitate data entry, the user/operator needs only to encode words (i.e., convert them into their abbreviations) prior to typing them. But, if abbreviations are used to reduce message space, then operators must decode the abbreviations (i.e., translate them into words) to understand the message. Abbreviations that are easy to decode may not be easy to encode.

Another factor which may influence the choice of an abbreviation technique is the number of words which are to be abbreviated. For example, command languages (languages used to execute a program conveniently, e.g., job control languages, text editors) typically have small vocabularies. On the other hand, query languages (Ehrenreich, 1980) and

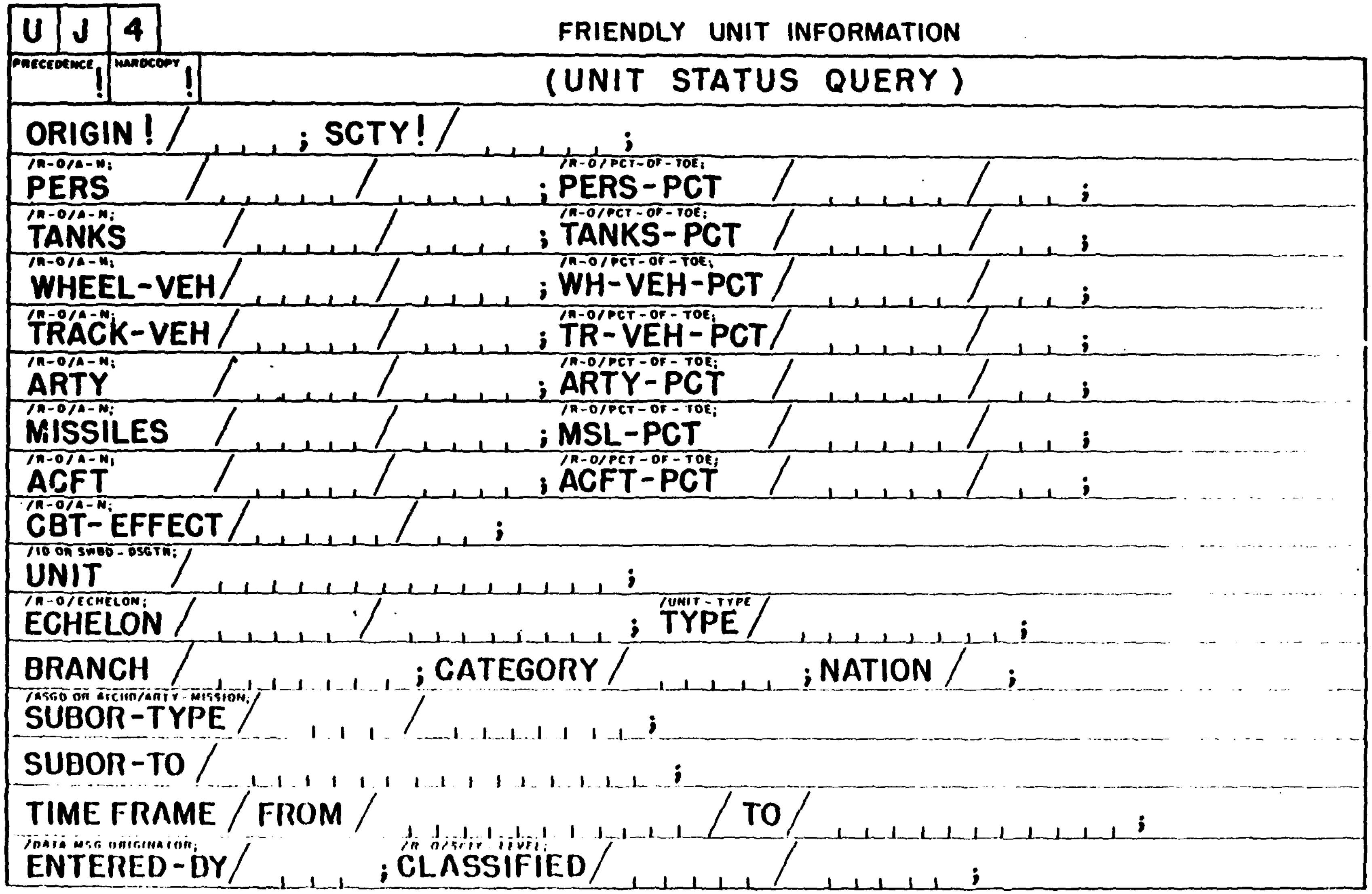

Figure 1. Sample display showing some of the abbreviations used on the TOS system *(taken from Baker, J. D., Mace, D. J., and McKendry, J. M. 1969. The transform operation in TOS: Assessment of the human component. Alexandria, VA: US Army Behavioral Science Research Laboratory Technical Research Note 212 (NTIS No. AD A697 716) August 1969).*

fill-in-the-blank (i.e., form-filling) dialogues may have over a hundred words in their vocabularies. An abbreviation technique that is suitable for a small vocabulary may not be suitable when the vocabulary is large. The technique of "minimum-to-distinguish" (also called "command completion" and "autocompletion") is an example.

Under the system of minimum-to-distinguish, an operator enters only the first few letters of a word. But enough letters must be entered to make the abbreviation unique. For vocabularies containing ten words, the first one or two letters of a word will usually suffice. But if a vocabulary contains a hundred words, then the number of initial letters that are needed will vary greatly from one word to another. Thus, minimum-to-distinguish requires that operators learn how many letters are needed to abbreviate each word.

Still other factors which must be considered in choosing an abbreviation technique are operator training, experience, and frequency of interaction (i.e., how often the operator uses the system and its abbreviations). Most any reasonable abbreviation technique will suffice for experienced operators who are constantly working with the system. But when operator turnover is frequent as is true for military systems or if the system is designed to support non-dedicated users, the shortest abbreviations might not be the best.

Finally, speed-accuracy and space-accuracy trade-offs should be considered. For instance, the longer an abbreviation is (and thus the more space it occupies), the greater the likelihood that it will be interpreted correctly. Likewise, the more letters that an operator enters when using the minimum-to-distinguish technique, the greater the likelihood that the abbreviation will be unique and therefore acceptable. However, this increase in accuracy occurs at a cost in the number of key strokes and the amount of space occupied on the display.

There are numerous techniques used to generate user-oriented abbreviations. These include techniques for producing abbreviations that are phonetic approximations of the original words (Schneider, Hirsh-Pasek, and Nudelman, 1981) and techniques for producing "natural" abbreviations (Ackroff and Streeter, 1981; Streeter, Ackroff, and Taylor, 1980). The latter refers to abbreviations which are similar to the ones people create for themselves. Still another abbreviation technique can be found in McBride, Lambert, and Lane (1981). Their abbreviation algorithm selectively deletes the less "important" letters in a word.

The two most common methods for creating abbreviations are truncation and contraction (Hodge and Pennington, 1973). The abbreviation technique of truncation involves retaining the first few letters of a word and deleting the remainder. Moreover, the number of letters that are retained may either be constant (fixed length abbreviations), or it can vary depending upon the length of the original word (variable length abbreviations).

In contraction abbreviations, some specified set of letters (usually vowels) are deleted starting at the right end of a word and progressing to the left. However, the first letter of the word is never deleted. (For Hodge and Perrington, 1973, the last letter of the word is also always retained.) Again, these abbreviations can be either fixed or variable in length. The reason for deleting letters in right to left order is that for some words, deleting all of the vowels might result in too short an abbreviation. An example is the word CREASE, whose contraction (vowels removed), fixed length (four letters) abbreviation is CRES. Examples of abbreviations formed by the truncation and contraction techniques are shown in Table 1.

A set of experiments by Moses, Mendez, and Ehrenreich (1980) compared performance on abbreviations generated by some of these techniques. In these experiments, participants studied 90 word-abbreviation pairs (e.g., CAPTAIN-CPT), seeing each pair either one, three, or six times (repeated items were not blocked within the list). Three techniques were used to generate the abbreviations: truncation-variable length, contraction-variable length (vowels and H, W, Y were removed), and abbreviations proposed for Army use (these abbreviations followed no systematic pattern). For each participant, one third of the abbreviations were formed by each technique and the abbreviations from the three techniques were randomly placed within the stimulus lists. Thus, participants could not discern an abbreviation rule when performing the task. The stimulus pairs were individually projected onto a screen and each time that they appeared, participants copied them using pencil and paper.

Following the study phase, participants were divided into groups. One group was tested on its ability to encode all 90 words (produce the abbreviation when given the word), while the other group was tested on its ability to decode all 90 abbreviations (recall the word when given the abbreviation).

For encoding, there was no significant difference between Army abbreviations and truncation abbreviations, and both were significantly superior to contraction abbreviations. Performance on the Army and truncation abbreviations ranged from 31 percent correct for stimuli seen only once during the study phase to 62 percent correct for stimuli seen six times. Decoding performance, however, showed no significant differences among the three abbreviation techniques. Abbreviations which had been seen only once during the study phase were correctly decoded 70 percent of the time and performance increased to 88 percent correct for stimuli that had been seen six times.

Poor encoding performance, as in the Moses et al. experiments, can be attributed to the absence of a systematic relationship between words and their abbreviations. This forces participants to rely upon rote memory

Table 1

EXAMPLES OF ABBREVIATIONS WHICH VARY ACCORDING TO TECHNIQUE, LENGTH, AND INCORPORATION OF ENDINGS

		ENDINGS				
		Not Incorporated		Incorporated[a]		
		ABBREVIATION LENGTH		ABBREVIATION LENGTH		
		Fixed	Variable[b]	Fixed	Variable[b]	Original Term
ABBREVIATION TECHNIQUE	Truncation	MILI	MILI	——[c]	——	MILITARY
		VEGE	VEGET	——	——	VEGETATION
		ARTI	ARTIL	——	——	ARTILLERY
		ATTA	ATTAC	ATTAG	ATTACG	ATTACKING
		FORW	FORW	FORWS	FORWS	FORWARDS
	Contraction	MLTR	MLTR	——	——	MILITARY
		VGTT	VGTTN	——	——	VEGETATION
		ARTL	ARTLL	——	——	ARTILLERY
		ATTC	ATTCK	ATTCG	ATTCKG	ATTACKING
		FRWR	FRWR	FRWRS	FRWRS	FORWARDS

[a]Endings are incorporated into abbreviations by appending a G, D, or S to the abbreviations of words having ING, ED, or S as their suffix.

[b]The variable length rule is:

If length of word is:	then length of abbreviation is:
5 letters or less	do not abbreviate
6–8 letters	4 letters
9 letters	5 letters

In computing the length of a word, all letters are counted, including suffixes.

[c]Where dashes (---) appear, the abbreviation is the same as when endings are not incorporated.

to perform the task. That is, they have to learn every abbreviation as well as its association to a word. But if the abbreviations were generated by a simple rule which the participants understood, then the memory load would be greatly reduced. Even for decoding, knowledge of the abbreviation rule might help the participants in recalling the correct word.

If knowing a rule helps participants to process abbreviations, then the simpler the rule, the greater the benefit. But the simpler the rule, the greater the likelihood that it will produce the same abbreviation for more than one word. For example, when using the truncation fixed-length rule to abbreviate TRANSLATE and TRANSPORT, the resulting abbreviation, TRAN, is identical for both items. To circumvent this problem, some abbreviations will have to deviate from the rule (i.e., deviant abbreviations).

When deviant abbreviations occur, rote memorization is reintroduced into the task. Even if a simple secondary rule exists for generating the deviant abbreviations, users have to learn which words are abbreviated using the secondary rule. By default, all of the other abbreviations are formed by the primary rule. Although the operator is still required to do some learning, the amount of learning is small.

To determine the value of teaching operators abbreviation rules, three experiments were performed (a pilot study is reported in Moses et al., 1980). These experiments tested different rules to determine their ease of use. In addition, the experiments examined the problem of deviant abbreviations. Finally, a method for representing common word suffixes (i.e., ING, ED, and S) was created and tested. The experiments did not, however, investigate acronyms, e.g., "radar", "snafu," or the practice of stringing together the initial letters of different words, e.g., "USA", "IBM".

EXPERIMENTAL APPROACH

Three experiments were performed to investigate (a) people's subjective ratings of abbreviations, (b) their ability to encode words, and (c) their ability to decode abbreviations.

Each experiment considered four variables: abbreviation technique (truncation or contraction), abbreviation length (fixed or variable), the effect of incorporating endings (ING, ED, and S) into abbreviations, and the effect of intermixing abbreviations which were generated by an abbreviation rule with those which were not (deviants). The same design was used for each experiment and is shown in Figure 2.

Endings were incorporated into abbreviations by appending either a G, D, or S, to those words having ING, ED, or S as a suffix. For abbreviations formed by the truncation technique, the first few letters of the word were retained as previously described, but then the appropriate suffix letter

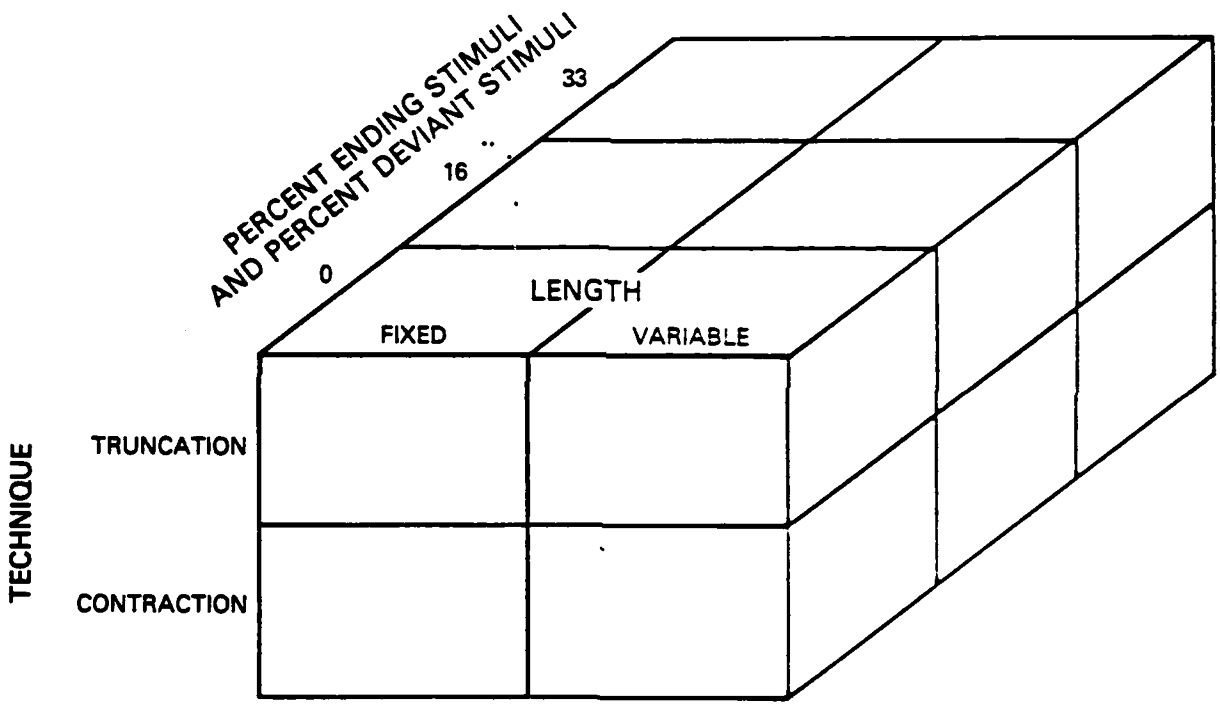

Figure 2. Design used for the rating, encoding and decoding experiments.

was added. A similar rule formed abbreviations by the contraction technique. This rule made abbreviations of words with the appropriate suffixes one letter longer than abbreviations of equal length words without the suffixes (see Table 1). Either 0, 16, or 33 percent of the abbreviations in each condition incorporated endings.

Deviant abbreviations did not obey any of the four rules, i.e., truncation-fixed length (T-F), truncation-variable length (T-V), contraction-fixed length (C-F), or contraction-variable length (C-V). Overall, these deviant abbreviations were unsystematic though "reasonable." Deviant abbreviations never incorporated endings, and abbreviations that incorporated endings were never deviant. Whatever percentage of abbreviations in a list incorporated endings, then an equal percentage of other abbreviations were deviant (e.g., if 33% of the stimuli incorporated endings, then another 33% were deviant). Although the "endings" variable and the "deviation" variable always co-occurred, they are quite distinctive. Thus, significant effects found in the data could always be reasonably attributed to either one or the other.

Each participant performed in only one of the 12 conditions and remained in that condition throughout the three experiments (rating, encoding, and decoding). Before performing the encoding and decoding tasks, but not the rating task, participants were informed of the rules by which the abbreviations were formed.

RATING EXPERIMENT

In this experiment, participants were shown word-abbreviation pairs and asked to rate the "goodness" of the abbreviations. The abbreviations were formed by either the T-F, T-V, C-F or C-V method. Participants were not told about the abbreviation method. In addition, some of the abbreviations incorporated endings and some were deviant.

Method

Participants. In response to a request for participants, 144 military, enlisted personnel were assigned to the experiment. They came from varied backgrounds and occupational specialties. (Immediately prior to this experiment, the participants performed in a similar set of experiments where they rated, encoded, and decoded stimuli without knowing the rules used to generate the abbreviations. This experiment is not reported here.)

Materials. A set of terms (e.g., PENETRATE, NUCLEAR HAZARD) used on military command and control systems served as a source of stimuli for this experiment. To meet certain experimental requirements, some additional terms were added to this pool. All terms consisted of either one or two words, each word being five letters or longer in length.

From the pool of terms, 16 lists were constructed; the purpose for having more lists than conditions is explained below. Each list consisted of 72 term-abbreviation pairs (e.g., PENETRATE - PENE). When a term consisted of two words, each word was abbreviated individually. The abbreviation for the term was then formed by joining the abbreviations for the two words with a space between them (e.g., CIVILIAN BRIDGE - CIVI BRID).

Four lists were created by using one of the abbreviation methods (T-F, T-V, C-F or C-V) to form all of the abbreviations in a list. These lists were labeled "(0)" since they contained no deviant abbreviations and no abbreviations which incorporated endings (although some of the words did end in ING, ED and S).

Another four lists, labeled "(16A)", were created out of the four (0) lists. This was done by having endings incorporated into 16 percent of the abbreviations and by making another 16 percent of the abbreviations deviant. To assure the representativeness of the 16 percent condition, a second set of four lists, labeled "(16B)", was created. These lists were identical to the (16A) lists except that the terms having endings and the terms with deviant abbreviations were different from those in the (16A) lists.

Finally, out of the four (0) lists, four lists labeled "(33)" were constructed. In these lists, 33 percent of the abbreviations were deviant and another 33 percent incorporated endings. In both the 16 and 33 percent conditions, an asterisk always appeared alongside each word-abbreviation pair containing a deviant abbreviation (e.g., *DISPLACE-DISL). Examples of the four lists (i.e., 0, 16A, 16B, and 33) formed by using the T-F abbreviation method are shown in Table 2. Lists formed by the T-V, C-F, and C-V methods were similarly constructed.

The 72-term-abbreviation pairs were typed on six pages. Alongside each pair was a rating scale ranging from one to six. The digit one was labeled "poor" and the digit six was labeled "excellent."

Procedure. Participants were randomly assigned to one of 16 groups, with the restriction that 12 participants were assigned to each of the four (0) and four (33) lists, while 6 participants were assigned to each of the four (16A) and four (16B) groups.

Participants were instructed to circle a number on the rating scale to indicate how well each abbreviation represented its corresponding term. In addition, they were told to remember the term-abbreviation pairs because they would be tested on them later. Participants were not informed of the rules used to generate the abbreviations in their lists and were given about 20 minutes to perform the task.

Results and Discussion

Within each list, there were three categories of stimuli: terms where the abbreviations followed a simple rule ("simple" stimuli), i.e., T-F, T-V, C-F or C-V; terms having ING, ED or S as a suffix ("ending" stimuli);

Table 2

Sample sections of lists T-F(0), T-F(16A), T-F(16B), and T-F(33)

LIST T-F(0)	LIST T-F(16A)	LIST T-F(16B)	LIST T-F(33)
ARTILLERY-ARTI	ARTILLERY-ARTI	ARTILLERY-ARTI	ARTILLERY-ARTI
CIRCLE-CIRC	CIRCLE-CIRC	CIRCLE-CIRC	*BATTLE-BATL
REPEATED-REPE	POSITIONED-POSID	SPRAYED-SPRAD	SPRAYED-SPRAD
MILITARY PEOPLE-MILI PEOP	MILITARY PEOPLE-MILI PEOP	MILITARY PEOPLE-MILI PEOP	MILITARY PEOPLE-MILI PEOP
SCREEN-SCRE	*BATTLE-BATL	*ENVISION-ENVN	*ENVISION-ENVN
DETONATE-DETO	DETONATE-DETO	DETONATE-DETO	POSITIONED-POSID

and terms whose abbreviations deviated from the simple rules ("deviant" stimuli). Note that lists (0), (16A), (16B), and (33) each had ending stimuli although only the latter three lists incorporated the endings into the abbreviations. This is demonstrated in the third row of stimuli in Table 2.

Since lists (16A) and (16B) were similarly designed, the data from these two lists were pooled prior to the analyses for the three experiments. This is justified by the fact that eight of nine independent *t*-tests comparing performance between the lists showed no significant differences.

Figure 3 shows mean ratings broken down by stimulus categories: simple, ending, and deviant. Each category has three factors: abbreviation technique, abbreviation length, and percentage of abbreviations which incorporated endings and which deviated from the simple abbreviation rule (the same percentage for both). A three-factor analysis of variance was performed on each stimulus category.

Rule Generated Abbreviations. For abbreviations formed by a simple rule (simple stimuli), those formed by the contraction technique were rated slightly but significantly higher than those formed by the truncation technique (3.93 versus 3.56), $F(1,132)=5.57$, $p< .02$. However, ratings for simple stimuli were not affected by either the length of the abbreviations or the percentage of deviant abbreviations (or abbreviations with endings).[1]

Abbreviations Incorporating Endings. The mean rating for abbreviations that incorporated endings (ending stimuli) was higher with the contraction method than with the truncation method (3.92 versus 3.34), $F(1,88)=8.59$, $p< .01$. However, there was no significant difference due to abbreviation length and participants rated equally abbreviations that incorporated endings (conditions 16 and 33) and those that did not (condition 0).

Deviant Abbreviations. Abbreviations which deviated from the simple rule (deviant stimuli) were rated higher when they appeared in a list of contraction abbreviations as opposed to a list of truncation abbreviations (3.60 versus 3.04), $F(1,88)=8.09$, $p< .01$. This difference is probably an artifact. Since contraction abbreviations were rated higher than truncation abbreviations, this could have produced a bias towards higher ratings in the contraction lists. Abbreviation length and proportion of deviant abbreviations had no significant effect upon the ratings given deviant stimuli.

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[1] F ratios are not reported for main effects that were not statistically significant (i.e., $p> .05$). In addition, interactions are mentioned only if they were statistically significant. Complete ANOVA tables are reported in Appendices A, B, and C.

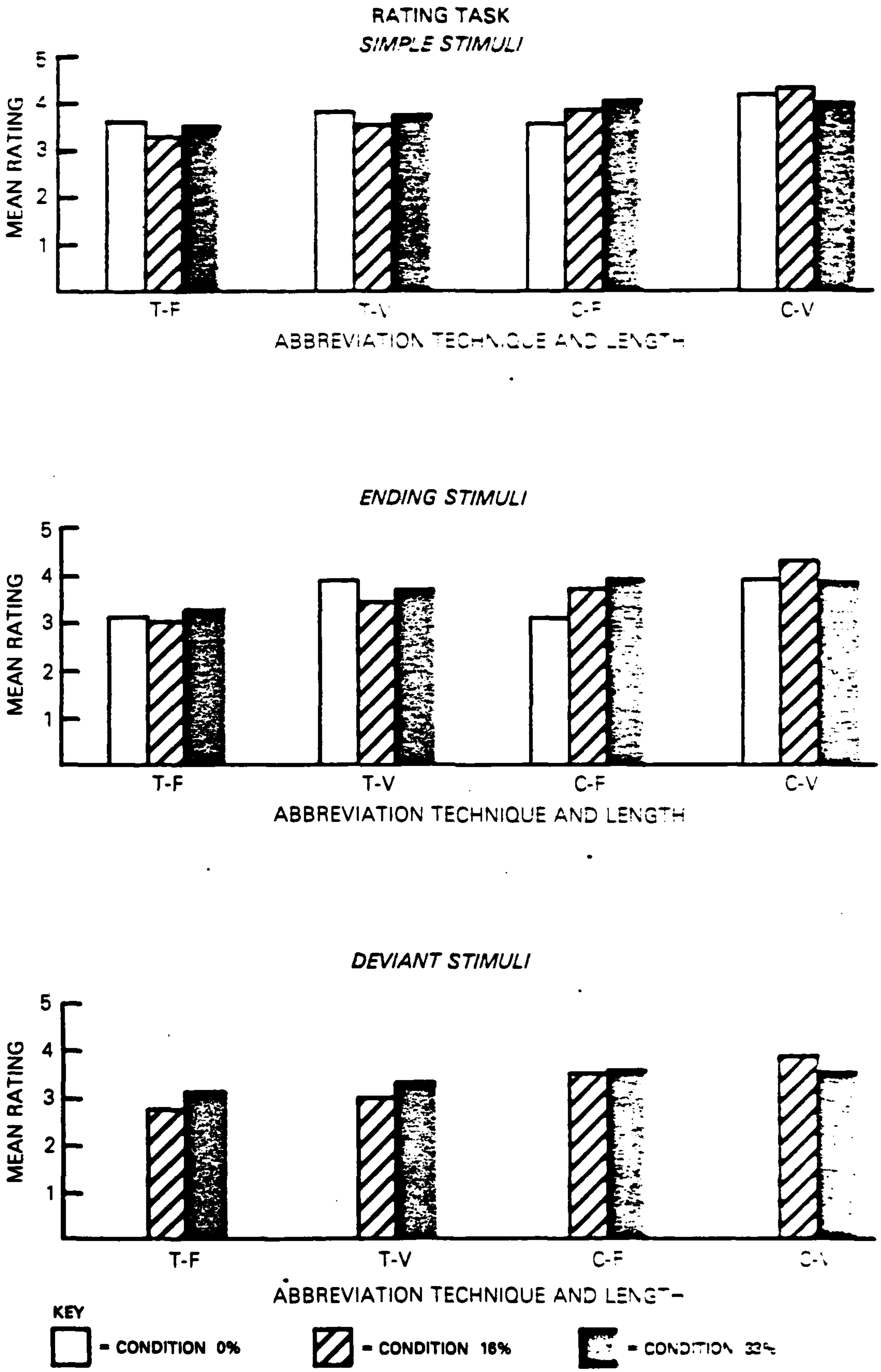

Figure 3. Mean rating of abbreviations by abbreviation technique, abbreviation length, and list condition (i.e., percentage of abbreviations that are deviant and that incorporate endings).

Rule Generated Versus Deviant Abbreviations. For each of the eight lists in conditions (16) and (33), deviant abbreviations were rated lower than rule generated abbreviations. Using a binomial distribution (i.e., sign test for matched pairs), the probability of this occurring by chance is $p = .008$, two-tailed test. Thus, within a list of abbreviations generated by a simple rule, abbreviations that deviate from that rule are not judged to be as "good".

Summary. Subjective ratings of abbreviations found contraction abbreviations to be slightly preferred over truncation abbreviations. On the other hand, there was no preference as to abbreviation length. Also, participants had no preference regarding whether or not an ending was incorporated into an abbreviation. As for abbreviations formed by a rule, they were rated higher than abbreviations generated in an unsystematic manner.

ENCODING EXPERIMENT

This experiment investigated the ability to encode words after learning the rules used to generate abbreviations. After having studied the word-abbreviation pairs during the rating experiment, participants were taught the relevant abbreviation rules. In addition, participants in the appropriate list conditions were taught how to incorporate endings into abbreviations and were told that some abbreviations were deviant.

Method

Participants. The participants in this experiment were the same as those in the rating experiment. Each participant served in the same condition, e.g., T-F(0), C-V (16A), as he or she had served previously.

Materials. From each of the lists used in the rating experiment, half of the terms (but none of the abbreviations) were selected. Included in these terms were half of those having abbreviations which incorporated endings and half of those having abbreviations that were deviant. Thus 16 new lists, each containing 36 terms, were created. Terms whose abbreviations were deviant had an asterisk before them (i.e., *DISPLACE), as had been the case in the rating experiment.

The 36 terms in a list were typed on four pages. Alongside each term was a space in which participants could write the corresponding abbreviation.

Procedure. Participants were given written instructions on how to generate abbreviations (e.g., "Generate abbreviations by retaining the first four letters of a word . . . ."). The instructions were unique to the participant's condition (T-F, T-V, C-F, or C-V). For participants in conditions (16) and (33), the instructions also described how endings were to be incorporated into abbreviations. In addition, these instructions mentioned that some of the terms had abbreviations which deviated from the simple rule and that each of these terms was marked with an asterisk. The participant was told that the correct abbreviations for these marked (i.e., deviant) terms were the ones seen previously in the rating experiment. To help them understand the instructions, participants were given practice terms to encode. After completing the practice, they were tested on their ability to encode 36 items. During the test, participants were allowed to refer to the written instructions describing how to generate abbreviations. Participants were given approximately 20 minutes to read the abbreviation rules, perform the practice trials, and complete the test.

Results and Discussion

The encoding task was analyzed in the same manner as the rating experiment.[2] Figure 4 shows the mean percentages of correctly encoded terms.

Rule Generated Abbreviations. For terms to be encoded using rules (simple stimuli), encoding performance was significantly better with the truncation technique than with the contraction technique (.87 vs .64), $F(1,132)=26.56$, $p< .001$. This can be attributed to the fact that truncation is a simpler rule than contraction. In contraction, the participants must distinguish vowels from consonants while in truncation, the participants need simply count off the first few letters. There were no significant differences due to abbreviation length or proportion of terms with deviant abbreviations. Although none of the two-way interactions were significant, there was a significant three-way interaction, $F(2,132)=3.69$, $p< .05$. The interpretation of such an interaction is unclear.

Abbreviations Incorporating Endings. When endings were incorporated into abbreviations, encoding performance was marginally better with truncation than with contraction (.62 vs .52), $F(1,88)=3.63$, $p< .10$. However, it was easier to ignore a word's ending (.72 correct in condition 0) than it was to incorporate it into an abbreviation (.57 correct in conditions 16 and 33), $F(2,132)=4.62$, $p< .02$. Finally, when encoding terms with endings, there was no significant difference due to abbreviation length.

Deviant Abbreviations. Analysis indicated that performance did not depend upon the proportion of deviant abbreviations in the list, or upon the length or technique used to abbreviate the other terms in the list. There was, however, a significant three-way interaction, $F(1,88)=7.05$, $p< .01$.

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[2] The encoding and the decoding experiments were analyzed using both raw scores and scores transformed by the arcsin transformation. For two interactions, an effect that was barely significant using the raw scores was not significant using the arcsin transformation. These two interactions are thus not reported. The statistics reported in the paper are based on the raw scores.

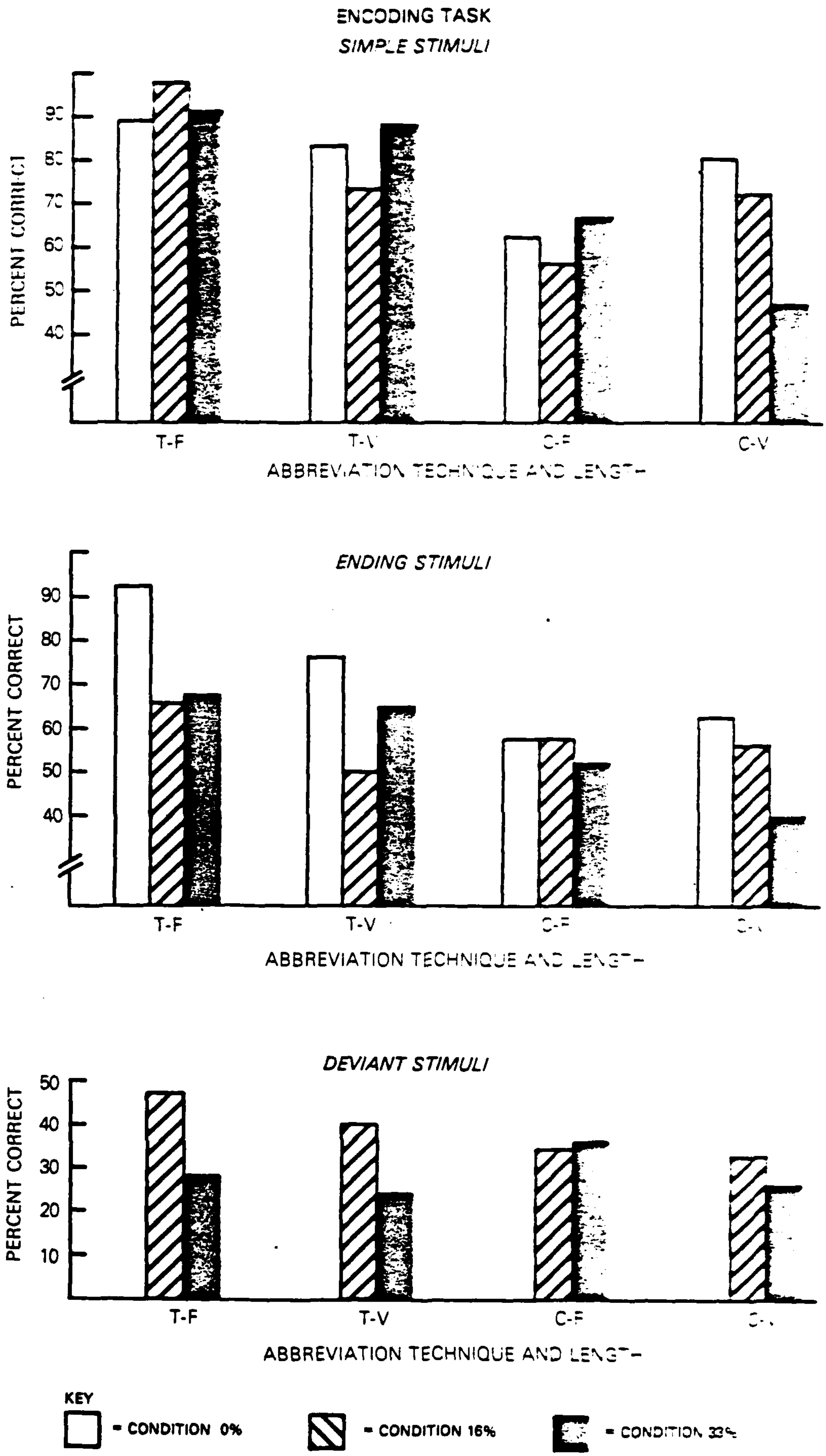

Figure 4. Mean encoding performance by abbreviation technique, abbreviation length, and list condition (i.e., percentage of abbreviations that are deviant and that incorporate endings).

Rule Generated Versus Deviant Abbreviations. For all of the eight lists in conditions (16) and (33), participants were better at encoding terms whose abbreviations followed a rule than in producing abbreviations that followed no rule. (This difference can be reasonably attributed to knowledge of the rule and not to orthographic or other differences between the two sets of abbreviations. See General Discussion.) Using the binomial distribution, the probability of this occurring by chance is $p = .008$, two-tailed test.

Summary. When participants knew the abbreviation rules, truncation abbreviations were easier to produce than contraction abbreviations. In addition, it did not matter if the abbreviations were fixed or variable in length. But performance was poorer when endings had to be incorporated into abbreviations. As for terms whose abbreviations were deviant, their presence did not affect the encoding of terms which followed a rule. However, terms having deviant abbreviations were marked with an asterisk. This will be discussed again later. Finally, the encoding of terms whose abbreviations followed a rule was superior to the encoding of terms whose abbreviations did not.

DECODING EXPERIMENT

The final experiment investigated the ability to decode abbreviations when the rules used to generate the abbreviations are known. Also examined was the performance on both deviant abbreviations and abbreviations which incorporated endings.

Method

Participants. The same participants performed in the decoding experiment as had performed in the prior two experiments. Each participant served in the same condition as he or she had served previously.

Materials. Each list used in the rating experiment had previously been split in half (see Encoding Experiment). The present experiment utilized the half lists not used for the encoding experiment. Only the abbreviations (and not the terms) from these half lists were used.

For each of the 16 conditions, a list of 36 abbreviations was formed. Each list contained the appropriate percentage of abbreviations which incorporated endings and the appropriate percentage of deviant abbreviations. Deviant abbreviations always appeared with an asterisk before them (e.g., *DISL). The items used in the decoding experiment were different from the items used in the encoding experiment. All items, though, had appeared in the rating experiment.

The 36 abbreviations for each list were typed on three pages. Alongside each abbreviation was a space for writing the term represented by the abbreviation.

Procedure. Participants were given approximately 15 minutes to decode the words. Participants retained the instruction sheets given to them in the encoding experiment, which described the rules for generating abbreviations.

Results and Discussion

Responses were scored in two ways. One method, strict scoring, considered a response correct only if it was identical to the word seen in the rating experiment. The second method, liberal scoring, considered a response correct even if it was misspelled or if it contained a different ending (e.g., ING, S, ED). As an example, consider the abbreviation PENE which had been paired with PENETRATE in the T-F condition during the rating task. If the participant's response to this stimulus was PENATRATES, the response was marked incorrect under strict scoring and correct under liberal scoring.

The decoding data were analyzed in the same manner as the data in the previous two experiments. Figures 5 and 6 show the mean percentage of abbreviations that were correctly decoded using liberal and strict scoring, respectively.

Rule Generated Abbreviations (Liberal Scoring). Using liberal scoring, truncation and contraction abbreviations were decoded equally well (.63 and .59, respectively). Additionally, the ability to correctly decode a rule generated abbreviation did not depend on how many deviant abbreviations appeared in the list. However, variable length abbreviations were slightly easier to decode than fixed length ones (.65 versus .57, respectively), $F(1,132)=8.21$, $p<.01$. This can be accounted for by the fact that variable length abbreviations had as many or more letters than corresponding fixed length abbreviations.

There was also a significant interaction between the rule used to generate abbreviations and the presence of deviant abbreviations, $F(2,132)=4.77$, $p<.01$. Performance on contraction abbreviations was superior to performance on truncation abbreviations when there were no deviant abbreviations in the list (.68 versus .62 correct for lists 0). But the situation reversed for lists containing deviant abbreviations (.52 versus .68 correct for lists 33). Thus, truncation appears to be a better abbreviation technique when deviant abbreviations are present.

Rule Generated Abbreviations (Strict Scoring). When performance on rule generated abbreviations was analyzed using strict scoring, all of the significant effects described above were again found. However, with strict scoring, there was a statistically significant effect due to abbreviation technique. Overall, abbreviations formed by truncation were easier to decode than abbreviations formed by contraction (.54 versus .48), $F(1,132)=4.53$, $p<.05$. This slight superiority of truncation appears to result from the fact that it is easier to correctly spell a word when given its first few letters as opposed to its first few consonants. When spelling, people may be more likely to err on a vowel than on a consonant as the former are less distinctive. Since truncation abbreviations contain vowels, words decoded from them would more often be spelled correctly.

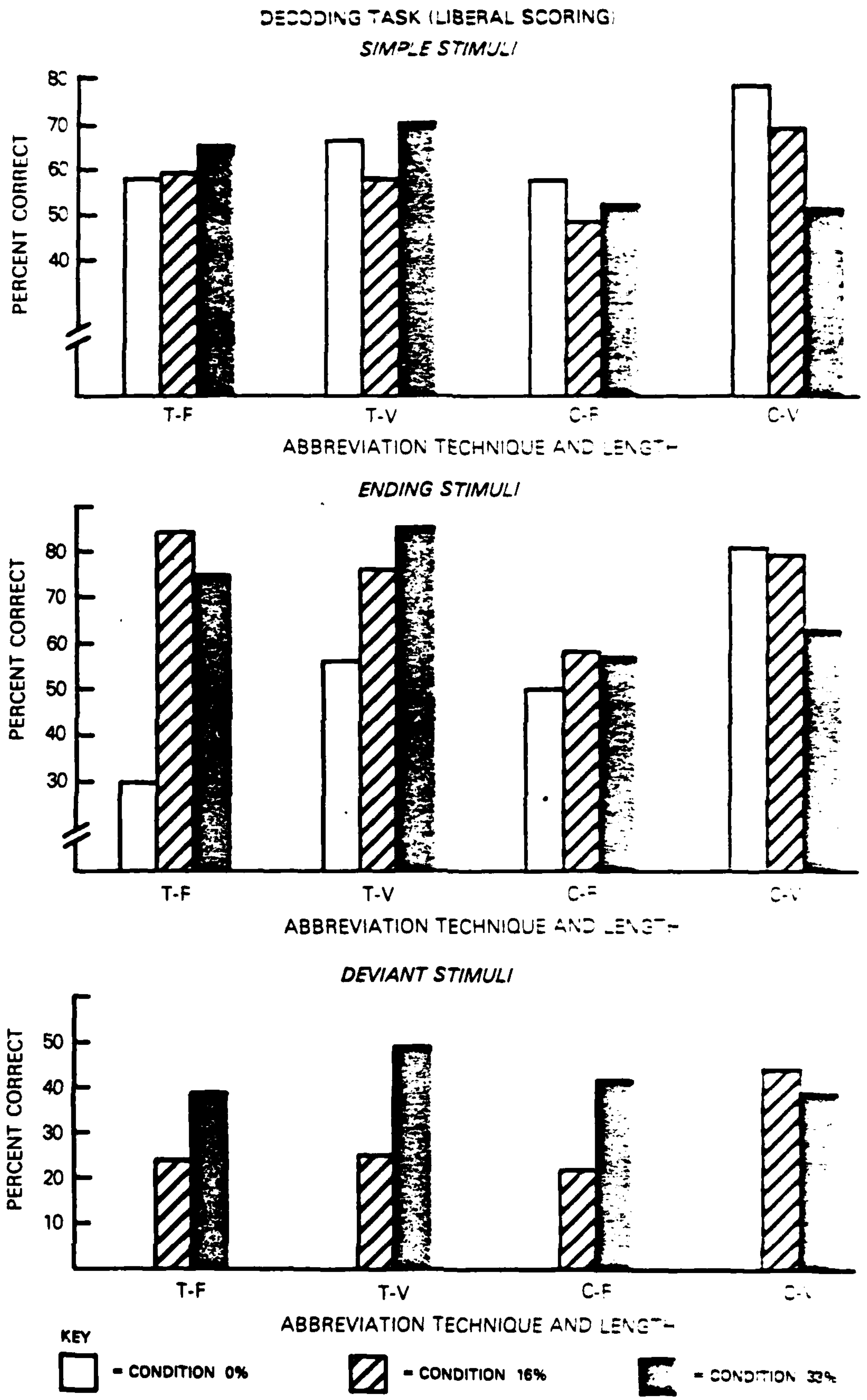

Figure 5. **Mean decoding performance (liberal scoring) by abbreviation technique, abbreviation length, and list condition (i.e., percentage of abbreviations that are deviant and that incorporate endings).**

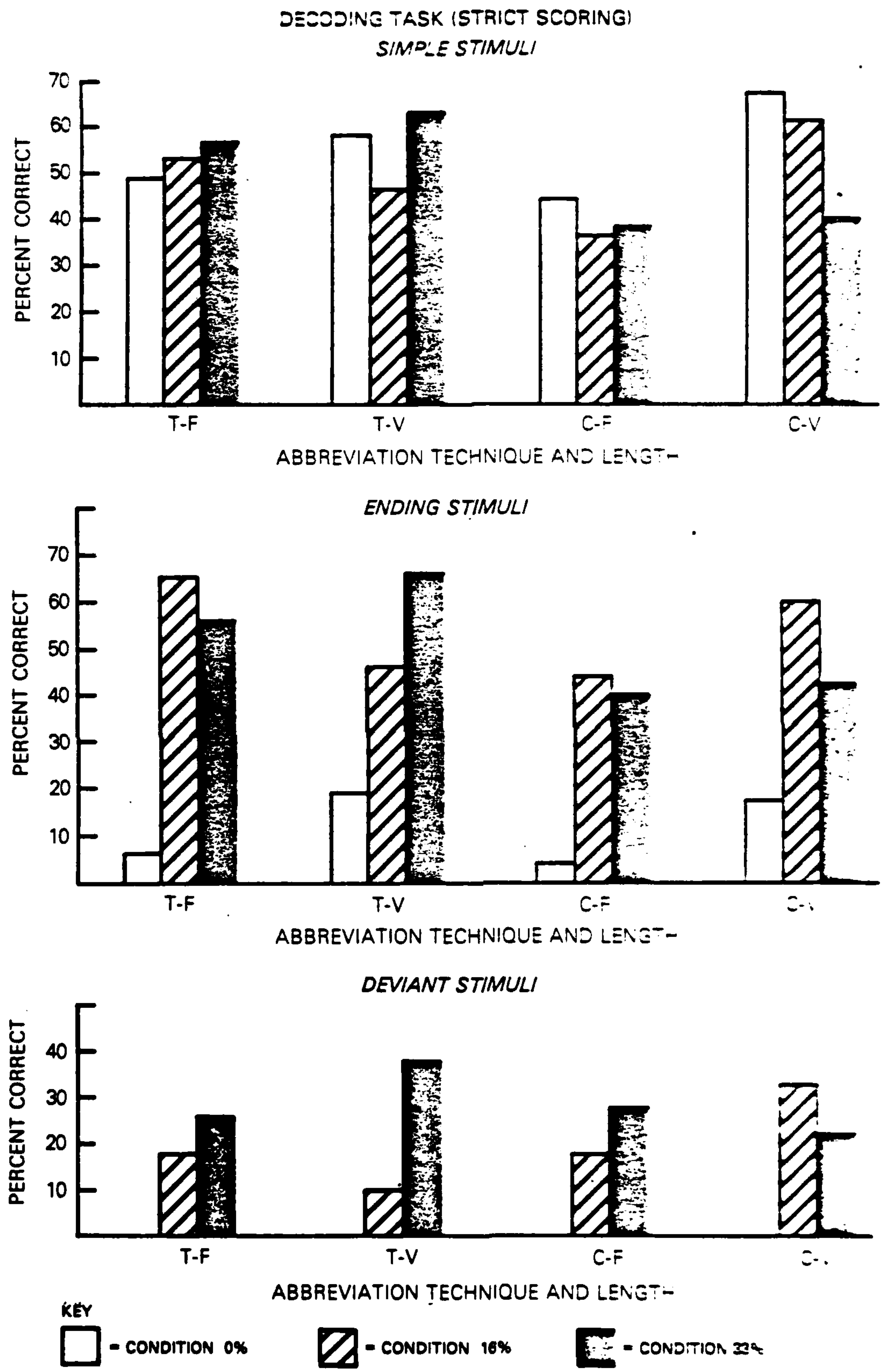

Figure 6. **Mean decoding performance (strict scoring) by abbreviation technique, abbreviation length, and list condition (i.e., percentage of abbreviations that are deviant and that incorporate endings).**

To probe this hypothesis, spelling errors from a small subset of the decoding data were examined. In the contraction conditions, there were six times as many errors involving vowels as consonants. The corresponding ratio was only one to one in the truncation conditions.

Relationship Between Decoding Performance and Rating Scores. In order to determine how well a participant's rating of a term-abbreviation pair correlated with his or her ability to decode the abbreviation, 2 x 2 contingency tables were created. A separate contingency table was constructed for each participant in condition (0) (thus only rule generated abbreviations were considered). One axis of the table divided decoding responses into correct and incorrect. The other axis divided ratings (taken from the rating experiment) into "high" and "low". A high rating was defined as above the mean rating given by that participant. For each abbreviation that a participant had to rate and decode, an entry was made in the contingency table. Contingency tables in which the marginal sum of any individual column or row was less than four were not examined, as the data were unsuitable for computing correlations.

Two correlations were computed for each participant: the phi coefficient and the tetrachoric coefficient. The latter coefficient has the advantage of being less sensitive to how a variable (i.e., high-low rating) is dichotomized. However, it also has a relatively high standard error (Guilford, 1950, p. 332-339). From the individual correlation coefficients, a median was computed for each list condition. This was done separately from strict and liberal scoring and with the phi and tetrachoric coefficients. Not one of the medians for any condition exceeded 0.4. Thus, a participant's rating of an abbreviation is not a good indicator of whether he or she will decode it correctly.

Abbreviations Incorporating Endings. The ability to decode abbreviations incorporating endings (ending stimuli) was analyzed using strict scoring only. The results show that truncation abbreviations are correctly decoded more often than contraction abbreviations (.58 versus .46), $F(1,88)=6.04$, $p< .02$. As discussed above, this is probably due to the spelling assistance provided by the presence of vowels in truncation abbreviations. The data also show that in decoding abbreviations that incorporate endings, participants are much more likely to correctly produce the ending of a word (.52 correct in conditions 16 and 33) than when decoding abbreviations that do not incorporate endings (.12 correct in condition 0), $F(2,132)=52.21$, $p< .001$. Thus, the system for incorporating endings in abbreviations is effective during decoding although it was detrimental during encoding. However, there was no significant effect due to abbreviation length.

Deviant Abbreviations (Liberal Scoring). Decoding performance on deviant abbreviations improved as the proportion of deviant abbreviations in the list increased, $F(1,88)=9.71$, $p< .01$. Thus, deviant abbreviations in lists (33) were correctly decoded 42 percent of the time while for lists (16), the score was 29 percent correct. The greater experience with processing deviant abbreviations in condition (33) probably accounts for this superiority in performance. There were no other significant effects.

Deviant Abbreviations (Strict Scoring). The effects reported for liberal scoring were also found for strict scoring. In addition, there was a significant interaction between the abbreviation technique used on the rule generated abbreviations in the list and the proportion of deviant abbreviations, $F(1,86)=5.55$, $p< .05$. In condition (16), deviant abbreviations within contraction lists were easier to decode than those within truncation lists. The opposite was true for condition (33). The interpretation of this interaction is unclear but it appears to be related to a similar interaction reported earlier for rule generated abbreviations.

Rule Generated Versus Deviant Abbreviations. For each of the eight lists in conditions (16) and (33), rule generated abbreviations were correctly decoded more often than were deviant abbreviations. This was true for both strict and liberal scoring. Using the binomial distribution, the probability of this occurring by chance is $p = .008$, two-tailed test. Thus, abbreviations formed by rules were easier to decode than abbreviations for which there were no rules.

Summary. When participants knew the abbreviation rules, there were no major differences in the ability to decode abbreviations generated by the truncation and contraction techniques. Truncation, however, was superior in the presence of abbreviations which did not follow a rule. Also, the spelling of a word decoded from a truncation abbreviation was more likely to be correct than one decoded from a contraction abbreviation. As for abbreviation length, variable length abbreviations were decoded more often than fixed length ones. But the former were also longer and that probably accounts for the difference. With regard to the method used for incorporating endings into abbreviations, it did result in making those endings easier to decode. Finally, rule generated abbreviations were decoded more often than were deviant abbreviations.

GENERAL DISCUSSION

Teaching Operators the Rules

These experiments studied abbreviation performance when participants knew the abbreviation rules. This can be contrasted to the Moses et al. (1980) experiments in which participants had no knowledge of the abbreviation rules. For encoding, the best performance that they found was 62 percent correct for truncation-variable length abbreviations after six exposures to the stimuli. In comparison, the present experiment found 81 percent correct with the same abbreviation technique and an even better 92 percent correct for truncation-fixed length abbreviations (Moses et al. did not test the latter technique). This result confirms that abbreviations formed by a simple rule are easier to encode when operators know the rule.

The advantage of knowing the rule can also be seen when comparing rule generated to nonsystematically generated (deviant) abbreviations. In the Moses et al. experiments, truncation-variable length abbreviations were no better than Army abbreviations, which are nonsystematic. The same two sets of abbreviations were tested in the present experiments where participants knew the rules. Here, the truncation-variable length abbreviations were easier to encode than the nonsystematic ones. Thus, the improvement in performance is due to the participant's knowledge of the rules and not to orthographic or other differences in the stimuli themselves.

However, knowledge of the abbreviation rules did not facilitate decoding. In the present decoding experiment, performance on both truncation-variable length and contraction-variable length abbreviations was about 66 percent correct. In the Moses et al. experiment, where participants did not know the rules, participants also performed equally well on these techniques, with performance ranging from 70 percent correct after one exposure to the stimuli to 88 percent correct after six exposures. This better performance might be due to the fact that the Moses et al. variable length rule created longer abbreviations on the average. In addition, the study phase for the two experiments were different as were some other factors.

There was one important decoding difference in the results reported by the two experiments. Moses et al. found no differences in decoding performance for rule generated and nonsystematically generated abbreviations. However, the present experiment found deviant abbreviations to be at a distinct disadvantage. Thus, the participant's knowledge of rules might interfere with his or her ability to decode abbreviations which do not follow the rules.

Choosing an Abbreviation Rule

The present experiments found truncation to be the better abbreviation technique. This was quite clear in the encoding task and marginally true in the decoding task. But the superiority of truncation over contraction might be even greater outside the laboratory. In the above experiments, participants had ample time and no distractions. Also, they saw each word instead of hearing it or mentally conceiving it. But most working environments are not so favorable. Contraction is a relatively difficult rule to apply as compared to truncation. If operators had to apply it to words not written on a piece of paper, or when under heavy stress, then the difference in performance between truncation and contraction would probably be even greater. However, as operators became more experienced, this difference would diminish.

Likewise, other experimenters have reported truncation abbreviations to be equal to or superior to abbreviations formed by other techniques. Moses et al. (1980) and Moses and Potash (1979) report this for both encoding and decoding for participants who did not know the rules. Likewise, Schneider, Hirsh-Pasek, and Nudelman (1981) report the same for encoding but not decoding. Using response time measures, Rogers and Moeller (1981) found that with practice, truncation abbreviations are decoded faster than nonsystematically generated (Navy) abbreviations.

Despite the apparent superiority of truncation, a potential disadvantage revolves around the question of how many ambiguous abbreviations are produced by the truncation technique (Ehrenreich, in preparation). If there are many ambiguous abbreviations, then operators would be forced to learn numerous exceptions to the rule. The inherent limitations of a single abbreviation rule are further discussed below.

Although the present encoding experiments exposed no preference for fixed length as opposed to variable length abbreviations, this finding is probably not valid outside the laboratory. In the above experiments, participants saw the words written out and this might not be the case in a working environment. Since the variable length abbreviation method requires that an individual correctly count the number of letters in a word, it would probably lead to more errors than the fixed length method. It thus seems wiser to use fixed length abbreviations, particularly in situations where users are taught the abbreviation rules and where encoding performance is important.

The last issue examined in these experiments was the ability to incorporate endings (ING, ED and S) into abbreviations. This was done by adding either a G, D or S, as appropriate, to the end of an abbreviation. Performance with this technique was mixed. Although participants were more apt to correctly represent the ending when they decoded abbreviations, they were also more likely to err when encoding a word which had an ending. Unless it is crucial to the understanding of the message, it seems wiser to not incorporate endings into abbreviations. In many instances, extra space will have to be reserved on the screen and in computer memory to allow for the few instances where endings are important. In addition, use of endings will complicate the abbreviation rules the users must learn. Therefore, when there are only a few words for which endings are critical, it would be better that these words not be abbreviated.

Limitations of a Single Abbreviation Rule

A single rule sometimes generates the same abbreviation for different words. When this occurs, a way must be found to disambiguate the abbreviations. One solution is to apply a second rule. For example, the truncation-fixed length technique might be chosen as the primary abbreviation rule for a list of words which include PROVIDE and PROVOKE. But the abbreviations produced by these two words are identical, i.e., PROV. A second rule, e.g., contraction-fixed length, could then be used to abbreviate these few words.

But using two abbreviation rules places a memory load on operators. They must learn which words are abbreviated by the secondary rule. By default, all remaining words are abbreviated by the primary rule. If the number of words abbreviated by the secondary rule is small, then this elimination process would not be too difficult. In any case, the amount of learning required by this technique is much less than the amount of learning required when a unique abbreviation for each word must be learned.

One way to help the operator remember which abbreviations were formed by a secondary rule is to mark them. In the above experiments, an asterisk was placed before those abbreviations that were not generated by the primary rule. Likewise, computer software can be designed so that an asterisk appears before such abbreviations. Then, when users encounter abbreviations that they must decode, they will know by what rule it had been formed.

However, there is no practical method for marking words to indicate how they are to be encoded. When an individual is tasked with entering a statement into a computer, he or she must decide whether the primary or secondary abbreviation rule is appropriate. This decision can be made by looking up the words in a manual or by having previously learned the information. In the encoding experiment, the information was artifically affixed to the word by attaching an asterisk. Thus the experiment does not really tell us how successfully operators can learn to use a primary and secondary rule when encoding words.

The problem created by using a secondary rule can be minimized by judiciously avoiding words which have identical abbreviations under the primary rule. Although it may not be possible to eliminate all such words, their number can be kept small by replacing them with synonyms. This is not to suggest that words strongly embedded in the operator's job related vocabulary should be arbitrarily changed. But insofar as a vocabulary is being established for use on the system, some leeway in the choice of words is bound to be present. This would minimize the amount of learning required of the operator.

Looking back at the high performance observed in the encoding experiment, one can see that it is an overestimate of what to expect in a realistic situation. Since deviant abbreviations were marked with an asterisk, the observed encoding performance represents at best what might be expected if an individual had perfect knowledge of which words were to be abbreviated using the simple rule. For less skilled users, this would not be true and encoding performance would be lower. (Further discussion of this matter can be found in Ehrenreich, in preparation.) The same statement is not true for the decoding performance observed in the experiment. It is legitimate to assume that the system can be programmed to show deviant abbreviations with an asterisk or other marking.

There are other solutions to the problem of a single rule generating identical abbreviations for different words. One possibility is for the operator to type only as much of the initial portion of the word as is needed to uniquely identify it (i.e., the minimum-to-distinguish technique described previously). For example, if TRANSPORT were the only word beginning with a T, then the operator need only type T to enter the word. However, if TRANSLATE were also in the computer's lexicon, then as a minimum, TRANSP would need to be entered to uniquely identify the word. This is equivalent to a truncation-variable length rule but with the length depending on the orthographic uniqueness of a word. But the minimum-to-distinguish technique also places a memory load on the operator who has to remember how many letters must be entered for each word. Thus, this technique has the same drawback as the technique of using a primary and secondary rule. The more words being abbreviated, the greater the likelihood that some will have their first few letters in common. The question then is, which system results in faster learning and longer retention by the operator? Further comparison of the above two techniques can be found in Ehrenreich (in preparation).

Another possible solution to the problem of ambiguous abbreviations is to assure that they always occur in mutually exclusive modes of operation.[3] For example, the abbreviation C can represent either the COPY command or the CHANGE command. But since COPY might occur in the job control mode while CHANGE occurs only in the text edit mode, this sameness of abbreviation presents no practical problem. Likewise, even in the same operating mode, it is possible for two words to have identical abbreviations and yet be so syntactically and semantically disimilar that they can be disambiguated by the contexts in which they occur. In a query language situation, where the number and variety of permissible sentences is large, programming such a capability may involve a greater investment in software than is warranted by the problem. But the situation may be different when the operator is filling-in-the-blanks on a "form" being displayed on the video display terminal. Here, the exchange between operator and computer is restricted and words with identical abbreviations might only occur as responses to different questions. In such cases, the system can easily identify the correct meaning of an abbreviation since the alternative is not a permissible option. Thus, identical abbreviations may be acceptable, eliminating the need for a secondary abbreviation rule.

Guidelines

Based upon the preceding discussion, a set of guidelines are presented in Table 3. These guidelines are an extrapolation, in practical terms, of the results from these and other experiments on abbreviations.

The basic premise of these guidelines is that operators can work with abbreviations more effectively if they understand how they were created. One way to effect this knowledge is to generate abbreviations via a primary and secondary rule. The primary rule is used to abbreviate the great majority of words and the secondary rule is used as a backup. Many forms of primary and secondary rules can be suggested; for example, truncation-fixed length as a primary rule and contraction-fixed length as a secondary rule. In fact, the minimum-to-distinguish rule is simply a primary rule with a reiterative secondary rule, i.e., primary rule--use the first letter of a word to abbreviate it; secondary rule--if the abbreviation is not unique, add another letter (repeat secondary rule as necessary).

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[3] This consideration was brought to my attention by Robert Sollick.

Table 3

GUIDELINES FOR GENERATING ABBREVIATIONS

1. A simple, primary rule should be used to generate abbreviations for most items and a simple, secondary rule used for those items where there is a conflict.

2. Abbreviations generated by the secondary rule should have a marker (e.g., an asterisk) incorporated into them.

3. The number of words abbreviated by the secondary rule should be kept to a minimum.

4. Operators should be familiar with the rules used to generate abbreviations.

5. Truncation is an easy rule for operators to work with but it may also produce a large number of identical abbreviations for different words.

6. Fixed length abbreviations are preferable to variable length ones.

7. Abbreviations should not be designed to incorporate endings (e.g., ING, ED, S).

Although the question of which primary and secondary rule is best has not been answered, three criteria are obvious. First, the rules must be easy for an operator to understand. Second, they must be simple to apply, preferably without the aid of paper and pencil. And finally, the primary rule should be able to abbreviate uniquely all but a few of the words. Any reasonable choice for a pair of rules, even if they are not the "best," is sure to produce encoding performance that is superior to the performance obtained by using nonsystematic abbreviations.

Although it is also desirable to improve decoding performance, none of the techniques tested here had any effect. Fortunately, decoding appears to be intrinsically easy, with a learning curve that reaches a high level after only a few trials. As reported earlier, participants in the Moses et al. (1980) experiments were able to correctly decode the stimuli 70 percent of the time after one exposure and 88 percent of the time after six exposures.

The guidelines presented here cannot stand alone, and a human factors specialist or system designer must still consider the individual system and its operators when adopting them. But hopefully this paper and its guidelines provide a body of information and a set of options that will help in developing "user-oriented" abbreviations for automated systems.

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APPENDIX A ANOVA TABLES FOR RATING EXPERIMENT

Technique - Truncation, contraction
Length - fixed, variable
Condition - 0, 16, 33

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	7.297	4	1.824	2.052	.091
Technique	4.954	1	4.954	5.573	.020
Length	2.283	1	2.283	2.568	.111
Condition	.060	2	.030	.034	.967
2-Way Interactions	2.288	5	.458	.515	.765
Technique Length	.155	1	.155	.175	.677
Technique Condition	1.364	2	.682	.767	.466
Length Condition	.768	2	.384	.432	.650
3-Way Interactions	.633	2	.317	.356	.701
Technique Length Condition	.633	2	.317	.356	.701
Explained	10.218	11	.929	1.045	.411
Residual	117.341	132	.889		
Total	127.559	143	.892		

Table A1. ANOVA table for rating experiment - rule generated abbreviations (simple stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	14.049	4	3.512	3.600	.008
Technique	5.840	1	5.840	5.986	.016
Length	7.544	1	7.544	7.733	.006
Condition	.665	2	.333	.341	.712
2-Way Interactions	5.543	5	1.109	1.136	.344
Technique Length	.215	1	.215	.220	.640
Technique Condition	3.092	2	1.546	1.585	.209
Length Condition	2.236	2	1.118	1.146	.321
3-Way Interactions	.803	2	.401	.411	.664
Technique Length Condition	.803	2	.401	.411	.664
Explained	20.395	11	1.854	1.900	.045
Residual	128.781	132	.976		
Total	149.176	143	1.043		

Table A2. ANOVA table for rating experiment - abbreviations incorporating endings (ending stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	10.413	3	3.471	3.664	.015
Technique	8.137	1	8.137	8.591	.004
Length	2.187	1	2.187	2.309	.132
Condition	.088	1	.088	.093	.761
2-Way Interactions	1.570	3	.523	.552	.648
Technique Length	.312	1	.312	.329	.568
Technique Condition	.772	1	.772	.815	.369
Length Condition	.486	1	.486	.513	.476
3-Way Interactions	.706	1	.706	.745	.390
Technique Length Condition	.706	1	.706	.745	.390
Explained	12.688	7	1.813	1.914	.077
Residual	83.357	88	.947		
Total	96.045	95	1.011		

Table A3. ANOVA table for rating experiment - abbreviations incorporating endings (ending stimuli) - conditions 16 and 33 only.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	8.403	3	2.801	3.053	.033
Technique	7.420	1	7.420	8.087	.006
Length	.645	1	.645	.703	.404
Condition	.337	1	.337	.368	.546
2-Way Interactions	1.723	3	.574	.626	.600
Technique Length	.002	1	.002	.002	.964
Technique Condition	1.290	1	1.290	1.406	.239
Length Condition	.431	1	.431	.469	.495
3-Way Interactions	.292	1	.292	.318	.574
Technique Length Condition	.292	1	.292	.318	.574
Explained	10.417	7	1.488	1.622	.140
Residual	80.746	88	.918		
Total	91.164	95	.960		

Table A4. ANOVA table for rating experiment - deviant abbreviations (deviant stimuli) - conditions 16 and 33 only.

APPENDIX B ANOVA TABLES FOR ENCODING EXPERIMENT

Technique - Truncation, contraction
Length - fixed, variable
Condition - 0, 16, 33

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1.970	4	.493	7.022	.000
Technique	1.863	1	1.863	26.562	.000
Length	.042	1	.042	.599	.440
Condition	.065	2	.032	.468	.631
2-Way Interactions	.575	5	.115	1.640	.154
Technique Length	.213	1	.213	3.038	.084
Technique Condition	.186	2	.093	1.324	.269
Length Condition	.176	2	.088	1.256	.288
3-Way Interactions	.518	2	.259	3.694	.027
Technique Length Condition	.518	2	.259	3.694	.027
Explained	3.064	11	.279	3.970	.000
Residual	9.259	132	.070		
Total	12.323	143	.086		

Table B1. ANOVA table for encoding experiment - rule generated abbreviations (simple stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	1.768	4	.442	5.022	.001
Technique	.773	1	.773	8.781	.004
Length	.183	1	.183	2.076	.152
Condition	.812	2	.406	4.615	.012
2-Way Interactions	.419	5	.084	.952	.450
Technique Length	.055	1	.055	.623	.431
Technique Condition	.351	2	.176	1.995	.140
Length Condition	.013	2	.007	.074	.929
3-Way Interactions	.149	2	.074	.845	.432
Technique Length Condition	.149	2	.074	.845	.432
Explained	2.336	11	.212	2.413	.009
Residual	11.619	132	.088		
Total	13.955	143	.098		

Table B2. ANOVA table for encoding experiment abbreviations incorporating endings (ending stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.421	3	.140	2.036	.115
Technique	.250	1	.250	3.628	.060
Length	.165	1	.165	2.393	.125
Condition	.006	1	.006	.087	.768
2-Way Interactions	.215	3	.072	1.037	.380
Technique Length	.002	1	.002	.032	.859
Technique Condition	.209	1	.209	3.032	.085
Length Condition	.003	1	.003	.047	.828
3-Way Interactions	.086	1	.086	1.253	.266
Technique Length Condition	.086	1	.086	1.253	.266
Explained	.722	7	.103	1.496	.179
Residual	6.067	88	.069		
Total	6.789	95	.071		

Table B3. ANOVA table for encoding experiment - abbreviations incorporating (endings ending stimuli) - conditions 16 and 33 only.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.111	3	.037	.914	.438
Technique	.013	1	.013	.318	.574
Length	.081	1	.081	2.008	.160
Condition	.017	1	.017	.416	.521
2-Way Interactions	.102	3	.034	.841	.475
Technique Length	.000	1	.000	.007	.931
Technique Condition	.001	1	.001	.022	.883
Length Condition	.101	1	.101	2.494	.118
3-Way Interactions	.285	1	.285	7.054	.009
Technique Length Condition	.285	1	.285	7.054	.009
Explained	.498	7	.071	1.760	.106
Residual	3.558	88	.040		
Total	4.052	95	.043		

Table B4. *ANOVA table for encoding experiment - delvant abbreviations (deviant stimuli) - conditions 16 and 33 only.*

APPENDIX C ANOVA TABLES FOR DECODING EXPERIMENT

Technique - Truncation, contraction
Length - fixed, variable
Condition - 0, 16, 33

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.431	4	.108	3.190	.015
Technique	.043	1	.043	1.284	.259
Length	.277	1	.277	8.207	.005
Condition	.110	2	.055	1.634	.199
2-Way Interactions	.495	5	.099	2.932	.015
Technique Length	.079	1	.079	2.347	.128
Technique Condition	.322	2	.161	4.767	.010
Length Condition	.094	2	.047	1.390	.253
3-Way Interactions	.119	2	.060	1.767	.175
Technique Length Condition	.119	2	.060	1.767	.175
Explained	1.046	11	.095	2.814	.002
Residual	4.461	132	.034		
Total	5.507	143	.039		

Table C1. ANOVA table for decoding experiment (liberal scoring) - rule generated abbreviations (simple stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.587	4	.147	4.246	.003
Technique	.157	1	.157	4.531	.035
Length	.341	1	.341	9.868	.002
Condition	.089	2	.045	1.293	.278
2-Way Interactions	.645	5	.129	3.728	.003
Technique Length	.189	1	.189	5.451	.021
Technique Condition	.367	2	.184	5.307	.006
Length Condition	.089	2	.044	1.286	.280
3-Way Interactions	.182	2	.091	2.633	.076
Technique Length Condition	.182	2	.091	2.633	.076
Explained	1.414	11	.129	3.717	.000
Residual	4.565	132	.035		
Total	5.979	143	.042		

Table C2. ANOVA table for decoding experiment (strict scoring) - rule generated abbreviations (simple stimuli) - all conditions

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	5.731	4	1.433	27.987	.000
Technique	.262	1	.262	5.114	.025
Length	.124	1	.124	2.416	.123
Condition	5.346	2	2.673	52.208	.000
2-Way Interactions	.411	5	.082	1.605	.163
Technique Length	.070	1	.070	1.372	.244
Technique Condition	.233	2	.117	2.277	.107
Length Condition	.107	2	.054	1.048	.353
3-Way Interactions	.321	2	.161	3.136	.047
Technique Length Condition	.321	2	.161	3.136	.047
Explained	6.463	11	.588	11.477	.000
Residual	6.758	132	.051		
Total	13.221	143	.092		

Table C3. ANOVA table for decoding experiment (strict scoring) - abbreviations incorporating endings (ending stimuli) - all conditions.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.368	3	.123	2.238	.090
Technique	.331	1	.331	6.036	.016
Length	.016	1	.016	.282	.596
Condition	.021	1	.021	.383	.538
2-Way Interactions	.292	3	.097	1.772	.158
Technique Length	.105	1	.105	1.919	.169
Technique Condition	.158	1	.158	2.886	.093
Length Condition	.028	1	.028	.510	.477
3-Way Interactions	.286	1	.286	5.210	.025
Technique Length Condition	.286	1	.286	5.210	.025
Explained	.946	7	.135	2.461	.028
Residual	4.831	88	.055		
Total	5.776	95	.061		

Table C4. ANOVA table for decoding experiment (strict scoring) - abbreviations incorporating endings (ending stimuli) - conditions 16 and 33 only.

Source of Variation	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.573	3	.191	4.386	.006
Technique	.011	1	.011	.254	.616
Length	.139	1	.139	3.189	.078
Condition	.423	1	.423	9.713	.002
2-Way Interactions	.162	3	.054	1.243	.299
Technique Length	.009	1	.009	.207	.650
Technique Condition	.106	1	.106	2.436	.122
Length Condition	.047	1	.047	1.086	.300
3-Way Interactions	.174	1	.174	4.004	.048
Technique Length Condition	.174	1	.174	4.004	.048
Explained	.909	7	.130	2.988	.007
Residual	3.829	88	.044		
Total	4.738	95	.050		

Table C5. ANOVA table for decoding experiment (liberal scoring) - deviant abbreviations (deviant stimuli) - conditions 16 and 33 only.

Source of Variation	SUM OF SQUARES	DF.	MEAN SQUARE	F	SIGNIF OF F
Main Effects	.244	3	.081	1.978	.123
Technique	.015	1	.015	.365	.547
Length	.035	1	.035	.840	.362
Condition	.194	1	.194	4.731	.032
2-Way Interactions	.232	3	.077	1.881	.139
Technique Length	.003	1	.003	.063	.802
Technique Condition	.228	1	.228	5.552	.021
Length Condition	.001	1	.001	.029	.864
3-Way Interactions	.258	1	.258	6.286	.014
Technique Length Condition	.258	1	.258	6.286	.014
Explained	.734	7	.105	2.552	.019
Residual	3.616	88	.041		
Total	4.351	95	.046		

Table C6. ANOVA table for decoding experiment (strict scoring) - deviant abbreviations (deviant stimuli) - conditions 16 and 33 only.