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Abstract

It was examined whether an operator, when confronted with a variety of strategy-specific information aids during fault diagnosis, would have the ability to select the aid that matches his/her current strategy best. To answer this question, 18 process operators performed a simulated topographic search task to which several strategy-specific help functions had been added. The results indicated that the operators selected the help functions in accordance with the strategy they actually adopted. It is argued that for the task of fault diagnosis different types of information aids should be designed for different strategies and that the operator should be free to select the aid that suits his/her needs best.

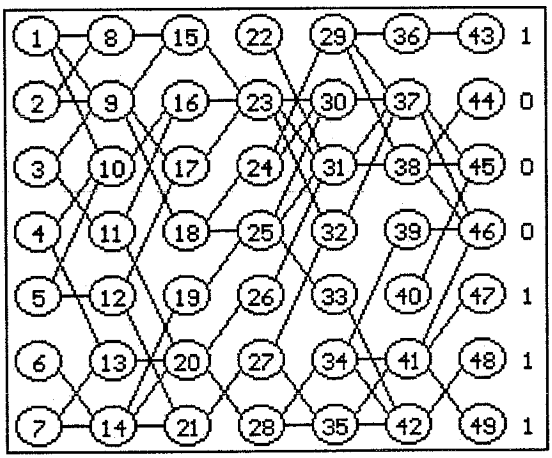
1. INTRODUCTION

One of the main tasks the human operator has to fulfil when supervising a highly automated production process consists of diagnosing faults. Fault diagnosis is commonly conceived of as determining the cause of a malfunctioning process from a set of observable symptoms. Of the various approaches being followed to assist the operator in overcoming the difficulties of this task, providing information aids is probably the most straightforward in keeping the operator an integral part of the man-machine system [1], [2]. Designing information aids for fault diagnosis requires consideration of the following two related points. First, even within relatively homogeneous groups of subjects, like university students [3] and maintenance technicians [4], there are large inter- and intra-individual differences in the use of diagnostic strategy. Secondly, the particular strategy a subject adopts determines to a large extent the kind of difficulties encountered during task performance [4]. Thus, it might make sense to design different types of information aids for different strategies and to have the operator select the information aid that is most helpful for his/her own strategy [5]. This, however, raises the question whether the operator will be able to do so. That is to say, when facing various strategy-specific information aids, is the operator capable of selecting the aid that supports the strategy he/she actually uses best? To answer this question, an experiment was set up in which a group of process operators had to perform a simulated fault diagnosis task to which several relatively simple strategy-specific information aids had been added in the form of computerized help functions. During the task, the operators were left completely free in strategy use and choice of help function. It was examined whether they selected the available help functions in accordance with their actual strategy.

2. METHOD

Subjects. A group of 18 male process operators of a chemical plant served as subjects. The operators differed in the amount of operating experience and they possessed varying degrees of process control skills. With respect to these variables they were fairly representative of the whole pool of operators of the plant involved.

Task. The task used was adapted from the topographic search problem TASK, originally developed by Rouse [6]. TASK requires fault finding in graphically displayed networks which consist of N rows and N columns of interconnected logical AND-gate components (Figure 1). In each network, signals flow through the connections from left to



trial 1: 23 31 status 0
trial 2: 8 15 status 1
trial 3: 10 16 status 0
trial 4: 10 correct

Figure 1. An example of a network and an illustration of the way a subject solved it. The tests made by the subject have been underlined.

right. There is, however, one randomly selected component which does not work and which therefore does not transfer its input signals. It is the task of the subject to locate this faulty component. He can achieve this by interpreting the values of the output units at the right-hand side of the network (1 is working and 0 is not) and by testing connections (with a cost of 1 point) and components (with a cost of 3 points) within the network. Having made a test, the subject receives its value until he tests the faulty component in which case the problem has been solved. During task performance, a chronological list of the test results obtained so far is kept at the right-hand side of the network.

Strategies. Two basically distinct strategies, referred to as *tracing-back* (TB) and *hypothesis-and-test* (HT), have been identified for the task [3], [7], [8]. In short, TB involves testing the inputs of a component the output of which has just been found to be 0. This is continued until the faulty component is encountered the characteristic feature of which is that none of its inputs is 0. HT involves testing the input or the output of a component belonging to the feasible fault set. This set consists of all the components that could have failed, given the information acquired so far. The feasible fault set can be derived by determining what components connect directly or indirectly to all components with a known value of 0 and do not connect to any component with a known value of 1. For example, in Figure 1 the complete feasible fault set prior to testing consists of 8, 10, 15, 16, 17, 22, 23, 26, 31 and 38. As will be evident, the amount and the complexity of the information being processed during task performance is considerably larger when adopting the HT strategy than the TB strategy. It thus seems appropriate to qualify HT as more cognitively demanding than TB. TB and HT should be regarded as idealized ways of performing the task. It is very well possible that a strategy is adopted which differs in one or more respects from these two strategies. Such a strategy is referred to as *indefinite* (IN). Furthermore, during task performance one strategy may be changed for another.

Help functions. Seven help functions (in the following referred to as h1, h2, ..., h7) were added to the fault diagnosis task each of which could be activated to obtain one of the following pieces of information:

1. the *input tree* of a particular component (i.e., all the components which can send signals to it),
2. the *output tree* of a particular component (i.e., all the components which can receive signals from it),
3. the *test results* obtained so far,
4. all the components reaching *all the 0-output* units,
5. all the components reaching *all the 1-output* units,
6. all the components reaching *at least one of the 0-output* units,
7. all the components reaching *at least one of the 1-output* units.

As can be seen, a help function gave only information the subject could also have derived by himself. Upon activation of a particular help function, the corresponding piece of information would be visually presented within the network itself. That is to say, with h1 and h2, the components involved, together with their interconnections, were coloured in red. With h3, the tested connections and components with a value of 0 were coloured in red and those with a value of 1 were coloured in green. With h4 and h6, the components involved were coloured in red, and with h5 and h7 they were coloured in green. It should be noted that an operative help function had to be deactivated when using another function or when performing a test. The help functions were developed with the purpose of supporting one or both strategies or neither strategy. More specifically, h1 was designed for the support of the TB strategy. This function was supposed to help in finding a path of interconnected components having a value of 0 and eventually leading to the faulty component. H4 and h7 were designed for the support of the HT strategy. It was supposed that these functions, especially when used in combination, would help in identifying the possibly faulty components. H3 was meant to support both TB and HT by assisting in mapping the list of test results at the right-hand side of the network onto the network itself. H2, h5 and h6 were actually meant as decoys in the sense that they seemed to be informative but were in fact useless for whatever strategy.

Procedure. A subject was tested individually in a separate room in which he sat in front of a PC which had been programmed to control the fault diagnosis task. First, the subject studied an extensive written task instruction in which accuracy rather than speed was stressed. However, he was left free to follow the strategy he preferred. Hereupon, the subject had to solve 8 practice problems. Following this, the subject studied a written instruction on the nature and the use of the help functions. He was told to be completely free in selecting any help function at any time during task performance. The subject was then given another set of 4 practice problems and he thereby got the opportunity to make use of the help functions. Finally, the subject had to solve 12 experimental problems. Here, the help functions were again available. On these problems, the subject was not allowed to make use of paper and pencil and he received no feedback. For each practice and experimental problem being presented, a different network was generated. A network could either be small (i.e., 5 rows and 5 columns) or large (i.e., 7 rows and 7 columns). Network size was balanced across the practice problems as well as the experimental problems.

Performance measures. Two sets of measures were used to describe the subject's performance in each experimental problem he solved. The first set was meant to capture the adopted diagnostic strategy according to an algorithm described fully in [7], [8]. In previous experiments, evidence has been gathered indicating that the algorithm is valid. The following three measures were constructed from the strategy classifications the algorithm produced: the proportion of TB, the proportion of HT, and the proportion of IN. Each proportion was expressed as a percentage of the total number of tests performed on a problem, with the exception of the test on the faulty component and the tests which the algorithm failed to classify into one of the strategies specified beforehand. The second set of measures related to the selection of the help functions. For each help function, the number of times it had been selected was counted. To control for variability in the length of problem solution, this frequency was divided by the number of tests needed to solve the problem.

3. RESULTS

Before being analyzed further, the subjects' scores were averaged across all the experimental problems being solved. To determine whether the subjects selected the help functions in accordance with their actual strategy, each strategy measure was correlated with each help function measure. Given the considerations underlying the design of the help functions, the following relationships were expected to emerge from this correlation analysis: the higher the proportion of TB, the larger the number of h1 and h3 requests, and the higher the proportion of HT, the larger the number of h3, h4 and h7 requests. Allowing for non-linearity of the relationships, Spearman's rank correlation coefficient r_s was applied (i.e., 1-tailed for the relationships being expected and 2-tailed for those not expected). Of all the 21 correlation coefficients computed, only two had a moderate size and reached significance at the 0.05 level. First, the proportion of HT correlated positively with the number of h4 requests ($r_s = 0.59$, $p = 0.006$, 1-tailed). Secondly, the proportion of IN correlated negatively with the number of h4 requests ($r_s = -0.47$, $p = 0.048$, 2-tailed).

To get a better insight into the working-style of the subjects having a preference for an IN strategy, the test behavior of these subjects was considered more closely. This inspection revealed that these subjects first worked in accordance with the HT strategy in that they tried to locate a possibly faulty component within the network. Subsequently, however, they differed from this strategy as they performed a relatively large number of redundant tests in an attempt to establish the real status of the component under consideration.

4. DISCUSSION AND CONCLUSION

Based upon the assumption that the operators would select the help functions in accordance with their task strategies, a highly specific pattern of relationships between type of strategy and type of help function was expected. The results show that this pattern of relationships is partly confirmed. First, use of the cognitively demanding HT strategy was accompanied with selecting h4, the help function displaying in the network to be diagnosed all the components reaching all the 0-output units. This finding indicates that, as expected, h4 is indeed utilized to help in identifying the components that possibly fail. Secondly, where no relationship between strategy usage and selection of help function was expected, it in general is not found so. For example, application of the HT strategy was not accompanied with selecting h5, the help function showing all the components reaching all the 1-output units. This finding should come as no surprise since h5 had been designed so as to be of no help for whatever strategy. Thus, the results point out that, in general, a particular help function is not utilized for supporting the actual strategy, whenever that help function has not been specifically designed for it.

In addition to this supporting evidence, there are, however, also a number of deviations from the pattern of relationships specified beforehand. First, use of the TB strategy was not associated with selecting h1, the help function displaying the input tree of a particular component in the network. As described above, h1 had been meant to help in tracing a path of zeros backwards into the network. One might argue that this relationship could not emerge because the TB strategy was hardly employed by the operators. As a matter of fact, the proportional use of TB was less than 15% on the average. It should be noted, however, that even the 2 operators preferring this strategy also (almost) never requested h1. A likely explanation for this finding is that the processing requirements of TB are so low that during this strategy no support is needed whatsoever. Secondly, application of the HT strategy was not accompanied with selecting h7, the help function showing all the components reaching at least one of the 1-output units. Like h4, h7 had also been designed with the purpose of helping in the identification of possibly faulty components. Actually, of the 12 operators favoring the HT strategy, only 5 requested h7 a reasonably number of times, i.e. more than 0.01 per test made. This finding indicates that several operators made insufficient use of the information provided by the acceptable outputs in order to assist in eliminating infeasible components. This tendency to underutilize disconfirming evidence has been observed repeatedly in the research literature [6]. Third, neither TB nor HT was associated with selecting h3, the help function presenting the test results obtained so far within the network itself. The failure to find these relationships may be attributed to the infrequent use of h3. Only 3 operators requested this help function more than 0.01 per test made. Obviously, the operators did not need support to map the always available list of test results at the right-hand side of the network onto the network itself. Fourth, application of an IN strategy was negatively related to selecting h4. This relationship, however, may simply have its origin in the positive relationship between selecting the same help function and employing the HT strategy. That is to say, one might argue that requesting h4 increased the use of HT at the expense of following an IN working-style. This explanation is supported by a more detailed analysis of the individual tests made during the task. More specifically, this analysis revealed that making an h4 request on a particular test, in comparison with selecting not any help function, increased the chance of an HT classification of that test from 0.23 to 0.66 and decreased the chance of an IN test classification from 0.45 to 0.25. Fifth, there were several operators making considerable use of h2, the help function showing the output tree of a particular component in the network. To these operators belonged 3 having a preference for the HT strategy and also 3 preferring an IN working-style. This finding is somewhat surprising since h2 was not supposed to be of any help for whatever strategy. Note, however, that the output tree of a given component may very well be used to establish whether that component reaches all the 0-output units but none of the 1-output units. Selecting h2 repeatedly can therefore be very helpful in identifying the components that possibly fail. Thus utilized, h2 gives the same information as the combination of the two help functions designed for the HT strategy, i.e. h4 and h7. This might explain why a number of the operators favoring the HT strategy selected h2 so frequently. That a number of the operators favoring an IN strategy did as well may then be attributed to the fact that these operators also followed a working-style of which the identification of possibly faulty components comprised an important phase.

The general picture emerging from the foregoing discussion is that the operators selected the help functions in accordance with their actual strategy. Thus, there is evidence to conclude that an operator, when facing a variety of strategy-specific information aids during fault diagnosis, is capable of selecting the aid that matches his/her actual strategy very well. Therefore, the most important message conveyed by the present study is that for the task of fault diagnosis every effort should be made to design different types of information aids for different strategies and to leave the operator completely free in choosing the aid that suits his/her needs best.

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