Designing the Interface to Encourage More Cognitive Processing

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Abstract. Cognitive engineering aims to provide operators with immediate access to as much relevant information as possible. However, this can encourage display-based strategies that do not involve committing information to memory. To overcome this problem, a somewhat counterintuitive method is discussed, based upon the theory of soft constraints [1], that involves delaying access to some critical information by one or two seconds. This design technique induces a more planful and memory-based strategy that can improve recall, develop more planning behavior, improve problem solving, and protect against the negative effects of interruption. Furthermore, we provide some preliminary results that this more memory-intensive strategy can be trained through past experience with high access cost and then used in situations where access cost is minimal. This was the case when only half of the training trials involved a higher access cost. Further research is needed to ascertain how long training effects last and what are the ideal training regimes for different types of task.

Keywords: Soft constraints, information access cost, strategy, memory, planning, problem solving, interruption, transfer.

1 Rationale for Increasing Access Cost

Interface design involves optimising interactions between human operators and the systems with which they work. Given increased technology, operators of complex systems can become deluged with information that they do not deeply process and adopt what is known as a 'display-based strategy', using the display as a form of external memory [1-3]. The unfortunate consequence is that critical information may not be processed deeply and subsequent performance may be impaired [3]. A novel, exciting, and counterintuitive solution, based upon both theory and empirical evidence, involves inserting a couple of seconds delay when operators attempt to access important information. Paying this small extra time cost induces a deeper cognitive processing strategy, involving more memory and planning, which improves performance in

D. Harris (Ed.): EPCE 2014, LNAI 8532, pp. 255–264, 2014.

some task situations where such factors are important [3-6]. This paper discusses the theory underpinning this technique together with empirical evidence concerning its beneficial effect and how it may be used for training a more cognitively intensive strategy.

Imposing a small access cost encourages a shift to a more memory-based strategy by changing the cost/benefit balance facing the operator, making a display-based strategy less attractive. The theory underpinning this approach comes from Anderson's [7] seminal work on adaptive cognition and the theory of soft constraints [1]. Gray et al. [1] proposed that a task is made up of 'hard' and 'soft' constraints. Hard constraints dictate what behaviours are possible whilst soft constraints concern what strategy the operator chooses. The interface designer can manipulate the cost/benefit balance facing the operator by imposing a small cost in accessing information (a hard constraint) that will increase the degree of memory-based strategy (a soft constraint) adopted by the operator. This strategy shift occurs because participants find it beneficial to encode and plan what to do with the information rather than paying the access cost of a brief time delay on each occasion the information is viewed [1]. Therefore, somewhat counter-intuitively, increasing the cost associated with accessing information in an interface can induce the deployment of a more memory-based strategy that involves greater planning. A similar finding is that when the cost of executing a move is increased during problem solving, by requiring a series of extra key presses, this also results in increased planning of problem solving [8-9]. However these studies were concerned with the extra time cost associated with making a move rather than that concerned with accessing information, as in the studies reported in this paper.

2 The Effects of Inducing a More Memory-Based Strategy by Increasing Access Cost

Information access cost is defined as the time, physical and mental effort involved in accessing task critical information [1]. In studies examining its effect, access cost typically varies among three levels [3-4]. With a Low access cost, some important goal-state information is permanently visible at the interface. With a Medium access cost, this information is covered with a mask that disappears immediately when a mouse cursor is moved into the area containing the information and reappears when the cursor is moved out of that area. A High access cost has the same mouse movement as a Medium access cost although it also involves an extra second or two lock-out time for the mask to disappear when attempting to view the goal-state information.

The result of increasing access cost is that the person engages in a more memory-based strategy, involving more encoding and planning. This was demonstrated originally by Fu and Gray [2] and subsequently in other studies [3-6] using the Blocks World Task (BWT, Figure 1). The BWT involves recreating a target pattern of colored blocks in a target window (top left of Figure 1) in a workspace window (top right of Figure 1) by dragging and dropping colored blocks from a resource palette (bottom of Figure 1). In the Waldron et al. [3] study, the three levels of Low, Medium and High access cost were used between participants with a lockout time of 1 second in the High access cost condition and participants had to recall the goal pattern in a surprise recall test. There was a switch from a display-based strategy in the Low access condition to a more memory-based strategy in the higher cost conditions, with more blocks correctly recalled in the Medium and High cost conditions (Table 1).

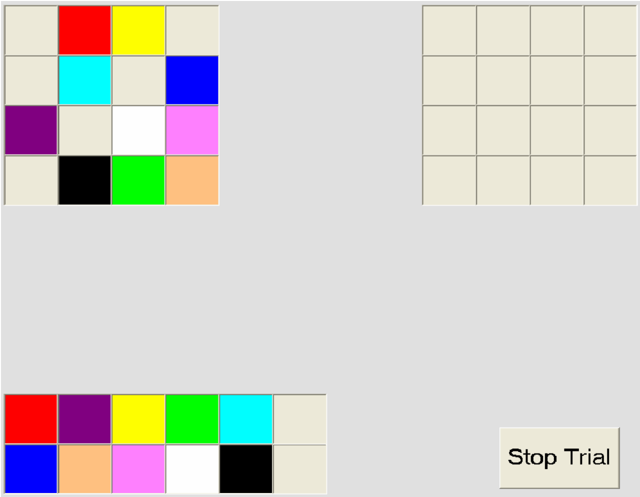

Fig. 1. Example of a Low information access cost start-state

Table 1. Effect of goal-state access cost on recall in the BWT [3: Experiment 1]

High Access Cost		Medium Access Cost		Low Access Cost	
Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
9.00	1.78	9.00	4.37	4.70	1.95

Typically better recall and better planning go together. A study by Waldron, Patrick and Duggan [10] directly investigated the effect of varying access cost on both the nature of planning (memory- versus display-based) and when planning occurred (before or during action) during problem solving. In a High access condition (with a 2.5 second lockout cost) more planning before action (i.e., before executing initial moves) was observed and less planning during action. This was demonstrated through longer first-move latencies and more moves executed per goal-state inspection. These findings therefore suggest that interface designers have a potential technique for inducing more intensive cognitive processing of information that involves greater encoding of information and planning of future moves.

However, this method is not a panacea as in some situations (e.g., fast-paced safety-critical environments) it may not be practicable or feasible and thus we need more evidence concerning when increasing access cost may be beneficial. Also, whilst one strategy for improving performance is to design the interface so that access cost is increased for some critical information, another strategy is to attempt to train operators to adopt a more memory-based strategy for future situations when an access cost cannot or should not be included within an interface. Consequently the remainder of this paper considers two issues. First, what other situation(s) may benefit from a more memory-based planning strategy? Second, to what extent is it possible to train people, using the access cost method, to adopt a more cognitively intensive strategy?

3 Increasing Information Access Cost to Mitigate Negative Effects of Interruption

One practical situation that may benefit from an increased access cost approach is where performance is interrupted. Interruptions are intrinsic to our everyday lives and a wealth of applied and laboratory research evidence suggests that their effect is almost universally negative [13-16]. This has been demonstrated in various settings including offices, the flight deck, nuclear power plants and hospitals [17-18]. Negative effects include delays in resuming the interrupted task [13] [19], increased time to complete the interrupted task [20], and decreased accuracy of performance [21]. These performance deficits are likely due to the forgetting of task related goals during interruption [22] and one might expect such forgetting to be mitigated if a more memory-based processing strategy is developed before interruption.

Two studies are reported that investigated this issue. The first study by Morgan et al. [4], using the BWT, found that High access cost (involving a 2.5 second delay) reduced forgetting of planned copying moves following interruption, particularly when interruption occurred on half of all trials. It also improved prospective memory following two different interrupting tasks, even when one required the same type of processing resource as the primary task. A second study by Morgan and Patrick [5] examined whether higher access cost could protect against interruption during problem solving. Specifically, whether it was possible to induce more internal planning in the four disk Tower of Hanoi (ToH) that would result in not only more efficient problem solving but also increased resistance to interruption. In Experiment 1, more memory-based planning was developed by imposing a High access cost (with a 2.5 second delay to uncover the goal-state) that resulted in fewer moves to solution and the development of a more efficient sub-goaling strategy with more perfect solutions. In Experiment 2, High access cost protected performance against a ten second interruption irrespective of the interrupting task (blank screen-control, dissimilar mental arithmetic, or similar three disk ToH). Participants resumed more problems from memory with a High access cost and executed more moves after interruption without reviewing the goal-state (Table 2). Also fewer moves were required to complete interrupted ToH problems (Table 2).

Table 2. Effect of goal-state access cost on performance after interruption [5: Experiment 2)

Post-interruption performance measure	IAC	Mean	SD
Number of trials resumed without re-visiting goal state (max = 9)	High	6.30	1.86
	Medium	1.89	1.41
Number of moves executed without re-visiting goal state	High	5.33	2.24
	Medium	0.88	0.81
Number of moves to complete primary task following interruption	High	9.87	0.39
	Medium	10.20	0.35
	Low	11.27	0.44

The more memory-based planning strategy, induced by High access cost, presumably strengthened participants' goals during planning and problem solving, making them less susceptible to decay and interference from interruption. The finding that planning is enhanced due to higher access cost is important because planning rarely occurs spontaneously [11] and people are reluctant to use internal as opposed to external memory resources to plan [12]. Increasing access cost provides a means of encouraging more planning and protecting against forgetting following interruption.

4 Increasing Information Access Cost to Maximize the Utility of an Interruption Lag

Another proposed method for overcoming interruption effects is to use an interruption lag, which is a time delay between interruption annunciation (e.g., telephone ringing) and initiation of the interrupting task (e.g., answering telephone), during which the person can prepare to return to the interrupted task [23]. This provides an opportunity to rehearse a goal prior to task interruption and associate it with a salient reminder/priming cue. An interruption lag can lead to faster primary task resumption [13] although the time saved can be less than that imposed by the lag [16]. It is therefore desirable that the interruption lag is used as effectively as possible to encode goals prior to interruption. One means of trying to effect this is to introduce an access cost to induce a more memory-based strategy that should, in turn, result in better encoding of goals during the interruption lag.

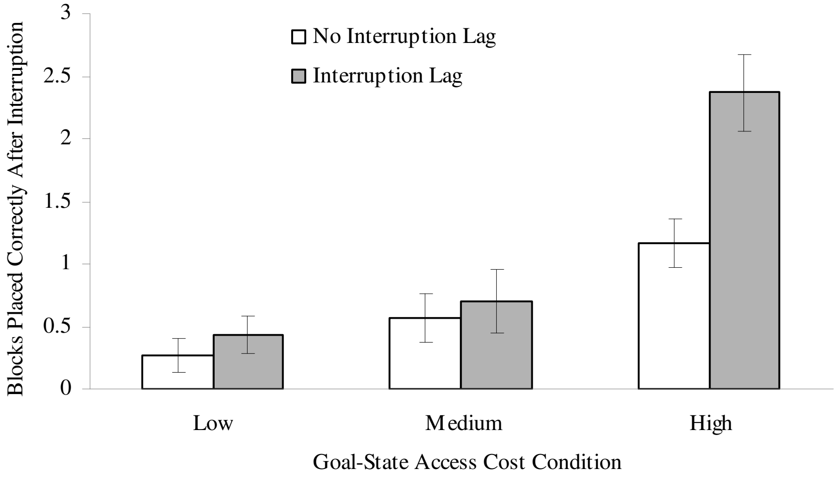

Fig. 2. Effect of access cost and interruption lag on recall after interruption [6: Experiment 2)

In order to examine this, Morgan et al. [6] used the BWT, and tested whether a 5-second lag was sufficient to recall planned moves and whether any benefit was dependent upon the strength of the memory-based strategy used to perform the task. Prospective memory was very poor with and without an interruption lag when the task was performed under Low and Medium access costs (Figure 2). However, prospective memory was not only improved under High access cost *without* an interruption lag, but this improvement was substantial *with* a lag (Figure 2).

5 Training a More Memory-Based Planning Strategy

The above studies have manipulated access cost through interface design and this has affected the degree of memory-based strategy adopted to perform the task. A further important issue is whether a high memory-based strategy can be trained and maintained when this access cost is no longer present in the design of the interface. The question is therefore whether it is possible to train a more memory-based strategy and the extent that this will carry-over to performance situations that do not involve an extra lockout time. This is not only a practical but also an important theoretical issue. The theory of soft constraints [1] emphasizes how the degree of memory-based strategy utilized to perform a task adapts to millisecond changes in the constraints of the current task environment. Gray et al. [2, p. 463] acknowledge that cost-benefit considerations may be overridden by factors such as training or by deliberately adopted top-down strategies. Interestingly, training relies on using past rather than current experience and therefore the following study investigated the relative contribution of past experience to present performance.

The study involved the BWT and a simple training and transfer design. Participants received twenty training trials with varying occurrences of high access cost (with a 2.5 second lockout cost in the High access cost condition) and then ten transfer trials under Medium access cost (i.e., with no lockout time). The extent that the high memory-based strategy, developed in training, was deployed in the medium access transfer environment is indicative of the degree of control exerted by past experience in the training environment as opposed to the constraints of the current transfer environment. It was predicted that increasing the amount of high access cost experienced during training would increase the degree of memory-based strategy deployed in the transfer environment.

5.1 Method

Participants. One-hundred and forty Cardiff University students participated for course credit and were randomly assigned to one of five conditions. There were 121 females and 19 males with an age range of 18-25 years (M=20.02 SD= 2.56).

Design. The experiment used the BWT and a between participants design with a training and transfer phase. The percentage of High access cost training trials was manipulated across five conditions ranging between 0 to 100% High access cost over 20 training trials (0%High = 20 Medium access cost training trials with no High access cost trials; 25%High; 50%High; 75%High; and 100%High). Medium access cost was used in the remaining training trials. Thus, in the 25%High condition, five of the twenty training trials involved High access cost and the other 15 involved Medium access cost. In order to facilitate comparison amongst these conditions on the training trials, five Medium access trials were presented on trials 1, 5, 10, 15 and 20 for all conditions, excluding 100%High. Apart from these trials, the order of High access cost trials was randomized. The transfer environment involved 10 Medium access cost trials.

5.2 Results and Discussion

One key measure of the degree of memory-based strategy is the number of blocks correctly copied after the first target window visit, which increases with more encoding and planning. The results are displayed in Figure 3 and it appears that more training with higher access cost led to a greater degree of memory-based strategy in both training and transfer situations. A 5 (condition: 0%High, 25%High, 50%High, 75%High, & 100%High) x 2 (environment: training and transfer) mixed ANOVA found, besides both main effects being significant, an interaction between the two variables, $F(4, 135) = 3.05$, $MSE = .26$, $p < .05$, $f = .30$. Participants in the 100%, 75%, and 50%High conditions copied more blocks correctly on the first visit to the target window than those in the 0%High condition in both training (*ps* < .001, .001, and .01 respectively) and transfer environments (*ps* < .05, .01, and .05 respectively).

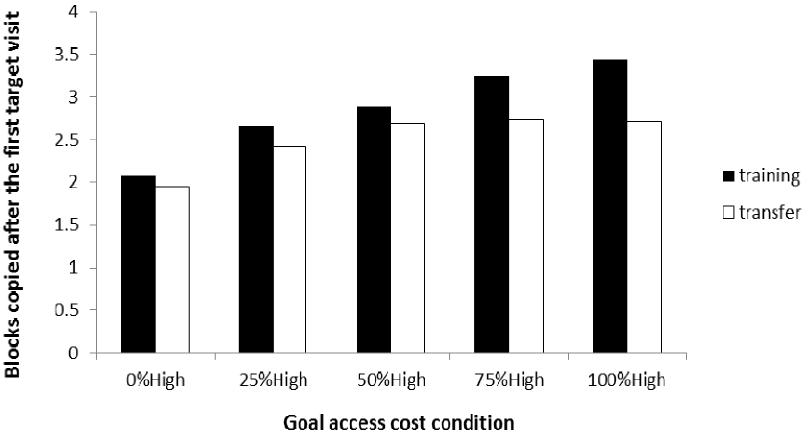

Fig. 3. Number of blocks copied after the first target window visit across training and transfer

Therefore more training with a high access cost increased the degree of memory-based strategy deployed in both training and transfer, as predicted. This indicates that there is an increasing carry-over effect from the training to the transfer trials because participants in the higher access cost training conditions did not exhibit the same degree of strategy as those without such training (Figure 3). Consequently we can conclude that the degree of memory-based strategy used depends not only on the current environment but also on past training. The effects of such training do not disappear immediately but are still evident over a series of 10 trials in which the access cost does not involve any lockout time.

This finding is important from both practical and theoretical perspectives. The results indicate that it is possible to increase the degree of memory-based strategy by not only providing 20 training trials with high access cost but also by dispersing fewer high access cost training trials amongst trials without such high access cost. The next research question is what is the minimal amount of training with high access cost necessary to achieve such an effect? From the current data, at least 50% of training trials are needed to increase the degree of strategy adopted when a lockout delay is no longer required to view the target pattern. However the current data does not inform us whether using less training trials than 20, and all with a high access cost, would also have a carry-over effect on transfer trials with no such cost.

6 Conclusions

Information access costs are not just an academic issue as they are intrinsic to our everyday computer environments when we try to avoid information clutter and when we have to pay such costs in opening and reopening applications, emails, or documents. Access costs are also imposed when a password has to be recalled or the "terms" of an agreement have to be read. However, even though such costs occur naturally within computer environments, deliberately manipulating them may seem to contradict the traditional principles of cognitive engineering that strive to provide users with immediately relevant information that takes advantage of human perceptual abilities. For example, ecological interface design proposes that complex relationships between variables should be made directly accessible to operators in a manner that allows effortless extraction of information from the interface [24]. However, the theory of soft constraints [1] together with associated empirical evidence [4-6] suggest that this may not always be the best goal for interface design. We do not propose this as a panacea and practical applications have to be selected carefully. Imposing an access cost is a possible design strategy when important information has to be retained, possibly because it is no longer available or has to be acted upon in a timely manner without having time to search again for the information source. Such a situation is relevant not only to everyday computer-based work situations but also safety-critical environments in which incidents occur because of a failure to recall critical task information, sometimes with devastating consequences [25]. This paper has focused on two research areas that may benefit from the introduction of information access delays. First, it provides a new means of mitigating negative effects of forgetting following interruption by encouraging a more memory-based strategy with increased information access cost. It also facilitates the use of an interruption lag. Second, we have collected some preliminary evidence that it may be possible to train a more memory-based strategy although at present we need to know how long training effects last and what are the ideal training regimes for different types of task.

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