The Impact of Representational format in a Dynamic Retargeting Task

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Abstract

It is well known that different representations of the same abstract structure could generate dramatically different representational efficiencies, task difficulties, and behavioral outcomes. This representational effect has been studied under the theory of distributed cognition (Zhang & Norman, 1994, 1995; Zhang, 1997), which attributes the major factor of the representational effect to the distribution of information across internal and external representations. Our previous study examined this effect in a static navigation task in aviation (Chuah, 1998; Chuah, Zhang, & Johnson, 2000). The study reported in this paper extends that previous study to a dynamic retargeting task in which the pilots had to dynamically fly the simulated airplane and keep track of location information. The experimental results are consistent with the predictions of the theory of distributed cognition.

Introduction

For most everyday tasks, the information needed for the task is distributed across information perceived from the external world and information retrieved from the internal mind. These tasks are known as distributed cognitive tasks (Zhang & Norman, 1994). The external representations in the environment and the internal representations in the mind dynamically integrate and interweave to result in a rich pattern of cognitive behavior. The principle of distributed representations is that a distributed cognitive task involves a system of distributed representations that consists of internal and external representations (Zhang & Norman, 1994, 1995). The task is neither exclusively dependent on internally nor exclusively dependent on externally processed information, but rather on the interaction of the two information spaces formed by the internal and external representations.

To navigate an airplane in aviation, a set of navigational instruments are selectively tuned to transmitting radio stations on the ground. The received signals are then presented onto a display in the cockpit for the navigator to interpret. A navigation instrument displays azimuth (or directional) information and distance information. However, different instruments display these kinds of information differently. As a result, the degrees of precision and efficiency as interpreted by the navigator are usually different.

Cockpit information displays are examples of distributed representation systems. Navigational information in a cockpit information system is represented through a variety of isomorphic navigation instruments. Although these instruments are isomorphic and provide similar information, they vary in their relative degree of directness and efficiency in their representation of scale information (Stevens, 1946; Zhang, 1997). The scale information of the orientation and distance dimensions in a cockpit information display is represented across internal and external representations and can dramatically affect the representational efficiency of the display and the navigator's behavior (Zhang, 1997). This study examines the cognitive properties of the representations that such instruments produce in dynamic navigation tasks. The basic assumption is that the most direct system generates the best behavioral outcomes because the information in direct systems is maximally represented in external representations.

Distributed representations

External representations are the representations formed from information gathered from the external environment. External representations include physical objects and/or symbols, relations and constraints between physical objects and their configurations relative to each other, and external physical rules, such as laws of physics. Through the human perceptual processes, the information necessary to form external representations is picked up by the sensory and perceptual systems. External representations are characterized as providing information that is directly perceived and applied toward a cognitive task without being explicitly interpreted. External representations contribute information that is otherwise unavailable from representations internally generated from memory, or from representations that are internalized from perceptual information (Zhang, 1997). Perceived information from within the external environment that must be represented internally in order for cognition to operate on it is, by definition, recreated as internal representations.

Internal representations are the representations that originate from within the mind and are not initiated form the perception of external stimuli. These internal representations are in the form of, but not limited to, mental images, propositions, production rules, and schemata. Cognitive processes retrieve information from long-term memory. This information may be selectively or incidentally retrieved, and is then employed to formulate internal representations.

Internal and external representational spaces together form a distributed representational space, which is where the representation of the task, in its abstract structures and properties, resides. External representations are not re-represented redundantly as internal representations. In combination with internal representations, external representations can directly activate and provide perceptual information necessary for responses and behaviors.

Representational effect

Representational effect is a psychological phenomenon that is observed when different isomorphic representations that have a common formal structure but evoking dramatically different cognitive behaviors (Zhang & Norman, 1994). As a result, different representations of one common problem can have a dramatic impact on the level of difficulty of a problem.

Navigational Displays

The cockpit informational displays in this experimental study are navigational displays, which include the instruments that provide directional guidance. As the experimental task is a position-fixing task, only the instruments that have the necessary information were provided and will be discussed here briefly. (A more in-depth review of cockpit navigational displays is provided in Zhang, 1997.). VOR (very high frequency omni-directional range), RMI (radio magnetic indicator), are the more prevalent navigation systems used for such a position fixing task. The generic moving map display refers to the more advanced cathode ray tube displays found in newer airlines that provide multiple types of information over a moving map within one display.

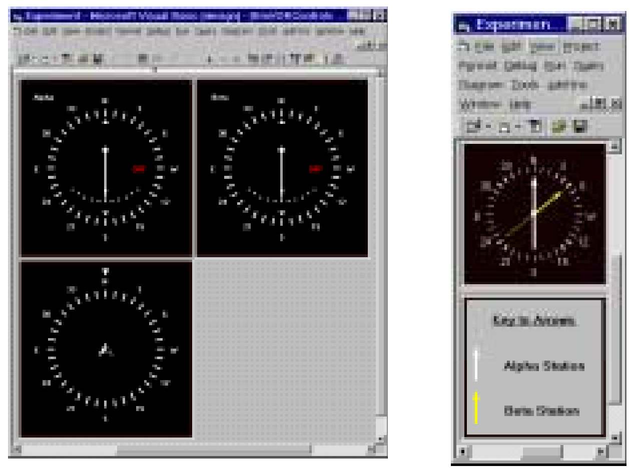
VOR indicator

The VOR equipment in the aircraft receives and interprets transmitted radio signals from the ground and shows directional information of the aircraft in relation to the VOR station on the ground. The VOR indicator is usually used to show the intended course of the aircraft and the lateral position of the aircraft in relation to that intended course. The VOR indicator in Figure 1A shows a selected 315º course. The TO indication at the right of center of the display indicates that proceeding on such a course will lead the aircraft to the station. The vertical needle (CDI, course deviation indicator), when in the center as shown, indicates the aircraft is on that selected course. If the CDI pivots to the left, this will indicate to the navigator that the aircraft is off the 315º course and needs to make a correction by navigating the aircraft towards the left to get back on course. The VOR indication (course selected) is independent of the heading of the aircraft.

The VOR indicator can also be used to determine the location of the aircraft relative to the VOR station. By tuning the VOR until the CDI centers with a TO indication, the displayed course will be the magnetic bearing of the aircraft to the VOR station. Likewise, by tuning the VOR until the CDI centers with a FROM indication, the displayed course will be the magnetic bearing of the aircraft from the VOR station.

RMI indicator

The RMI display is essentially the aircraft's heading indicator with the RMI pointer(s) providing navigational information (see Figure 1B). As a consequence, the RMI provides angular distance, and orientation of the aircraft relative to the radio station as magnetic indications. It is unnecessary for the navigator to do any computations to obtain magnetic bearing information.



VOR instrument RMI instrument

Figure 1: The two navigation instrument displays.

Experimental Study

The experimental hypothesis is that although the two navigation instruments provide the same and all the necessary information, the representational information is distributed in varying degrees across the internal and external representational spaces. Experimental participants were provided with bearing information as displayed by the instruments, and were then required to determine the current position of the aircraft on a map.

Representational study of experimental task

A representational analysis of the experimental task identifies the abstract structures of the task and the representational properties that are responsible for the representational effect that is to be studied. To successfully perform the position-fixing task with the given bearing information, it is necessary to perform a triangulation using the radio stations as end points and extending from them the bearings. The intersection of the bearings indicates the current position of the aircraft relative to the radio stations.

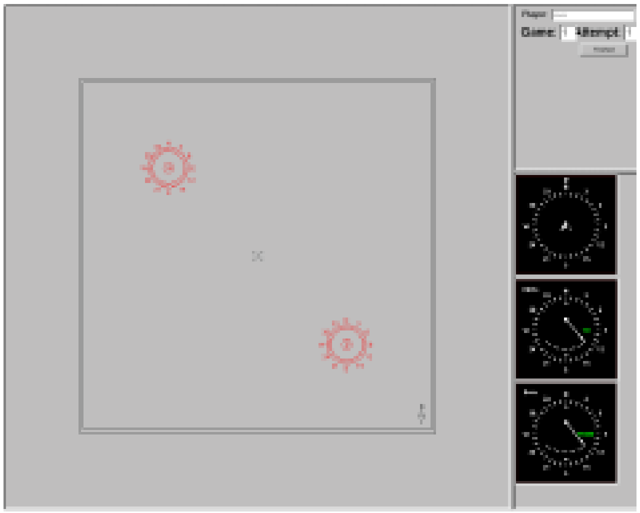


Figure 2: The Experiment task display (VOR)

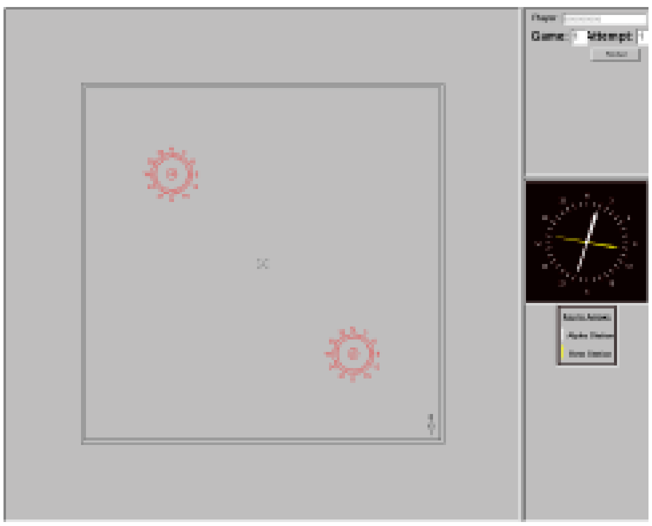


Figure 3: The Experiment task display (RMI)

The two types of instruments result in different representational spaces. The representational system with the most external information and the least internal information will be more efficient and direct (Norman, 1993; Hutchins, 1995). Furthermore, the position-fixing task requires a triangulation method to determine the aircraft position. Both the VOR and RMI provide the necessary magnetic bearing information immediately. It is not necessary to represent the information internally. The VOR method requires two VOR indicators, one heading indicator, and two DME indicators. The DME indicator shows the magnetic courses of the airplane relative to the two stations. The heading indicator shows the current heading of the airplane. So it does not provide the information readily, and it is necessary to derive the magnetic bearing information through mental calculations using the heading information with the relative bearing information provided by the instrument.

Table 1: Properties of the navigation systems.

Information readily available (externally represented)	Type of navigation system	
	VOR	RMI
Aircraft heading		√
Magnetic bearing	√	√
Orientation		√
Angular distance between aircraft and radio station		√

The hypothesis is that the RMI display will outperform the VOR instruments as it provides the most external vs. internal representations. Table 1 summarizes the properties of the two navigation systems. The prediction is that experiment participants in the RMI condition will complete the position-fixing task more quickly than the VOR conditions.

Method

Subjects. A total of thirty subjects, recruited from students at The UT-Houston and University of Houston, were randomly assigned to the two display types with fifteen per treatment groups.

Materials and Equipment. Two Pentium computers were used with 17-inch monitors set at similar SVGA resolutions. The displayed image consisted of a large map covering most of the screen area, an instrument panel with the navigation instruments unique to each experimental condition, and a control panel that served as the experiment interface. The map area displayed two radio stations and a square icon that represented the aircraft. The positions of the radio stations and aircraft were randomized at every trial. Figure 2 shows a screen capture of an experimental trial in the VOR condtion and Figures shows the RMI condition.

Design and Procedure. In a "Split-Plot" repeated measures design, two different types of navigational displays, namely RMI and VOR, were compared across 24 trials. A total of 30 subjects were randomly assigned to the two display types with 15 per treatment groups. The dependent variable was the time interval from the onset of navigational information until the aircraft location was identified. Data analysis was performed using the SPSS 9.0™ General Linear Model Repeated Measures procedure.

Experiment Task 1: Positioning Task

For each trial, the navigation instruments were displayed, providing the necessary and essential information. The participants would then read and interpret the navigation information and, by clicking and dragging the square aircraft icon, re-position it to where they believed the actual position of the aircraft was. They would commit their decision by clicking on the OK button. If the participants were correct to within a radius of 5% of the screen diagonal dimension, they moved on to a new trial. If they were incorrect, they were given another two attempts to locate the position.

Due to the complexity of the experimental task, the instructions were carefully administered, which limited the number of participants for each experimental session to two. Participants were first given a set of written instructions, then the experimenter provided with verbal explanations and further instructions. Each participant was given 2 trials to demonstrate his/her comprehension of the task prior to the start of the experiment. As the experiment required some manual dexterity to maneuver the computer pointer over the monitor screen, the computer mouse was configured for left-handed participants when necessary.

Experiment Task 2: Re-targeting Task

Experiment Task 2 is an extension of Experiment Task 1. The purpose of the study is to extend the results and broaden the implications of an observed representational effect from Experiment Task 1. The hypothesis of Experiment Task 2 is similar to that of Experiment Task 1. The predicted outcome is expected to be similar, with the differences between conditions compounded due to the dynamic nature of the task. The position-fixing task in Experiment Task 1 is a static task in which the aircraft is motionless with the instruments providing fixed and static indications for its location. The re-targeting task in Experiment Task 2 is a dynamic task, where the participant is to relocate from a known position to a desired destination. Experiment Task 2 continues on from where Experiment Task 1 stops. The known or starting position for Task 2 is the position of the aircraft at the completion of Task 1. The re-targeting task requires a relocation of the aircraft to a different location, one that is defined by the intersection of magnetic bearings from two radio stations. As the aircraft relocates and moves, the instruments are continually updated to indicate the aircraft's new location. The aircraft in this experiment was in motion, which required the participant to employ the updated information to maintain an awareness of the changing location. This experiment examines the representational effect in a dynamic setting, and compare it with the results from Experiment Task 1.

Table 2: Comparison between two conditions

	Position-fixing Task (Task 1)	Re-positioning Task (Task 2)
Main Effect of Display	F (1, 28) = 11.531 P < 0.01	F (1, 28) = 9.484 P < 0.01
Main Effect of Trials	F (23, 644) = 5.419 P < 0.01	F (23, 644) = 10.710 P < 0.01
Interaction between Displays and Trials	F (23, 644) = 2.115 P < 0.01	F (23, 644) = 0.580 P > 0.05

Results and Discussion

The results (Table 2) show that: for Task1 and Task 2, the main effect of display and the main effect of trials are significant. The interaction between displays and trials is also significant for Task 1, but not significant for Task 2.

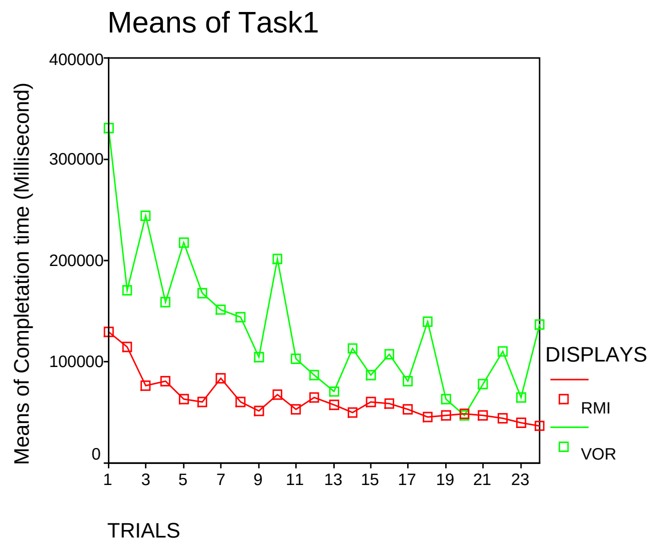


Figure 4:Position-fixing Task

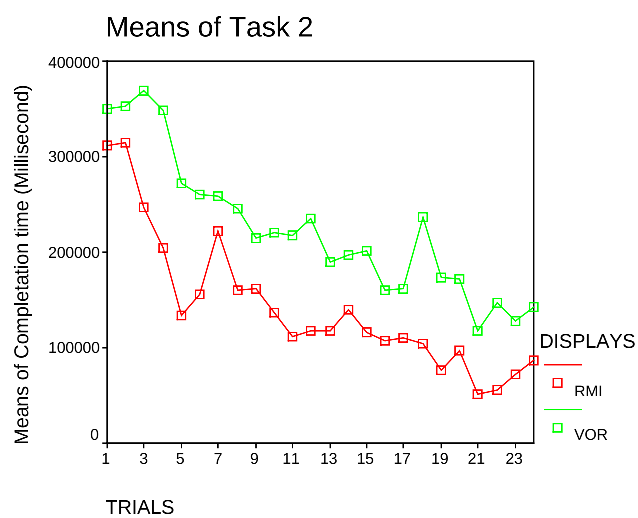


Figure 5: Re-targeting Task

The major finding from our analysis is that displays with more external information facilitate performance on position-fixing tasks and retargeting tasks. Figure 4 and 5 illustrate significant differences in task completion times between the conditions. According to the representational hypothesis, the RMI instruments provide more information that is readily available in the display than VOR. As a result, slower mental recoding of knowledge into internal representation is avoided, thus reducing mental workload and increasing task efficiency. The interaction between the trials and displays is also significant in Task 1. RMI present more "direct" displays so that subjects substantially reduce mental workload by obtaining more information from the external representation particularly at the beginning. The main effect of trials is also significant. There was a significant improvement in performance as participants became more familiar with the instruments and the tasks *per se*.

Discussion

According to the hypothesis, the predicted representational effect will favor the performance of the RMI over that of the VOR. This assumption arose from the representational analysis that deconstructed the cognitive task and identified the components and properties that would be responsible for such a representational effect. It was identified that the RMI navigation display provides all the necessary information externally and in a spatial and graphical layout whereas the VOR display provides most information represented and computed internally, with a high cognitive cost.

The solution time for the RMI condition was consistently faster times against the VOR condition. The RMI displays bearing information to the user in the magnetic compass scale, as opposed to the VOR instrument that provides the information in a relative degree scale. As a result, the navigator avoids costly mental workload by obtaining more of the information from the external representational space.

The solution time for the VOR condition was not expected to be as fast as the RMI display. There were no significant differences obtained from the interaction between displays and trials for Task 2. It is hypothesized that although the RMI provides all the necessary information for the Re-targeting task, the extraneous external information that the RMI displays provide may contribute to and facilitate other cognitive functions.

There were significant differences obtained from the interaction between displays and trials for Task 1. There is an obvious and noticeable learning process that is occurring, as the participants become more proficient and familiar with the instruments and the task itself. This may be attributed to simple skill acquisition or familiarization of the interface.

Conclusion

The experimental results were consistent with the predictions of the distributed cognition theory. The prediction was for representations to have a distributed space extending across the internal representational space and the external representational space. This prediction was supported by the observed representational effect. The representational effect predicted that isomorphic representations could produce varying behaviors due to the different distributions of internal and external representational information.

The observed behavioral variance from the experiment indicates that some representations are more ‘efficient’ in extending the necessary information for a task. Although the different isomorphic representations result in varying initial levels of performance and learning curves, performances appear to converge after a sufficient period of learning.

An argument could be made for learning and practice to eliminate such a representational effect. However, further research needs to be done in more complex and dynamic settings. The experimental task was a simple task in a very controlled and calm environment. In an unpredictable and complex environment such as that of the cockpit of an aircraft, the representational effect could be more pronounced and a possible regression to initial performance levels should be studied. Another issue that is worth of further study is whether the converged performance after learning for different representations will diverge again under extreme conditions such as high cognitive workload and time pressure.

Acknowledgements

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