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Workspace Availability and Soft Constraints

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WORKSPACE AVAILABILITY AND SOFT CONSTRAINTS

By

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I dedicate this to my family and friends without whom this project would not have been possible.

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ABSTRACT

According to the soft constraints hypothesis (SCH), when engaging in an interactive task, behavior could be broken down into selection between perceptual-motor and cognitive components. This approach holds that effort (measured in the time cost to perform each routine) guides selection, where quicker routines are more likely to be selected regardless of their origin (i.e., perceptual-motor or cognitive). This study examined the influence of SCH on a novel aspect of the task; the workspace area, where information was to be inputted. Study results support the idea that workspace availability influences the cost-benefit tradeoff driving soft constraints, and that the nature of that influence is guided by the role of the workspace area.

CHAPTER 1

INTRODUCTION

Imagine driving to an unfamiliar location using written directions. While driving, you may choose to lookup each directional step at a time until you reach your destination. Another option is trying to memorize as many steps as you can at one time and relying on your memory. Any chosen strategy will either offload memory effort by increasing the interaction with the environment, or minimize environment interaction for memory reliance.

For tasks involving interactive behavior, such as using directions, our strategy can be broken up further into low-level cognitive, perceptual, and motor resources (e.g., Gray & Boehm-Davis, 2000). A more interaction-intensive strategy is then characterized by greater reliance on perceptual-motor operations, while a memory-intensive approach relies more on cognitive resources.

Indeed, the way by which we select between low level cognitive, motor and perceptual routines (i.e., micro-strategies) has a strong role in shaping our total strategy and performance on complex tasks (Lohse & Johnson, 1996; O'Hara & Payne 1998, 1999; Kirsh & Maglio, 1994). However, the exact relationship between the selections of said routines has been the subject of some debate, with competing claims made about the way in which these components are selected.

One claim from embodied cognition has been that the human control system works to minimize cognitive demands, by favoring the use of perceptual-motor routines (Cary & Carlson, 1999; Ballard, Hayhoe & Pelz, 1995; Pelz, 1996; Hayhoe, 2000). A specific theory based on this view, the *minimum theory hypothesis* (MMH, Wilson, 2002), views working memory as limited; either possessing a limited number of slots (Miller, 1956), or limited amount of activation (Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996).

According to this view, the control system minimizes the demand placed on the limited capacity memory by offloading work into the perceptual-motor system. As a consequence of this hypothesis, when faced with a task in which different microstrategies (i.e., different combinations of perceptual, motor, and cognitive operations) are available, perceptual-motor routines are favored over memory ones, even when the cost (e.g., as measured by time) of their selection is greater than those of competing memory-based routines.

In contrast, proponents of the soft constraints hypothesis (SCH, Gray & Fu, 2004; Gray, Sims, & Fu, 2006) argue that the human control system tends to select between sequences of cognitive, perceptual, and motor resources by choosing ones that minimize effort (with more effortful routines defined as those taking longer to complete), regardless of the type of structural resource component implicated (i.e., cognitive, motor, perceptual). Effort serves as a soft, rather than hard, constraint, as it may be overridden by training or deliberately adapted strategies. Additionally, since effort constrains the system locally (in the selection of least effortful interactive routines at each step in the process) it may not produce globally optimal performance (optimal completion of the task).

In a study in which participants had to program a VCR, Gray and Fu (2004) found that increasing the perceptual-motor effort required to access information in the world (i.e., by requiring participants to uncover a window containing the to-be-programmed TV show times) led to greater reliance on information in the head (i.e., imperfect memory for the show-time information) and a decreased reliance on perceptual-motor resources (i.e., investment in the motor response to uncover the show-time information). Effort was quantified as the time cost associated with the various competing cognitive, perceptual and motor routines available. The experimental manipulation of covering the information window was effortful in that it required an additional mouse movement and mouse click, before the window uncovered, which translated to a penalty on the order of a few hundred milliseconds. The usefulness of the soft constraints hypothesis is that the small increase in perceptual-motor effort (in the order of milliseconds) was sufficient to encourage participants to shift to a more memory-intensive strategy.

Furthermore, the increased reliance on memory-intensive routines in response to the covered information window resulted in poorer performance. This finding was consistent with the local influence of soft constraints. This finding led the authors to argue that the local constraints at the microstrategy level, which propelled participants to minimize effort locally, were resulting in a sequence of routine selection that was globally inefficient.

Gray, Sims and Fu (2006) found similar results in a puzzle task where participants had to reproduce a block pattern from one window to another. Similarly to the VCR task, restricting perceptual access (via delaying access or other perceptual obstructions) to the window containing the relevant information led participants to rely more on memory, by making fewer perceptual accesses to, and spending longer time in, that window.

The results of both sets of SCH experiments are contrary to the minimum memory hypothesis. Instead of conserving memory resources, participants frequently selected more memory-intensive routines as perceptual motor effort was increased. This research demonstrated that the amount of effort (measured by time) required to perform the task, irrespective of whether that effort was perceptual-motor or cognitively based, acted as the constraining factor that moved the system toward locally optimal but not necessarily globally optimal performance.

1.1 Workspace Availability and Microstrategy Selection

Gray and colleagues (Gray & Fu, 2004; Gray, Sims, & Fu, 2006) manipulated effort by restricting either perceptual and/or perceptual-motor access to the *source* information only (i.e., information in the world that would serve as input values in the target task—e.g., show-time information to be used in the *workspace* VCR programming task). Although the SCH should, at least theoretically, apply to microstrategy selection with respect to all aspects of the task (i.e., effort required to access information and/or perform tasks with respect to both source and target information), the availability of *workspace* information was not held constant across studies nor was it considered in the experimental design. The workspace area serves as the input interface where learned information has to be reproduced. In the research by Gray and Fu (2004), the workspace information (i.e., information in the VCR-programming window) was unrestricted and constantly available throughout the whole experiment. In the research by Gray et al. (2006), the workspace information (i.e., the workspace area in which participants placed their blocks) was covered and only available after participants invested perceptual-motor effort in uncovering that window (i.e., by moving the mouse cursor into the target window).

The difference in availability of the workspace area between the two studies may have played a role in two ways.

First, restricting the source window resulted in a considerably stronger shift towards memorization (i.e., fewer, longer accesses to the information window) on the first study (Gray & Fu, 2004), where the workspace area was restricted, than on the second study, where the workspace area was more available (Gray, Sim & Fu, 2006).

Additionally, increasing the cost of accessing information to the source window inhibited performance on the VCR study, and improved it on the World Block study.

The differences between studies were not mentioned in Gray et al (2006), possibly because the two studies used different tasks (i.e., VCR programming vs. Block World task), and different performance criterion (i.e., mistakes vs. total time).

In the present study, we were interested in examining the extent to which the differences between the two studies by Gray and colleagues may be due to the availability of the target window. Consequently, we replicated the important features of the two experiments and manipulated workspace availability within the same task (i.e., VCR programming task). In the following section, we discuss how to tackle the potential effects of this additional soft constraint (i.e., workspace availability) in the context of an integrative task.

1.2 Workspace Availability Considerations

In the aforementioned studies, an increase in perceptual-motor access to the source window resulted in a strategic shift from an interaction intensive strategy (characterized by frequent short accesses to the task environment) to a more memory intensive strategy, characterized by fewer, longer accesses (Gray & Fu, 2004; Gray et al., 2006) to the information window. To measure strategy, interaction with task environment was determined by restricting, and observing the window containing task related information (source window).

We claim that this study's novel restriction of the workspace window (VCR window), will share common characteristics with previous source (info window) restrictions tested by soft constraints studies, but will also differ as function of differences between the two task windows. Our predictions are guided by three main assumptions.

First, we expect that during VCR window access, soft constraints principles should apply, with selection between perceptual, motor and memory routines dictated by *locally* minimizing effort. This means that any strategic changes resulting from restricting the workspace (i.e., covering the VCR) must occur at the time of VCR access. For that reason, we decided to look at the pattern of accesses to the VCR window, to infer the strategy influence of our novel VCR restriction. We generally expect that increasing effort to accesses the VCR should result in greater memorization in that window.

Second, we cannot assume that restricting access to the VCR window will have the same pattern of influence on the VCR window as restricting the information window has been found to have on information window accesses, as the two windows differ perceptually, and more importantly, functionally. This idea will be discussed in greater detail in the predictions section.

Third, as this task requires integration of information between two windows, the two task windows should not be observed in isolation. One possibility is that restricting one window, may influence strategy or performance on the other window as well. Another possibility is that the perceptual availability of the two windows may interact.

CHAPTER 2

EXPERIMENT 1

Two major research questions guided this study: (a) What influence will workspace availability have based on SC and its function in the task? (b) Can the influence of workspace availability and its relationship with source availability explain the differences between the two previous SC studies?.

These questions were addressed experimentally by using a similar VCR programming task to the original Gray and Fu (2004) study, with a novel addition. While the Gray and Fu (2004) study manipulated access to the source (information) window by varying its access cost in terms of effort, this study also manipulated workspace (VCR window) availability. The VCR window was either available for the entire duration of the experiment (baseline condition), or uncovered upon mouse entrance (perceptually restricted condition). For our source manipulation, the information window was either covered until mouse entrance (baseline condition), or covered and delayed by 1 second before uncovering upon mouse entrance (perceptually restricted condition). See Figure 2, P 21.

2.1 Predictions

2.1.1 Strategy Predictions

2.1.1.1 Restricting the Information Window. This study manipulation of restricting perceptual-motor access to the source (i.e., Delaying the information window) was expected to result in greater memory reliance characterized by fewer, and longer, accesses to the information window. Such results would simply serve as replication of previous soft constraints finding, congruent with the notion that increasing perceptual-motor effort in a task leads participants to minimize effort by relying on their memory.

2.1.1.2 Restricting the VCR Window. As stated previously, we expect the soft constraints hypothesis to apply to VCR accesses as well. As the soft constraints work locally, restricting perceptual-motor access at the VCR window should drive subjects to rely on memorization, and decrease their reliance on interaction-oriented routines during VCR access.

The next question is then, what could greater memorization at the VCR mean? In order to tackle this issue, it is useful to step back and examine the function of the two windows.

Recall that the information window contains the show-related information to be programmed. A shift towards memory-intensive strategy (i.e., longer, fewer accesses to the information window) should then be mostly associated with more effortful encoding.

The Workspace (VCR window), however, does not contain source information, but rather serves as an input interface where the show information is to be reproduced. Greater memorization at the VCR window, therefore, entails greater retrieval, as the VCR window does not contain any new information to be encoded.

Consequently, we expect that the additional constrain of covering the VCR window should lead participants to minimize effort at the time of VCR access, by putting more effort towards *retrieving* show information. This means, that participants at least should be spending more time at the VCR window.

2.1.1.3 Additional Information Window Influence. Recall, that the two task windows do not exist in isolation, but rather are integrated, where information from one window must be inserted in the other. From our first hypothesis we expect that limiting perceptual-motor access to the information window will result greater encoding at that window. This means that at the subsequent access to the VCR window, more information or more strongly encoded information will be available, which should take longer time to retrieve.

Therefore, restricting the information window should somewhat increase memory reliance at the VCR window (i.e., increase VCR access duration). Please note, however, that we expect this effect to be mild, as participants will be constrained differently at the VCR window, this issue will be brought up again in the next section.

2.1.2 Performance Interaction Prediction

Recall that the original Gray studies (Gray & Fu, 2004; Gray, et al., 2006), differed with respect to performance. Restricting perceptual-motor access to the source window resulted in diminished performance on the first study and improved performance on the other.

Considering the difference in workspace availability in the two studies, a major restricted question is then, how could the availability of the workspace area influence the effect of source (e.g., information window) availability on task performance?

As mentioned previously, a major issue to consider is the role of the two windows with respect to the soft constraints hypothesis. First, as soft constraints work locally, increasing effort to access the information window was expected to increase memorization at the time of access. In particular, greater memorization at the time of information access was expected to produce greater *encoding*, as the information window contains information to be learned.

However, the local influence of the soft constraints also means that the more effortful encoding produced by restricting the source (i.e., information window), does not guarantee an equally effortful retrieval at the VCR window, as local constraints at the time of retrieval (i.e., VCR access) are different (although from hypothesis 3, we do expect a modest increase in retrieval). In such a scenario, participants may 'waste' some of their encoded information by not putting forth full effort on retrieval, which will result in incomplete or incorrectly retrieved information. This is congruent with the soft constraints notion that locally optimal routines may not lead to globally optimal routines.

The manipulation introduced in this study of covering the VCR was designed to deal with this issue. Increasing perceptual-motor access to the VCR window was expected to locally encourage greater memorization at that window by restricting participants at the time of retrieval (VCR access).

Consequently, restricting the information window should result in greater memory when the VCR is also restricted, as participants will be locally constrained to not only encode more information during access to the information window (due to source restriction), but also to more effortfully retrieve information at the VCR window. This process of difficult retrieval has been shown to be very beneficial to memory (Bjork, 1988; Pavlik & Anderson, 2005).

We therefore expect an interaction with regard to performance, where restricting the source window (delaying the information window) should have a significantly stronger influence on performance when the VCR window is available as opposed to covered.

This prediction is also congruent with the difference between the two soft constraints studies, where covering the source window diminished performance under an available workspace area (Gray and Fu, 2004) and improved it when the workspace area was covered (Gray, Sim & Fu, 2006).

2.1.3 Summary of Predictions

In summary, we expect the effect of restricting the source (information window) to result in more effortful encoding at the time of information access, and somewhat more effortful retrieval at the VCR window. Restricting the VCR should result in considerable increase in memory reliance at the VCR window, associated with more effortful retrieval.

Furthermore, we expect an interaction between both perceptual-motor restrictions, with covered VCR window enhancing the effect of restricting the information window on performance, as opposed to an available VCR.

2.2 Hypotheses

2.2.1 Hypothesis 1

Increasing effort to access the information window (i.e., via adding a delay) will result in fewer accesses and longer average access duration to that window.

2.2.2 Hypothesis 2

Increasing effort to access the VCR window (i.e., via adding a cover) will result in longer average access duration to that window.

2.2.3 Hypothesis 3

Increasing perceptual-motor access to the Information window will result in fewer accesses and average access duration to the VCR window.

2.2.4 Hypothesis 4

Covering the information window will influence performance differently depending on the availability of the VCR window (interaction). Under an available VCR window, restricting the information window should be considerably better for performance than under a restricted (covered) VCR window.

2.3 Method

2.3.1 Participants

There were 64 participants in the study, who were university undergraduates from an institution in the south east United States, who took part in the experiment for course credit. Participants (n = 16) were randomly assigned to one of four conditions (see below).

2.3.2 Stimuli and Materials

A computer-based VCR programming interface was created in Visual Basic and presented on a 17" monitor. As per Gray and Fu (2004), the interface consisted of two windows: An information window (source) and a VCR window (target). The information window contained five pieces of show-related information: A show name, date (MM/DD/YYY), start time (HH:MM:AM/PM) and end time of the show, and a two-digit channel on which the show should be recorded). The VCR window (target) contained 8 buttons representing each parameter to be programmed in the show (i.e., show name, show hour, etc.). The VCR also contained 2 arrow buttons used to assist subjects in programming numerical information, as well as a monitor which displayed each change to a show parameter.

The character length of the shows was very similar with the average show length at 12.8 (SD=1.7) characters. Real movies were selected as show names. Specifically, old movies were chosen to minimize familiarity. The shows were given arbitrary times and dates, as long as they were real dates in the near future. The order of shows was not randomized.

2.3.2 Procedure

The study began with a demonstration of the VCR programming task, as participants watched the experimenter program all of the details of one practice show, available in the information window (i.e., show name, channel, date, and start/end time), into the VCR window. During the demonstration, each aspect of the programming task was explained to the participant. Participants then practiced programming the information for two practice shows and any questions regarding features or procedures of the task were answered at that time. After each of the practice shows had been programmed successfully (all participants successfully completed this stage), the experimenter left the room while participants programmed five additional shows. Once participants were certain that all relevant information had been entered in the VCR correctly, they were instructed to press an end trial button in the VCR window. All five show parameters entered by participants in the VCR window had to match the criterion information given in the information window. Participants were immediately notified if their programming was correct or incorrect. If a show was programmed incorrectly, participants were given an error message, but were not notified where mistakes took place. After correctly programming a show, participants moved on to the next show until all shows had been programmed correctly. The experiment took about 20 minutes to complete.

The number and duration of accesses to both task windows (Information and VCR windows) were recorded into a log file for each access/trial. In addition, the “End Trial” button was time-stamped regardless of whether the trial was completed correctly or not. This allowed for measuring trial length when the button was pressed correctly, and the number and time of mistakes when the button was pressed incorrectly. These measures allowed for reconstruction of participants’ strategy and performance during the task.

Prior to the experiment, participants were assigned to one of four conditions that differed on access cost/availability of the source (show information) and target (VCR) windows. In the first condition, the information window remained covered unless the mouse cursor entered its boundaries, at which point this window was immediately uncovered and available to participants. The information window was covered immediately once the mouse cursor had left its borders. The VCR window was available throughout this condition (i.e., covered/non-delayed source and available target). In the second condition, the information window was covered as per the previous condition but there was also a delay of one second, after the mouse cursor entered its boundaries, before the window was uncovered. As per the first condition, the information window was covered immediately once the mouse cursor had left its borders. The VCR window was available throughout the condition (i.e., covered/delayed source and available target). In the third condition, the information window was identical to the first condition. In addition, the VCR window remained covered unless the mouse cursor entered its boundaries, at which point this window was immediately uncovered and available to participants (i.e., covered/non-delayed source and covered target). In the final condition, the information window was identical to the second condition and the VCR window was identical to the third condition (i.e., covered/delayed source and available target).

Table 1: Study Design for Experiment 1

Condition	Description	Information Window	VCR Window
1	Both Windows Avail.	covered	available
2	Restricted Info Window	covered and Delayed(1 Second)	available
3	Restricted VCR Window	covered	covered
4	Restricted Both	covered and Delayed(1 Second)	covered

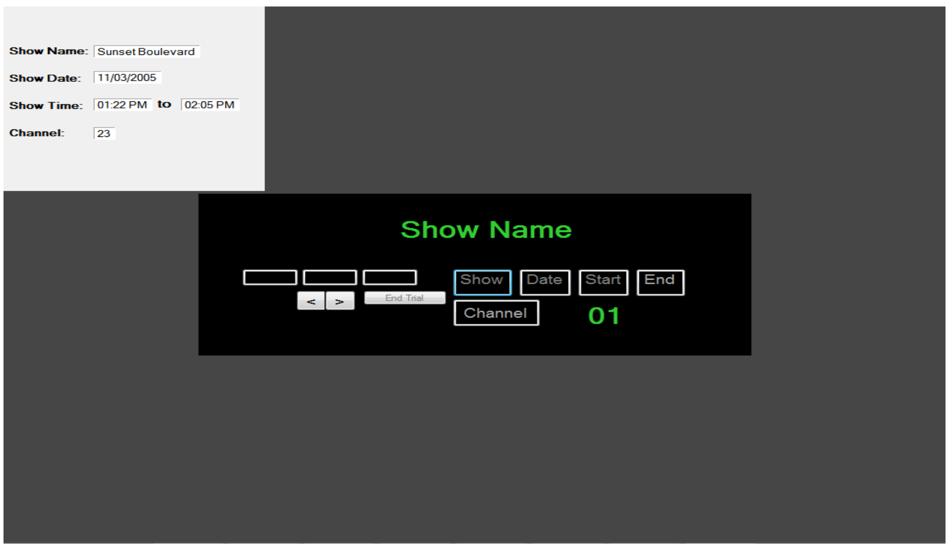

Figure 1: A screen shot of the two task windows when uncovered. The information window (top-left) contains the show related information to be programmed into the VCR window (Middle).

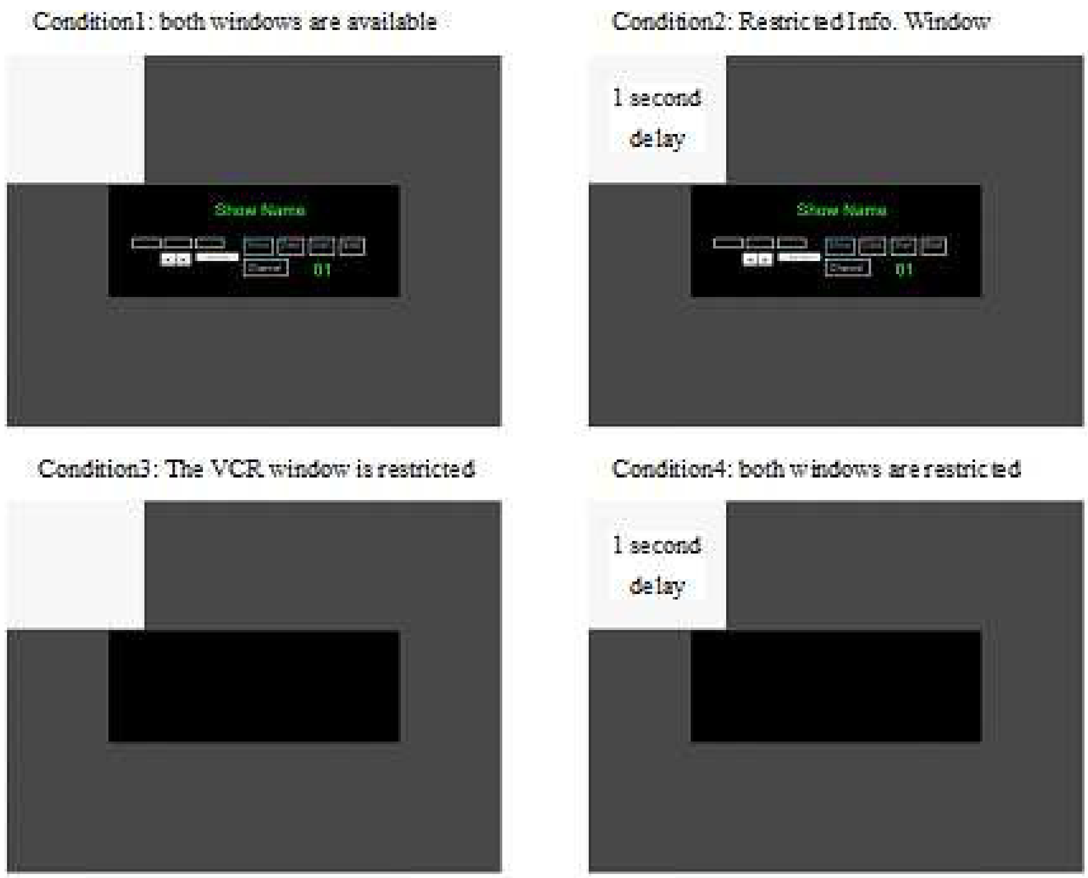

Figure 2: Experiment 1 screen shot. Each one of the 4 conditions is depicted here at its default state (prior to mouse entrance for both windows). Unless delayed, each covered window uncovered immediately following mouse entrance. Delayed windows took 1 second to uncover after mouse entrance. All covered windows were immediately covered once the mouse cursor left their borders.

2.4 Results

This study contained 5 measures of interest. The two variables of number of accesses and average access duration (in seconds) to the both windows were used to examine strategy, while total task time was used as the performance measure. The 1 second delay to the information window was not counted in this analysis for neither total time nor average access duration.

2.4.1 Strategy: Number of Accesses. Duration of First Access

A 2X2X4 mixed plot analysis of variance (ANOVA) was performed, with information availability (covered vs. delayed info. window) and VCR window availability (available vs. covered) serving as between subjects factors, and access features (i.e., number of information window accesses, average access duration to the information window, number of VCR window accesses, average access duration to the VCR window) serving as within-subjects variables**.** For complete results see tables 2 and table 3.

Restricting the information window impacted all 4 measures of strategy. In support of the first hypothesis, delaying the information window meant fewer accesses ($t= -3.40$, $p<0.01$), and longer average access duration ($t= 2.72$, $p=0.01$) to the information window. The average number of information window accesses in the two conditions containing an available information window was 34.22 (SD = 9.57), and for delayed information window, M = 26.22 (SD= 4.36). For average duration to the information window, M = 1.43 seconds (SD= .56) and 1.97 seconds (SD= .54), for available and restricted information window conditions respectively. For more information, see table 2 below.

In support of H3, restricting the information window also resulted in fewer accesses ($t= -2.44$.$p=0.02$), and longer average access duration ($t= 2.33$, $p=0.02$) to the VCR window. For VCR accesses, this corresponds to a decrease in average accesses from M = 27.25 (SD= 8.79) on the two conditions when the information window was available, to M= 22.96 (SD= 6.15), where the information window was perceptually restricted. For duration, when the information window was available, M=6.34 (SD= 2.21). Covering the information window, increased the average access duration at the VCR window to M=7.76 (SD=2.61).

For H2, Covering the VCR window increased the average access duration to the VCR window ($t= 3.98$, $p=0.01$). When the VCR window was available, M=5.74 (SD=1.37). Average duration to the VCR window increased when the VCR was covered, with M= 8.36 (SD= 2.70).

No interactions between the availability of the two windows approached significance on any of the dependent measures. See the following table for mean access number and durations to the two windows, for each condition.

Table 2: Number of Accesses and Access Durations to the Two Windows by Condition

	Info Availability	VCR Availability	Mean	Std. Deviation	N
Info Accesses	Not Delayed Info	Available VCR	34.6875	10.09765	16
		Covered VCR	33.75	9.320229	16
		Total	34.21875	9.570568	32
	Delayed Info	Available VCR	27.6875	3.380705	16
		Covered VCR	24.75	4.837355	16
		Total	26.21875	4.368024	32
	Total	Available VCR	31.1875	8.216575	32
		Covered VCR	29.25	8.617312	32
		Total	30.21875	8.40912	64
VCR Accesses	Not Delayed Info	Available VCR	26.5625	7.402421	16
		Covered VCR	27.9375	10.19457	16
		Total	27.25	8.791491	32
	Delayed Info	Available VCR	24.5625	5.278494	16
		Covered VCR	21.375	6.71193	16
		Total	22.96875	6.156478	32
	Total	Available VCR	25.5625	6.405328	32
		Covered VCR	24.65625	9.121437	32
		Total	25.10938	7.831798	64
Average Info. Window Duration	Not Delayed Info	Available VCR	1.42077	0.639597	16
		Covered VCR	1.44891	0.478526	16
		Total	1.43484	0.555832	32
	Delayed Info	Available VCR	1.95862	0.34532	16
		Covered VCR	1.98544	0.701014	16
		Total	1.97203	0.543755	32
	Total	Available VCR	1.68969	0.574716	32
		Covered VCR	1.71718	0.650286	32
		Total	1.70343	0.608933	64
Average VCR Window Duration	Not Delayed Info	Available VCR	5.16139	1.280592	16
		Covered VCR	7.51457	2.342083	16
		Total	6.33798	2.208334	32
	Delayed Info	Available VCR	6.32049	1.241456	16
		Covered VCR	9.20437	2.849347	16
		Total	7.76243	2.611599	32
	Total	Available VCR	5.74094	1.373307	32
		Covered VCR	8.35947	2.705463	32
		Total	7.05021	2.504212	64

2.4.2 Performance: Total time

As mentioned previously, performance was assessed by using the total time to complete each trial as the dependent variable. This 2X2 ANOVA contained information window availability (available vs. delayed) and VCR window availability (available vs. Covered) as between subjects factors, with total time serving as a within-subjects variable.

Covering the information window had a marginally significant effect on performance ($F=3.56$, $p=.06$), increasing total time from $M= 302.08$ seconds ($SD= 48.19$) to $M= 324.03$ seconds ($SD= 44.83$). There were no other significant main effects or interactions.

2.5 Discussion

2.5.1 Strategy Predictions: Main Effects

First, this study successfully replicated the results obtained by Gray and colleagues, where an increase in perceptual effort to access the source (Information Window) resulted in fewer accesses, and longer access durations to the information window, indicative of an effort-induced strategic shift. Consistent with the first hypothesis made in this study, subjects accessed the information window fewer times, but spent longer time on each access when the information window was delayed.

Next, we predicted that covering the VCR window would result in a strategic shift in that window. This hypothesis was confirmed by the measure of average duration to the VCR window. Much like source (information window) restrictions, previously performed by Gray and colleagues (and replicated in our experiment), a small increase in the perceptual-motor effort to access the workspace area (i.e., covering the VCR window) resulted in a significant increase in the average access duration to that window.

2.5.2 Encoding vs. Retrieval

While this manipulation of the VCR window is novel, a few features of the task lead us to believe that the longer access durations to the VCR window are indicative of greater reliance on memory routines. First, participants had completed 2 practice trials which allowed for ample experience with the VCR interface prior to the experimental trials. This makes the possibility that the longer access durations were attributable to greater time spent toward familiarization with the interface less likely. Additionally, the only function of the VCR window was to serve as an input interface where encoded information was to be reproduced. It is therefore reasonable to expect that the longer access duration to the VCR window (produced by the VCR restriction) were associated with greater reliance on retrieval memory routines. The findings support our second hypothesis.

Additionally, the greater memorization brought on by restricting the information window, was expected to moderately increase retrieval at the VCR window. This prediction was confirmed in this study, as restricting the information window led to longer access durations in the VCR window. The rational for this finding is that restricting the information window led participants to encode more information, which took longer time to retrieve, at the subsequent VCR access.

2.5.3 Performance Predictions: Interaction

No interaction between source and target availability with regard to performance was found. In contrast to our prediction, covering the information window was not more beneficial to performance under a covered VCR, as opposed to an available VCR.

One possibility, however, is that the VCR effect was simply too weak throughout the four conditions to produce an interaction. In this study, the VCR was either available or covered. As according to the soft constraints hypothesis, effort is measured by time, the covered VCR condition increased perceptual-motor effort to the extent that it required participants to move their mouse cursor over the VCR window to uncover it, as opposed to simply moving their eyes in the case of the baseline condition. This restriction translates to a few hundred milliseconds penalty, much smaller than the information window restriction, which contained a 1 second delay.

CHAPTER 3

EXPERIMENT 2

The second study aimed to expand upon the initial predictions of the first study, by increasing the strength of the VCR restriction.

Like the first study, this study manipulated access to the source (information) window as well as the workspace (VCR) window. While the VCR in the first study was either available (baseline condition) or covered (restricted condition), in this study the VCR was either covered (for the baseline condition) or covered and delayed by 1 second. Like in the first study, the information window was either covered (baseline condition), or covered and delayed (restricted condition).

Increasing the VCR restriction in this second study was meant to ensure that the lack of interplay between the two source restrictions in the previous study was not due to a disproportionally weak VCR restriction. We were interested in whether a stronger VCR restriction will confirm our previous performance prediction; showing greater improvements in performance in response to a restricted information window under a restricted VCR, as opposed to an available VCR.

3.1 Method

3.1.1 Participants

The participants (n = 64) were university undergraduates from an institution in the south east United States, who did not participate in the first study and took part in the experiment for course credit. Participants (n = 16) were randomly assigned to one of four conditions (see below).

3.1.2 Stimuli and Materials

See experiment 1.

3.1.3 Procedure

The procedure was identical to that of the first experiment, except for the VCR availability. Again the four conditions differed on access cost/availability of the source (show information) and target (VCR) windows. In the first condition, the information window remained covered unless the mouse cursor entered its boundaries, at which point this window was immediately uncovered and available to participants. The information window was covered immediately once the mouse cursor had left its borders. The VCR window was also covered unless entered by the mouse cursor. In the second condition, the information window was covered as per the previous condition but there was also a delay of one second, after the mouse cursor entered its boundaries, before the window was uncovered. As per the first condition, the information window was covered immediately once the mouse cursor had left its borders. The VCR window was again uncovered upon mouse access. In the third condition, the information window was identical to the first condition (i.e., covered only). In addition, the VCR now required participants to wait for one second before uncovering upon mouse entrance and covered again once the mouse cursor left its boundaries. In the final fourth condition, both windows had 1 second delays each before uncovering upon mouse entrance.

Table 3: Study Design for Experiment 2

condition	description	Information Window	VCR Window
1	Both Windows Avail.	covered	covered
2	Restricted Info Window	covered and Delayed(1 Second)	covered
3	Restricted VCR Window	covered	covered and Delayed(1 Second)
4	Restricted Both	covered and Delayed(1 Second)	covered and Delayed(1 Second)

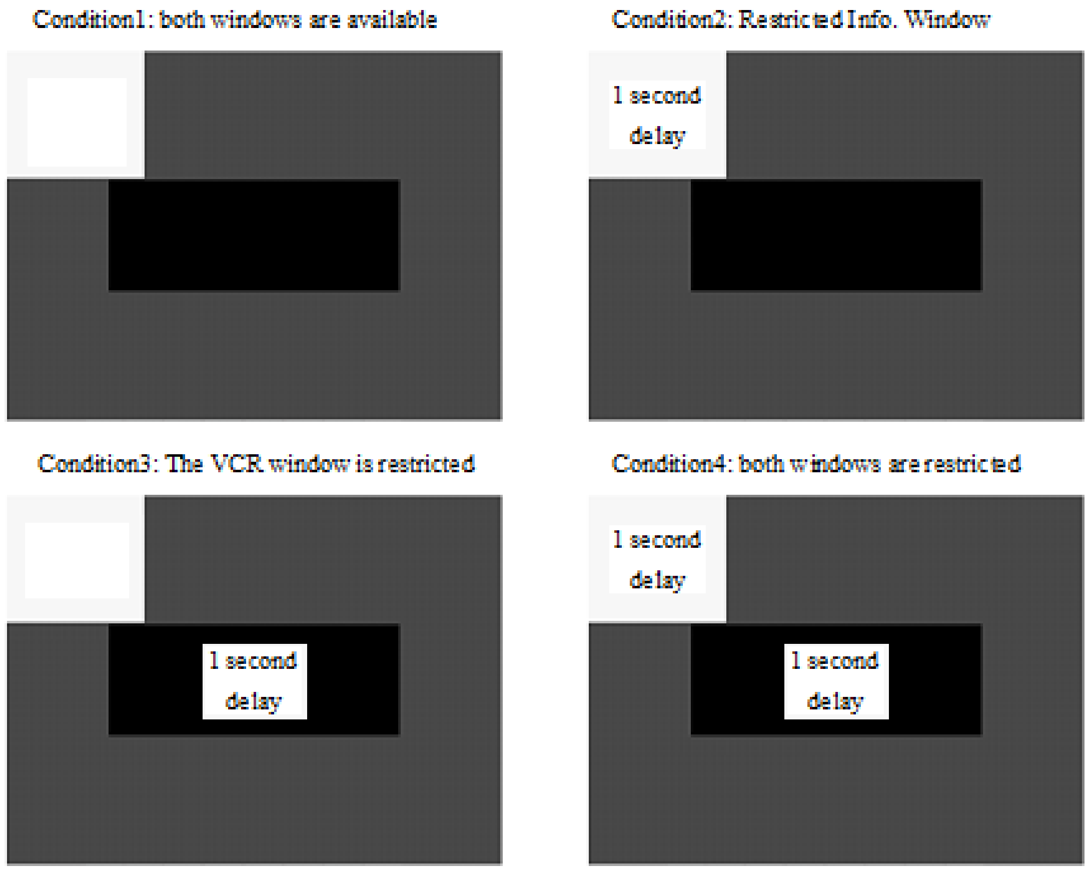

Figure 3: Experiment 2 screen shot. Unless delayed, each covered window uncovered immediately following mouse entrance. Delayed windows took 1 second to uncover after mouse entrance. All covered windows were immediately covered once the mouse cursor left their borders. See figure 1 for a view of the uncovered windows.

Experiment 1

condition	description	Information Window	VCR Window
1	Both Windows Avail.	covered	available
2	Restricted Info Window	covered and Delayed(1 Second)	available
3	Restricted VCR Window	covered	covered
4	Restricted Both	covered and Delayed(1 Second)	covered

Experiment 2

condition	description	Information Window	VCR Window
1	Both Windows Avail.	covered	covered
2	Restricted Info Window	covered and Delayed(1 Second)	covered
3	Restricted VCR Window	covered	covered and Delayed(1 Second)
4	Restricted Both	covered and Delayed(1Second)	covered and Delayed(1 Second)

Comparing Both Studies

condition	description	Information Window	VCR Window
1	Both Windows Avail.	covered	available
2	Restricted Info Window	covered and Delayed(1 Second)	available
3	Restricted VCR Window	covered	covered and Delayed(1 Second)
4	Restricted Both	covered and Delayed(1 Second)	covered and Delayed(1 Second)

Figure 4: Comparing both experiments.

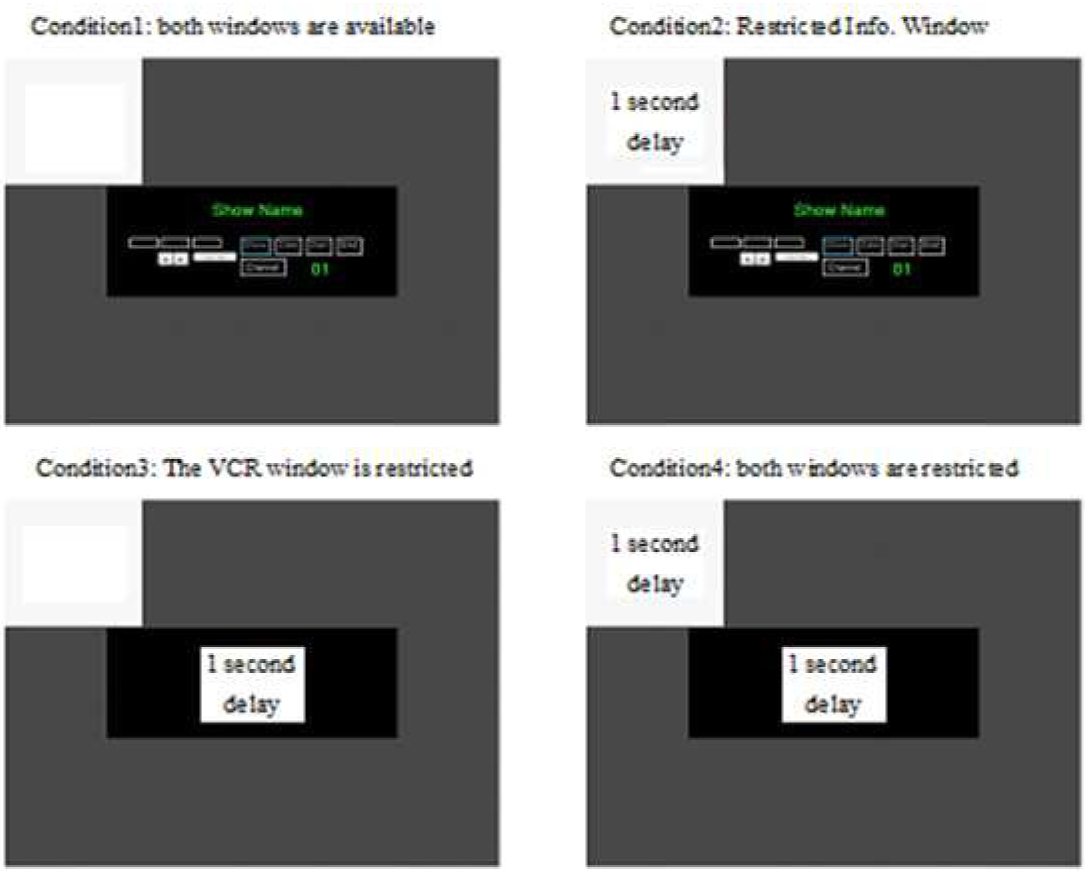

Figure 5: A screen shot of the combined conditions from the 2 experiments.

3.2 Results

Like in the first study, we first analyzed strategy parameters (i.e., the number of accesses and access duration to the two windows) to validate this new experiment. Then, performance interaction was tested with total time as the dependent variable.

3.2.1 Strategy: Validation of Study 1 Results

A 2X2X4 mixed plot analysis of variance (ANOVA) was performed, with information availability (Covered vs. Delayed Info. Window) and VCR window availability (covered vs. delayed) serving as between subjects factors, and access features (i.e., number of information window accesses, average access duration to the information window, number of VCR window accesses, average access duration to the VCR window) serving as within-subjects variables.

3.2.2 Comparing Experiments 1 and 2

The trends for the second study were particularly weak (e.g., No influence on average access duration for either window) and did not fully reproduce the pattern obtained in the first study, therefore no subsequent analysis of performance was done.

The failure to reproduce previous results may have been due the stronger baseline VCR condition in this study. Therefore, the new manipulation introduced in this study was compared to the baseline conditions from the first study. This comparison reproduced the results found in study 1. Covering the information window decreased the average number of accesses to the information window ($t=-2.82$, $p=.01$), and increased the average access duration ($t=2.64$, $p=.01$). For accesses to the information window, this corresponded to a decrease from $M=31.50$ ($SD= 9.23$), when the information window was available, to $M=28.50$ ($SD= 5.05$), when the information window was restricted. For access duration, $M= 1.56$ ($SD= 6.30$) for available information window, and $M= 2.03$ ($SD= 5.20$) when the information window was restricted.

Delaying the VCR resulted in an increase in the average time spent in the VCR window ($t=6.54$, $p<0.001$). The average VCR duration was $M=5.74$ ($SD= 1.37$), under an available VCR, and $M=10.27$ ($SD = 2.67$), when the VCR was restricted. For more information see the following table which contains mean access duration and number to both windows for all experimental conditions.

Table 4: Number of Accesses and Access Durations to the Two Windows by Condition

	Info Availability	VCR Availability	Mean	Std. Deviation	N
Info. Accesses	Covered Information	Available VCR	34.688	10.0977	16
		Delayed VCR	28.313	7.2546	16
		Total	31.5	9.23528	32
	Delayed Information	Available VCR	27.688	3.38071	16
		Delayed VCR	23.313	5.58234	16
		Total	25.5	5.05454	32
	Total	Available VCR	31.188	8.21657	32
		Delayed VCR	25.813	6.85536	32
		Total	28.5	7.98013	64
VCR Accesses	Covered Information	Available VCR	26.563	7.40242	16
		Delayed VCR	24.813	5.21816	16
		Total	25.688	6.36238	32
	Delayed Information	Available VCR	24.563	5.27849	16
		Delayed VCR	20.375	4.80104	16
		Total	22.469	5.40003	32
	Total	Available VCR	25.563	6.40533	32
		Delayed VCR	22.594	5.42312	32
		Total	24.078	6.07442	64

Table 4 - Continued

	Info Availability	VCR Availability	Mean	Std. Deviation	N
Average Info. Window Duration	Covered Information	Available VCR	1.4208	0.6397	16
		Delayed VCR	1.705	0.61034	16
		Total	1.5629	0.63174	32
	Delayed Information	Available VCR	1.9587	0.34532	16
		Delayed VCR	2.0912	0.65663	16
		Total	2.025	0.52044	32
	Total	Available VCR	1.6898	0.57479	32
		Delayed VCR	1.8981	0.65374	32
		Total	1.794	0.61959	64
Average VCR Window Duration	Covered Information	Available VCR	5.1614	1.28055	16
		Delayed VCR	10.0438	2.51503	16
		Total	7.6026	3.16316	32
	Delayed Information	Available VCR	6.3206	1.24153	16
		Delayed VCR	10.5106	2.88368	16
		Total	8.4156	3.04963	32
	Total	Available VCR	5.741	1.37333	32
		Delayed VCR	10.2772	2.67219	32
		Total	8.0091	3.10927	64

3.2.3 Performance: Total Time

As mentioned previously, performance was assessed by using the total time to complete each trial as the dependent variable. This 2x2 ANOVA contained two between subjects factors, information window availability (available vs. delayed), VCR window availability (available vs. Covered), with total task time as the within-subjects variable.

The interaction between the two source windows was significant (F=9.31, p=0.03. Under an available VCR, an available Information Window had M = 291.61 Seconds (SD = 46.33 Sec), while restricted information window had M = 329.33 Sec (SD = 38.39 Sec). When the VCR was covered, an available information window had M = 321.97 Sec (SD = 50.78 Sec), while a covered VCR had M = 295.62 Sec (SD = 29.27 Sec).

Table 5: Total Time by Information and VCR Window Availability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16982.393[a]	3	5660.798	3.209	0.029
Intercept	6135758	1	6135758	3478.619	0
Info Availability	517.847	1	517.847	0.294	0.59
VCR Availability	45.007	1	45.007	0.026	0.874
Info Availability * VCR Availability	16419.54	1	16419.54	9.309	0.003
Error	105830.9	60	1763.849		
Total	6258571	64			
Corrected Total	122813.3	63			

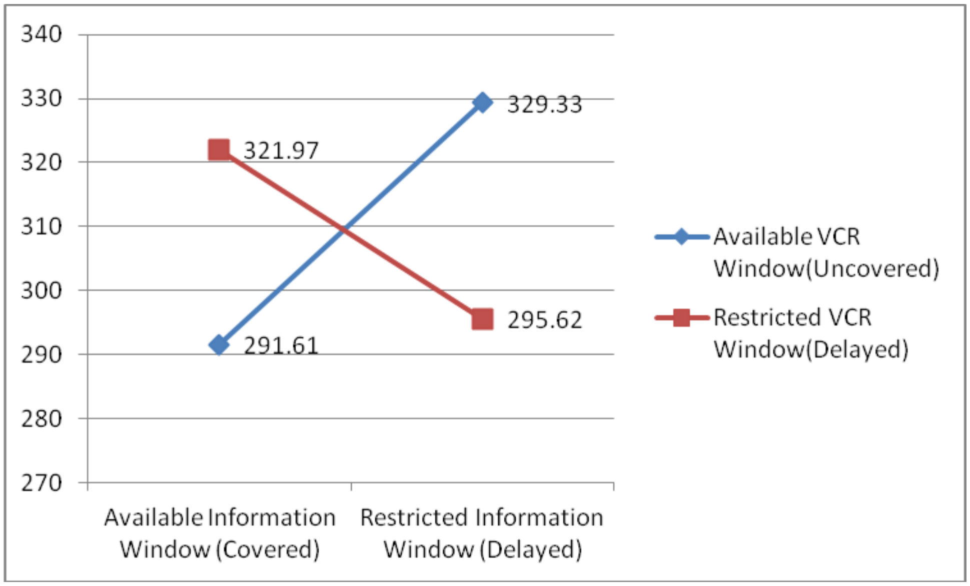

Figure 6: Total Time (in seconds) by Information and VCR Window Availability

3.3 Discussion

3.3.1 Performance Interaction Revisited

The second study aimed to reexamine the performance interaction prediction from the first study with one difference; for this study, the perceptual-motor restriction to the VCR window was considerably stronger than on the first study. This was done to examine whether the lack of influence of the VCR window in the first study was due to a disproportionally weak VCR manipulation.

Restricting the information window was expected to be more beneficial for performance under a restricted (delayed) VCR, as opposed to an available VCR. This hypothesis was confirmed. That is, when the VCR window was completely uncovered, restricting (delaying) the information window slowed performance. In contrast, when the VCR was restricted (delayed), delaying the information window improved performance. This finding confirms the fourth hypothesis. For more information see general discussion.

This finding is also consistent with the difference between the two Gray studies, where source restriction improved performance under a covered workspace area (Gray, Sim & Fu, 2006), and diminished it when the workspace was available (Gray & Fu, 2004).

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CHAPTER 4

GENERAL DISCUSSION

4.1 Replication of Previous Findings

First, both studies successfully replicated the original SC findings, where small increases (in the order of milliseconds) in the effort to access the window containing relevant information to be learned (i.e., information window), meant greater reliance on memory-intensive routines, characterized by fewer accesses and longer access durations to the information window (Gray & Fu, 2004; Gray, Sim & Fu, 2006).

4.2 Validation of Workspace Availability

Consideration of the role of the workspace window according to the soft constraints hypothesis was the main focus of this project. We expected the VCR window to factor into soft constraints, as behavior at the VCR window was expected to follow a pattern that minimized effort when selecting between cognitive, perceptual, and motor resources. Considering the role of the VCR as the input interface, greater memorization at the VCR window was expected to be associated with greater retrieval. A few findings in both experiments support this prediction.

First, in both studies, increasing perceptual-motor access to the workspace area (i.e., covering or delaying the VCR window) resulted in longer access durations to that window. These longer accesses are attributed to greater memorization considering the strength of the effect, coupled with the relative familiarity of participants with the VCR interface. In particular, as the VCR lacks information to be learned, greater memorization in the VCR window was associated with greater retrieval.

Second, covering the information window resulted in greater time spent at the VCR as well. This effect indirectly validates the workspace window's role in retrieval, as more effortful retrieval at the VCR window is expected given that more encoding was performed at the information window (due to restricted information window).

Finally, the performance interaction found in the second study also lends support to the importance of the role of the two windows. Recall that restricting the information window was beneficial for performance when the VCR window was covered, and diminished performance when the VCR was available. We argue that when the VCR was available, covering the information window diminished performance as participants were locally constrained to rely on memorization during *encoding*(due to the restricted information window), but were not sufficiently constrained to fully retrieve their encoded information (at the VCR window). In contrast, when the VCR window was covered, restricting the information window improved performance as participants were constrained locally at both windows to effortfully encode and retrieve learned information. This finding is also consistent with the performance difference between the two previous SC studies.

4.3 Future Recommendations

A more accurate design may prove useful, considering the narrow, low-level of analysis (at the millisecond level) used in this study. Examining eye responses during access to the two windows, for example, can provide more information as to the strategies performed at each window.

Another option is comparing behavioral data to a processing model programmed to minimize effort locally. Taking into account factors such as forgetting rate and probability of encoding is necessary to obtain an accurate estimate of the cost of competing memory and perceptual-motor routines. Once exact estimates of the cost-befit tradeoff are obtained, it would be possible to examine whether the best fit with human data is one that minimizes effort (SCH) or favors the use of perceptual-motor routine over memory reliance (MMH).

APPENDIX A

INFORMED CONSENT FORM

You are invited to participate in a research project entitled "Effective Software Training," conducted by Dr. Neil Charness at the Florida State University.

This project seeks to understand how training method may impact computer users' performance when confronted with an unfamiliar software package. It will utilize different techniques to facilitate goal achievement through optimized training regimes.

As a participant in this study, you will be asked to follow instructions to complete a task using new software under time constraints. This task will entail performing a few VCR related activities.

All information you provide is considered completely confidential. All your answers will be kept confidential to the extent allowed by law. As such, records of all data, including identifying information, will be afforded the following confidentiality. They will be kept in locked files in a secure area with names separate from identification numbers, and any publication of results will combine individual responses with many others to professionally report findings in group form only.

Participation in this study is voluntary and there are no significant risks to you. Any stress or discomfort evoked in this study should not go beyond mild levels of stress. If your stress or discomfort levels become uncomfortably high at any time during the study, please notify your experimenter at once and the study will stop immediately. If needed, the experimenter can refer you to a counselor. Benefits associated with participation include the gathering of valuable data to optimize training procedures and strategies and the knowledge to make recommendations to older adults to enhance the adoption of new technologies. These findings may also provide potential guidelines for the development of tutorials to train older adults to learn to utilize communication software systems.

I, __________________________, freely and voluntarily and without undue inducement or element of force, fraud, deceit, duress, or other form of constraint or coercion, consent to participate in this study. I understand the experimental procedures to be conducted and my questions have been answered to my satisfaction. I understand that I may decline to answer any question presented during this study or withdraw from this study at any time without prejudice, penalty, or loss of benefits to which I am otherwise entitled. That is, my grade in the course will not be affected if I choose to withdraw from the study, nor will I receive an experiment credit penalty. I understand that I will receive .5 credits for my psychology course. If I do not complete the study I will receive a partial prorated, based on level of completion, experiment credit. However, I will still be obliged to fulfill my experiment participation for the psychology course in which I am enrolled, and failure to do so may affect my course grade. The session will last approximately 25 minutes.

I understand that I may contact Professor Neil Charness, Department of Psychology, Florida State University, Tallahassee, Florida, USA 32306-1270, phone (850) 644-6686, for answers to pertinent questions about this research or if I have any comments or concerns resulting from participation in this study.

If I have any questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I may contact the Chair of the Human Subjects Committee, Institutional Review Board, through the Vice President for the Office of Research at (850) 644-8633.

I have read and understand this form and give my consent to participate.

____

Participant Signature   Date
(month/day/year)

APPENDIX B

IRB APPROVAL EMAIL

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

APPROVAL MEMORANDUM (for change in research protocol)

Date: 10/18/2010

To: Neil Charness

Address: Psychology Department, 1107 West Call Street, Tallahassee, FL 32306
Dept.: PSYCHOLOGY DEPARTMENT

From: Thomas L. Jacobson, Chair
Re: Use of Human Subjects in Research (Approval for Change in Protocol)
Project entitled: Center for Research and Education on Aging and Technology - CREATE III (Grant Title) CREATE III: Tools and Training to Promote Cognition and Health (Site Title) FSU Collaborative Project 1 : Effective Software Training (Project Title)

The form that you submitted to this office in regard to the requested change/amendment to your research protocol for the above-referenced project has been reviewed and approved.

If the project has not been completed by 8/29/2011, you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

By copy of this memorandum, the chairman of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: HSC No. 2010.5248

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BIOGRAPHICAL SKETCH

Avner Dachoach

Avner Dachoach was born in Tel-Aviv, Israel in 1985. In 2002, Avner and his family immigrated to the United States and settled in Miami, Florida. Avner transferred to FSU during the fall of 2004, and graduated with his bachelor's degree at the summer of 2009. He enrolled at FSU's graduate program at the fall of 2010, majoring in cognitive psychology. Avner's research interests include aging, skill learning, and interface design.