PSYCHOLOGICAL ISSUES IN ONLINE ADAPTIVE TASK ALLOCATION

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ABSTRACT

Adaptive aiding is an idea that offers potential for improvement over many current approaches to aiding in human-computer systems. The expected return of tailoring the system to fit the user could be in the form of improved system performance and/or increased user satisfaction. Although the utility of the concept has been demonstrated in limited ways in a variety of contexts, there has been no substantial research effort devoted to addressing the many issues relevant to adaptive aiding. These include such issues as the manner in which information is shared between human and computer, the appropriate division of labor between them, and the level of autonomy of the aid.

In order to investigate these and other issues relevant to human-computer interaction, a simulated visual search task has been developed. Subjects are required to identify targets in a moving display while performing a compensatory sub-critical tracking task. It is also possible for the computer to identify targets. By manipulating characteristics of the situation such as imposed task-related workload and effort required to communicate with the computer, it is possible to create conditions in which interaction with the computer would be more or less desirable. The results of preliminary research using this experimental scenario are presented, and future directions for this research effort are discussed.

INTRODUCTION

The idea of providing the human operator with some form of computer assistance is not new. Computers have been used for years in a variety of applications. Often the complexity of modern systems and the potentially high costs of system failure have been invoked as justification for computerizing portions of the operator's job.

The decision as to which tasks will be performed by computer has all too often been based upon which tasks could be automated. In situations where total automation was not feasible, the task allocation decision has been based upon relative abilities of human and computer. For example, humans would be given tasks requiring "flexibility" and computers would perform tasks requiring "consistency". A number of lists of human vs. computer abilities are available for this purpose (e.g., Licklider, 1960).

For several reasons, this "traditional" approach to computer aiding may be less than satisfactory. For example, thanks to progress in artificial intelligence, the distinction between human and computer abilities is much less clear. Thus, the human and computer may be viewed as partners, with abilities which partially overlap. As a result, it may be inappropriate to allocate tasks based solely on computer abilities.

Another factor which should be considered is individual differences. Aptitudes and abilities, cognitive styles, and attitudes have been cited as affecting human behavior in a number of situations. Lists of human abilities are characteristic of a prototypical human and do not reflect these differences.

Human performance varies not only across individuals but also within individuals over time. People become fatigued. They have a limited capacity to perform. The "mix" of required tasks may impose an inordinate amount of workload, and performance may degrade as a result.

Finally, the quality of the computer's performance may depend upon conditions. For example, suppose the computer must have certain state information in order to make decisions. If the quality of that information is degraded, performance of the computer will be affected.

In light of these shortcomings, it seems desirable to make computer aids adaptive. An adaptive aid could step in when needed and provide assistance in a form appropriate to the situation. In situations where no assistance was needed, the aid could remain inactive. In principle, it seems that such an approach to aiding could improve overall system performance substantially.

RELEVANT ISSUES

The concept of adaptive aiding is also not new (Chu & Rouse, 1979; Rouse, 1975, 1981). However, it has not been implemented in any real-world applications, probably because the manner in which this should be done is not at all straightforward. A number of issues must be considered before progress can be made (Rouse & Rouse, 1983). For example, what should the focus of adaptation be? Should the aid be adapted to group characteristics, or to individuals? Should adaptation be done once, or dynamically over time?

Another issue is the method of adaptation. At least three approaches are imaginable. Tasks may be allocated, with either the human or computer in control of task performance. Alternatively, tasks may be partitioned between the two partners, with each performing task components. Finally, one partner may assist the other by performing a transformation of a task (e.g., the computer could filter noise from a visual display).

If human and computer are to be partners, then there must be some means for the two to communicate. But what should be the nature of communication? If communication is explicit, there is less uncertainty as to what is being communicated, but the human must invest resources in receiving and transmitting information. This resource demand may be less if communication is implicit, but there may be less certainty as to what is communicated. There may also be a need for the human to invest resources into determining what the computer is doing.

When system control is shared by human and computer, which partner should be in charge? Suppose tasks are to be allocated dynamically. Which partner--human or computer--should make the decision as to task allocation? As with the nature of communication, the resources required to make decisions and inform the partner must be considered.

Finally, if it appears that it would be advantageous to have the computer make decisions such as task allocation, what is the basis for decision making? It will be necessary to imbed models in the computer's knowledge base if such decisions are to be possible. These models must incorporate characteristics of the task situation, the human's task performance, and the computer's performance in order to be effective. Although the results of research in human problem solving and information processing provide a partial data base to support such models, many parameters must be obtained via specific research in human-computer interaction. The goal of the work reported here is to investigate these and other relevant issues.

EXPERIMENTAL APPROACH

In explaining the approach adopted in this research effort, it helps to consider a hypothetical situation. Suppose a variety of tasks must be performed for overall system operation to be successful. Human performance of these tasks on an individual basis is acceptable, but the degree to which tasks may be time-shared successfully depends upon the level of difficulty and combination of concurrent tasks. Further, suppose a computer is available which may perform a subset of these tasks. The computer's task performance may or may not be as good as the human's best performance, but may be preferable if the human's performance degrades.

An attempt was made to create this situation experimentally.

In designing the experimental scenario, one goal was to maintain a semblance of realism, rather than create an "artificial" laboratory task. However, the characteristics of the task environment were determined analytically, and little attempt was made to provide a high-fidelity simulation of an actual task.

A target recognition task was created as one of the tasks in the scenario because of differences in human and computer abilities in this area. Humans readily impart meaning into what is seen, and are excellent at "perceptual organization". Computers, on the other hand, have a great deal of difficulty analyzing scenes, but excel at figure rotation and template matching. Thus, humans should be better at identifying features in a meaningful scene, whereas computers should be better if the scene is a relatively homogenous field of objects.

Description of Experimental Tasks

The target recognition task employs a color graphic terrain display, as illustrated in Figure 1. The terrain display depicts an intracoastal waterway with varying proportions of water. Water areas are colored blue. Also included in the terrain are green trees, tan ground, black buildings, white roads and parking lots, and cars and boats of assorted colors. To simulate flight over the terrain the display pans down the CRT. Subjects are given the goal of identifying or spotting boats of a certain type which are in use in the waterway.

Targets may be identified only when they are in the region defined by the heavy black horizontal lines. When the subject is identifying targets, identification is accomplished by using a mouse to position the cross-hair cursor on top of the target and then pressing a button on the mouse. When the button is pressed a "+" appears on the screen to acknowledge the action. Hits and false alarms are tallied in the upper left corner of the screen. (See Figure 1.)

It is also possible for the computer to perform the spotting task. If the human is in control of the allocation decision, the aid may be activated by positioning the cursor on top of the word "AID" (to the left of the terrain display in Figure 1), and pressing the button on the mouse. The cursor then disappears, and the aid identifies targets until the human resumes control by again pressing the button on the mouse.

The relative performance of human and computer may be expected to vary over time. In light of the human's perceptual abilities, this task should be easier for the human when the proportion of water in the picture is low (such as when flying over a narrow channel). This is because the human is able to organize the scene and automatically exclude a large portion (i.e., the land areas) from consideration.

The computer, on the other hand, is deficient in these organizational abilities, and scans the whole scene, identifying boats with a "template matching" approach.* As a result, the computer does not always differentiate land from water, and its false alarm rate increases with the proportion of land in the display. Thus, the human may be expected to excel when the proportion of water is low, and there is greater potential for the aid to excel when the proportion of water is high.

Target identification is not the only task which must be performed. In addition to looking for boats, the human must also perform a subcritical tracking task. The tracking display is shown in the upper left corner of Figure 1.

The tracking display contains a green region flanked by yellow and red regions. The horizontal black line to the right of these regions moves up and down, and the arrow within the green region indicates the direction of the control input. The degree of instability of the controlled element is determined by a difficulty parameter which is entered by the experimenter at the beginning of a run and remains constant throughout the run. The human's goal is to keep the black line within the green region by using bang-bang control via the space bar on the terminal keyboard. When performing both tasks, the subject identifies targets with the right hand and tracks with the left.

The primary reason for incorporating the tracking task into the scenario is to create conditions in which assistance from the computer is required in order to maintain satisfactory performance. If target identification were the only task required, it is conceivable that a subject could maintain acceptable performance over a wide range of difficulty. However, performance should be more sensitive to difficulty manipulations (i.e., changes in terrain composition) if tracking is also required. The difficulty parameter of the tracking task may be varied to insure that such is the case, and the option of "shedding" the tracking task in favor of the target identification task is eliminated by disabling mouse inputs whenever the tracking indicator is in a red region.

With respect to the adaptive aiding concept, it is possible to specify qualitatively when the computer should be used in this environment. First, the aid should be used if its potential target identification performance exceeds that of the human. It is expected that this occurrence is most likely when tracking is non-trivial and the terrain is mostly water. Second, the aid should be used to look for boats if the human's tracking

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*In reality the computer "knows" the identity and location of every object in the display and makes responses on a probabilistic basis. The template matching explanation is provided to subjects.

performance degrades to an unacceptable level. Excluding the case in which acceptable tracking is impossible due to the level of tracking difficulty, it is anticipated that this occurrence would also be related to the amount of water in the display.

AN EXPERIMENT

A pilot study was conducted to evaluate the accuracy of some of these ideas by assessing the effects of task parameters on subject's performance. Since one of the purposes of this experiment was to identify conditions in which the need for computer assistance would be likely, no aid was available to subjects.

Two subjects served in three sessions each. The first session served as training and consisted of one 5-minute run at each of four levels of tracking difficulty. In the second and third sessions, the easiest tracking condition was excluded and only three levels of tracking difficulty were used. Thus, there were two independent variables in the pilot study: tracking difficulty and terrain composition. Dependent measures included rms tracking error, spotting accuracy (i.e., percent identified) and spotting latency (i.e., average time to identify a target once it entered the spotting window).

The results of this study are presented graphically in Figures 2-4. Time is represented on the abscissa of each graph, as the values shown represent the sequence of terrain types encountered by subjects over the course of a run. One interval on the abscissa corresponds to approximately 20 seconds of real time. To facilitate interpretation of these figures, terrain is also identified as either predominantly land or predominantly water. The break or dashed line in the middle of each graph reflects missing data. Due to hardware constraints, targets in these areas are not accessible to subjects, and there is a 1-2 second interval of "dead time" in the middle of each run.

Figure 2 depicts rms tracking error for three levels of tracking difficulty, averaged across both subjects. Two characteristics of Figure 2 are noteworthy. First, rms tracking error increased with increases in the difficulty parameter of the tracking task. Second, rms tracking error increased with the amount of water in the display. This effect seems to have been stronger when tracking was relatively easy, but is noticeable at each of the levels of tracking difficulty employed in this study.

From Figures 3 and 4, it may be ascertained that performance on the target identification task was also affected by changes in the terrain composition. Increases in the proportion of water in the display were accompanied by decreases in spotting accuracy (although small) and increases in spotting latency. Unlike rms tracking error, there was no noticeable effect of tracking difficulty manipulations upon target identification; as a result, the plots in Figures 3 and 4 represent performance averaged across three levels of tracking difficulty.

If the three dependent measures are compared to each other, some clear relationships emerge. First, there is an obvious negative relationship between spotting accuracy and spotting latency. Product-moment correlations at different levels of tracking difficulty ranged from -.61 to -.70. Of course, these results were obtained with only two subjects, so generalizations should be made with caution; however, if further experiments continue to reveal this relationship, this may have implications for online adaptation.

Although spotting accuracy is the stated performance criterion, its utility as an online measure is limited due to two factors. First, observed decrements in spotting accuracy were quite small, usually no more than 2-3 missed targets. Second, it seems desirable to be able to offer assistance <u>before</u> a target is missed, rather than stepping in too late to do any good. Spotting latency is easily assessed online; if the relationship of latency to accuracy proves to be sufficiently strong, the latency measure may be useful as a basis for online computer adaptation.

It may also be noted that rms tracking error is related to both spotting accuracy and spotting latency. Since it is an easily calculated, continuous measure, rms tracking error may also be useful as a basis for decision making. However, the results from this pilot study indicate that rms tracking error may not be as useful for this purpose as spotting latency, because its response to task changes considerably lags the response of spotting latency to these changes. (A comparison of Figures 2 and 4 reveals a difference of almost 20 seconds in the most difficult tracking condition.)

PLANS FOR FUTURE RESEARCH

Current plans are to conduct a full-scale experiment this summer. Independent variables will be the same as those reported here: terrain composition and tracking difficulty. Additionally, an initial attempt will be made to have the computer make the decision as to allocation of the target identification task. Undoubtedly the decision algorithm will be rather simplistic; however, this should provide insights necessary for more effective decision aiding in the future.

At present, it is possible to imagine several alternative approaches to allocation which might be appropriate. For example, in addition to unilateral decision making by human or computer, a "hybrid" approach could prove to be useful. In this case, the computer could monitor the human's performance and assume control of the target identification task when his performance on either task began to degrade. The human could then resume control of target identification when he felt able to do so.

If online adaptation is to be effective, it will be necessary to identify appropriate measures to serve as the bases for decision aiding, and to develop adequate models of how important variables interact. Effort will be devoted to achieving both of these goals. Identification of measures will be approached in a manner similar to that described here, by obtaining multiple performance measures and noting relationships between intermediate behavior and ultimate performance. A preliminary conceptual model of human-computer interaction has been developed (Morris, Rouse, & Ward, 1984, in preparation), and will be evaluated as research results become available. An "armchair" analysis of the problem indicates that such a model should include not only aspects of the task situation but also should take into account such factors as the human's perception of his own and the computer's performance, and human information processing resource limitations.

Also of interest are a number of issues relevant to problems which may arise when the computer aid degrades in some way. For example, under what conditions will the human realize that the aid has degraded, and will it be possible for the human to cope with the loss of the aid? Investigation of these and other questions may entail consideration of knowledge requirements and the human's "mental models" of the aid and situation.

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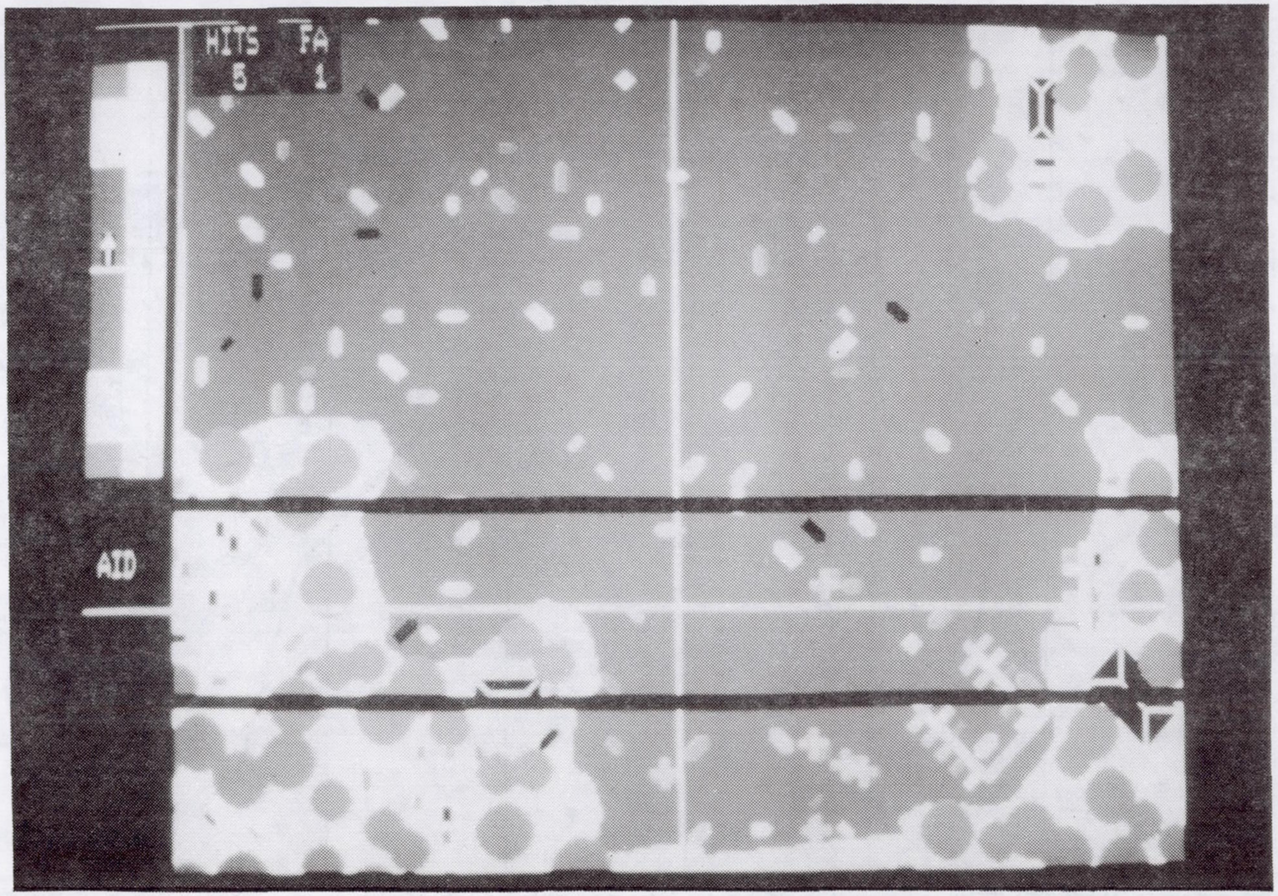

Figure 1. Task display.

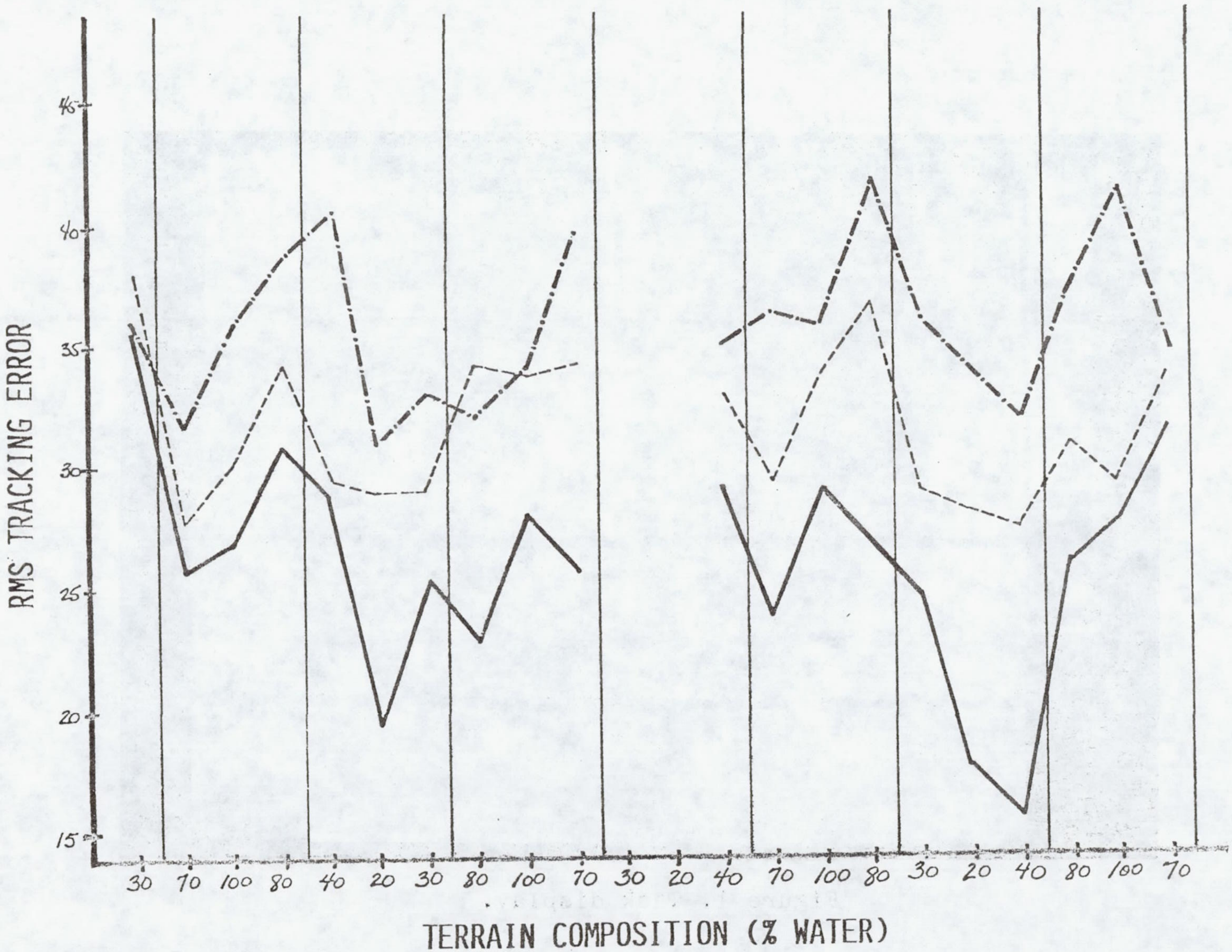

Figure 2. RMS tracking error.

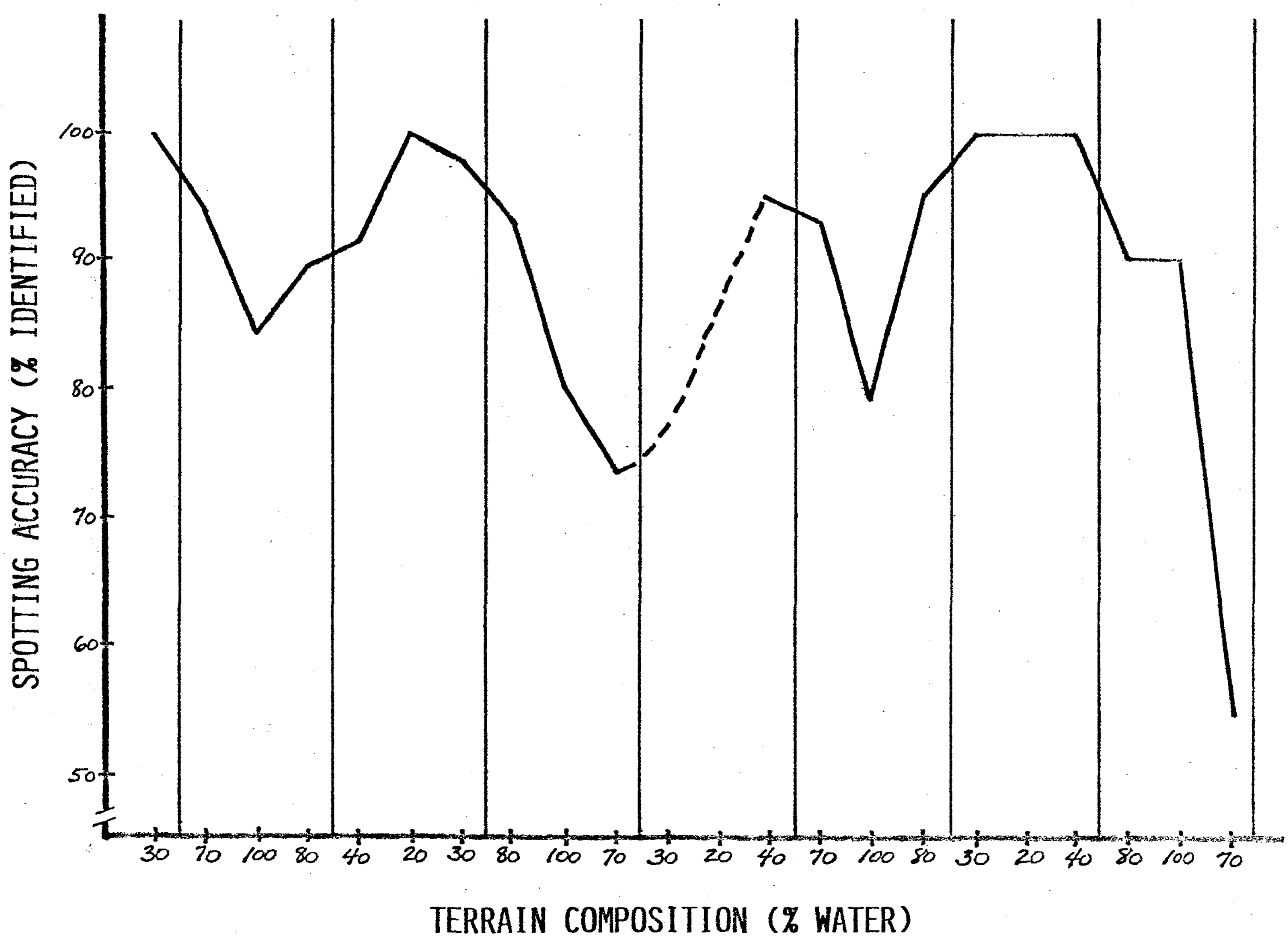

Figure 3. Spotting accuracy.

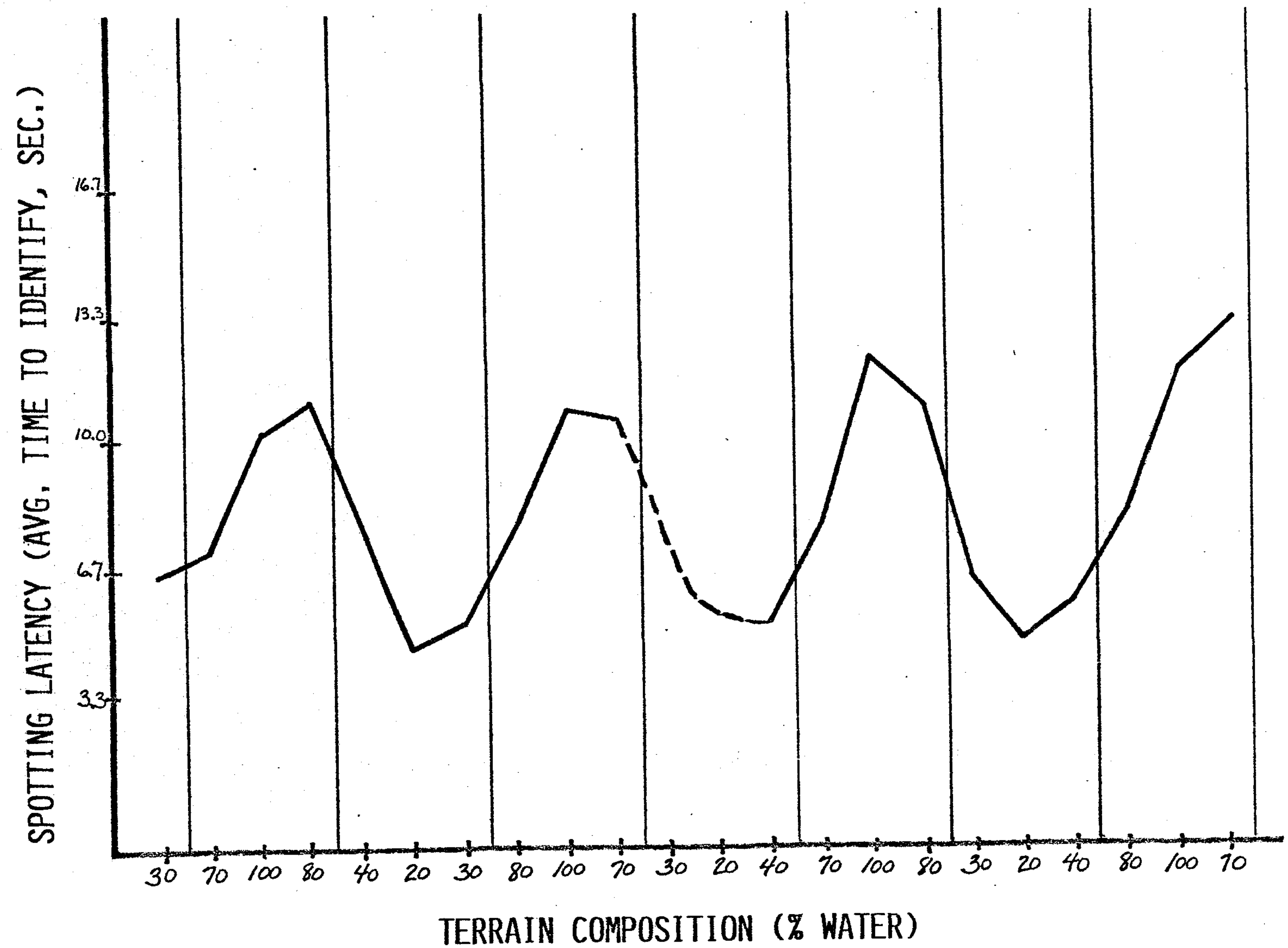

Figure 4. Spotting latency.