

AGE DIFFERENCES IN TEMPORAL PROXIMITY

by

MONICA MARIE HUFF

(Under the direction of Robert Mahan)

ABSTRACT

The purpose of this study was to investigate age-related differences in temporal proximity performance in a dynamic decision-making task. Participants were asked to imagine that they were military supervisors deciding to continue or abort a pilot's mission based on information they were receiving from an on-board intelligent decision support system. The information was presented as snapshots of information over three different time periods. The participants needed to combine the information from the three different time periods to reach their decision. Age differences were found based on the type of graphical format and temporal proximity condition. Displaying the relationship between cues in a meaningful way is the key to designing for integration over time. More research incorporating temporal proximity and animation is needed.

INDEX WORDS: Age differences, Animation, Human factors, Information displays, Object displays, Proximity Compatibility Principle, Temporal proximity

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MONICA MARIE HUFF

B.A., Miami University (Oxford, OH), 1992

M.S., Clemson University, 1995

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MONICA MARIE HUFF

Approved:

Major Professor: Robert Mahan

Committee: Adam Goodie
Stuart Katz
Richard Marsh

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
December 2002

DEDICATION

I dedicate this dissertation to my husband, Reign, for his never-ending love and support, and to our two wonderful daughters, Gabby & Scout.

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CHAPTER 1

AGE DIFFERENCES IN TEMPORAL PROXIMITY

In the last few decades there has been a dramatic change in the conditions of the work environment. Technological advancements in computer applications and systems have changed the way many jobs are performed. With an increasing aging population and the need to train and re-train older adults on the use of technology-driven applications, more research examining age differences in display design is needed. By the year 2030, the older adult population (65 and older) of the United States is projected to be 70 million, more than twice the 1999 number. Approximately 20% of the population is expected to consist of older adults by the year 2030 (Administration on Aging, 2000).

Technology has been increasingly used to support workers whose jobs depend on monitoring, tracking, coordinating, and interpreting trends in dynamically changing environments. The issues involved in the design of decision-making and probabilistic information displays are becoming progressively more important with the influx of computer-based intelligent systems, coaches, and graphical aids (Barnett & Wickens, 1988). In addition to the increase in computer systems and applications, the amount of information available has risen sharply.

A critical issue for older adults is whether technological advances enhance or impede their lives. Unfortunately, most interface designers have failed to consider older adults as a user group in the design process (Czaja, 1996). Some of the changes in cognitive abilities that have been found to decline with age that could affect computer

usage and decision-making include: working memory capabilities, encoding and retrieval processes, information processing speed, limited resources, inference formation, and attention capacity (Craik, 1986; Czaja, 1996; Park, 1992; Morrell & Echt, 1996; Salthouse, Mitchell, Skovronek, & Babcock, 1989). Older adults often take more time to learn a system, require more help, and make more errors than younger adults when performing a variety of computer-related tasks (Czaja, 1996; Kelley & Charness, 1995; Morrell & Echt, 1996; Rogers, Fisk, Mead, Walker, & Cabrera, 1996). Given the processing and cognitive requirements for performing these types of tasks on a computer, a more diverse sample of the population needs to be studied using real-world applications.

A multiple cue decision-making task can be used to provide a real-world scenario for examining age differences. This type of decision-making task requires weighting and combining of various cues to achieve an overall estimate of the current situation (Barnett & Wickens, 1988). In dynamic work environments, a person must often remember a subset of changing display information that is embedded within other task-relevant variables. The graphic display of information provides a form of decision support with the potential to improve the performance of the human-machine interaction in complex, dynamic task environments (Bennett, Toms, & Woods, 1993; Buttigieg & Sanderson, 1991). For example, Venturino (1997) found that in a keeping-track task fire department dispatchers could not remember many changing or dynamic values without relying on external aids.

The primary focus in display research has been on improving the usability of the display to aid decision-making and increase situational awareness (Hess, Detweiler, &

Ellis, 1999; Sarter & Woods, 1995; Wickens & Carswell, 1995). When information needs to be both individually processed and integrated, there are often performance trade-offs based on the type of display and the kind of task. Having a single graphical format that can support both types of tasks is preferable, because of both the limited space available in a display and the additional work required from the user having to switch between display formats and levels depending on the type of task (Bennett & Flach, 1992; Bennett, Payne, Calcaterra, & Nittoli, 2000). In complex and dynamic tasks, displays need to allow parallel extraction of integrated (general) and cue value (specific) information (Bennett et al., 1993).

To briefly clarify terms, in this study dynamic refers to tasks that are changing over time and complexity refers to working memory and workload requirements of the task. Past research has tended to focus on static information displays, but future research needs to focus on dynamic displays. Animation is one graphical tool that may aid in the displaying of dynamic complex information.

Animation

Studies examining changes in dynamic information have typically used a static display to represent the dynamic change. Computer-generated animation has been defined as a series of rapidly changing images shown in an ordered sequence that create the representation or illusion of movement when there is no physical movement of an object in the visual field (Lightner, 2001; Rieber, 1990a, 1991a). Some of the suggested benefits of using animation include: freeing working memory for other tasks, better communicating changes over time, increased attention to specific information, enhanced mental rehearsing or processing of stimuli contingencies, and increased integration of

procedural information (Park & Hopkins, 1993; Rieber & Kini, 1991). The use of animation is believed to make the combining of information easier, because people can direct their limited attention resources within rather than between stimuli (Carswell & Wickens, 1996; Lightner, 2001). For example, an animated graphic for displaying temperature information can rise or fall as temperature increases or decreases. Whereas, a static display requires the user to compare two separate graphical displays. However, mixed results have been found in the learning and performance benefits provided by an animated display (Hays, 1996; Park & Hopkins, 1993; Rieber, 1990b).

Animation has often been added to a display for aesthetic reasons rather than congruency between the type of task and display (Levin, Anglin, & Carney, 1987; Rieber, 1990a, 1990b). Although, some research has found benefits for using animation when both motion and trajectory contribute to the learning of a spatial task (ChanLin, 1998; Rieber, 1991a, 1991b; Rieber & Kini, 1991), there has been little research on the benefits or costs to information processing when using an animated display.

The animated graphics are viewed as a way to potentially speed up and aid the decision-making of visual information (Lightner, 2001). Animated graphics in training, simulations, applications, and everyday displays have increased without understanding the relationship between underlying cognitive mechanisms and the effect of using animated demonstrations on skill acquisition (Morrell & Echt, 1996). Although participants often state preferring to use an animated display to a static display, research is needed for understanding the conditions under which animated graphics are most effective (Harrison, 1995; Palmiter & Elkerton, 1991, 1993; Payne, Chesworth, & Hill, 1992; Rieber, 1991a, 2000).

Based on a review of the animation literature, Park and Hopkins (1993) found that there were conflicting findings on the effectiveness of an animated display depending on the methodological approach used and the type of task studied. They recommended that animation be selectively used and proposed six conditions under which animation could be used most effectively. These conditions were: 1) displaying sequential actions in a procedural task; 2) explicitly representing system functions and behaviors that are not visible; 3) *simulating causal models of complex system behaviors*; 4) *focusing attention on a specific task or feature*; 5) illustrating a difficult task to describe verbally; and 6) providing a visual analogy for a symbolic or abstract concept. The italicized conditions seem especially relevant to the decision-making task used in this experiment. This study simulated a decision support system for displaying dynamically changing information over time and was, therefore, thought to provide an effective use of an animated display.

Another potential problem with the animation literature is that the majority of studies have only examined the use of animation with children and younger adults. A more varied adult population needs to be studied for understanding performance and basic psychological differences in the cognitive processing of animated graphics. If a dynamic display can provide more integration and visual support for older adults, it could help alleviate some of the age disadvantages found in learning and using technology-driven applications. See the Appendix for additional perceptual factors related to viewing animation. In the next section, research in probabilistic decision-making and older adults will be reviewed.

Aging and Probabilistic Decision-Making

Very little research has been conducted that includes older adults performing probabilistic decision-making tasks. A few studies are reviewed that suggest older adults can do as well as younger adults in these types of decision-making tasks. For example, Walker, Fain, Fisk, and McGuire (1997) found that older and younger adults made the same decisions, even though older adults required more time. They used a driving route-selection task that was considered equally familiar for both age groups. Chasseigne, Grau, Mullet, and Cama (1999) also found that older adults performed similarly to younger adults in learning a multiple cue weather forecasting task. The task was to learn the relationship between three cues and predict the pleasantness of the following day's weather. They concluded that the age differences found between the younger and older adults were related to a decrement in the older adults' flexibility of functioning rather than the level of uncertainty in the task.

One of the few studies that included older adults in a Multiple Cue Probability Learning (MCPL) paradigm was the Chasseigne, Mullet, and Stewart (1997) study that examined age differences in performance based on the cues relationship, a direct relation (DR) or an indirect relation (IR). They found that in the DR task older adults (ages 65-90) were able to learn the task nearly as well as the younger adults (ages 20-30). However, in an IR task, the older adults performed significantly worse than the younger adults due to their inability to utilize the inverse cue. In a follow-up experiment that just examined performance for the older adults in the IR task, they found that performance improved for the young-old (ages 65-75), but not for the old-old (ages 76-90) when the IR relationship between the cue and criterion was explicitly given to the participants. By

eliminating the need to discover the inverse relation on their own, the young-old were able to improve performance, but not the old-old. Processing speed and working memory capacity explained some of the age differences found. Chasseigne et al. concluded that flexibility of functioning in the old-old group could be used to explain their inability to modify functioning either internally (when relationship of cues given) or in response to external information (outcome feedback).

In addition to age differences found based on the type of cue relationship, age decrements in probabilistic decision-making may be linked to differences in the type of display proximity. By changing the way information is displayed, age differences may be minimized. Age differences in temporal proximity performance were analyzed in this study to determine if display changes would facilitate probabilistic decision-making in an older adult population. To understand temporal proximity better, the proximity compatibility principle (PCP) must first be understood. In the following sections, relevant PCP research is reviewed, followed by a definition of temporal proximity and ways that it can be used to benefit the integration of information in a dynamic decision-making environment.

Proximity Compatibility Principle (PCP)

According to the PCP, the function of a display is defined along a continuum ranging from simultaneous processing of all values (e.g., analyzing trends) to independent processing of single data points. Display proximity (or perceptual proximity) refers to how close together display components should be located to each other based on how similar they are. A high proximity display is configured for perceiving the unity of the visual elements and recognizing the pattern that is created.

Hence, emergent or whole features will seem to stand out more in a high proximity display. A low proximity display is composed of separable or perceptually distinct cues that are more beneficial when visual elements need to be independently processed (Carswell & Wickens, 1996). An example of a high-proximity display is the Microsoft® Windows Start Menu which cascades windows in close spatial proximity to aid menu selection.

The PCP states that a task should have high display proximity if the task requires high processing proximity (Wickens & Carswell, 1995). Processing proximity (or mental proximity) refers to the extent different information sources or cues are utilized within the same task (e.g., integrated or compared). An example of a high processing proximity task is searching on the Internet for the cheapest airfare, because the decision-maker has to make use of several pieces of information that need to be compared (e.g., dates, price information, airline) to complete the task.

In higher processing proximity tasks, integrated-object displays are thought to support information integration better, because they combine several data values into a single object. The integrated-object changes shape dynamically depending on the individual variables. For example, a rectangle is considered a configural or integrated-object display because it has emergent features of area, closure, and symmetry (Barnett & Wickens, 1988; Buttigieg & Sanderson, 1991). Object or configural displays have repeatedly elicited superior performance compared to bar graphs for tasks requiring information integration and conversely, when information required independent processing a more separable display has been found more effective (Carswell & Wickens, 1987; Carswell & Wickens, 1996; Elvers, Adapathya, Klauer, Kancler, & Dolan, 1993;

Goettl, Wickens, & Kramer, 1991; Wickens & Andre, 1990; Wickens & Carswell, 1995; Wickens & Hollands, 2000). Most of this research has focused on the display of dynamic information at a single time or instant in space without examining how to effectively display the changes over time.

The PCP has been used as a framework for designers to match the processing requirements of the task to the visual design of the interface to optimize human-computer interaction. Animated displays and temporal proximity have not been explored as much in the PCP literature. To begin with, the definition of temporal proximity has not been consistently used or well established. In the following section the previous research on temporal proximity will be reviewed and a new definition proposed.

Temporal Proximity

For the last decade, temporal proximity has been an under utilized component of the PCP. While the PCP has been researched thoroughly in terms of matching the type of task to the display, temporal proximity has not been adequately studied. Temporal proximity has been previously defined as a component of the PCP for matching the type of task requirements to the type of interface design incorporated (Wickens & Andre, 1990; Wickens & Carswell, 1995; Wickens & Hollands, 2000). Wickens and Carswell (1995) described temporal proximity as two tasks performed in the same time frame to achieve the same goal. Their description of temporal proximity was presented in a section detailing the non-integrative processing of similar tasks (i.e., lower proximity tasks). The tasks were described as potentially being uncorrelated, using different processing mechanisms, and having no direct influence across the variables. For example, they described driving a car while reading directions as having temporal

proximity, because the tasks are performed in the same time frame with the same end-goal.

Other researchers have defined temporal proximity in dissimilar ways and the new definition used in this study attempts to integrate these various interpretations and meanings. For example, Burns (2000) defined temporal proximity as *when* information should be displayed in complex systems. She found that temporal proximity in conjunction with spatial proximity improved performance in a simulated power plant detection task, but not temporal proximity alone. Barnett and Wickens (1988) also used temporal information as a time condition to reflect *when* information was displayed (e.g., simultaneously or sequentially). *When* information was displayed was a key component of the temporal proximity definition used in this study.

Hansen (1995) used temporal proximity in a different context to present *historical* information rather than when information should be displayed. He used time tunnels to represent configural changes of the system over time. Hansen focused on the importance of providing temporal historical information in a complex system to increase the observers' familiarization with the system and to aid in the detection of problems. He found that in a complex system providing the historical information in a graphical format made operators more confident in their judgments. Some problems noted with the time tunnels he used included the lack of any real-world reference and any feedback on performance. However, he concluded that a more realistic task would require the controllers to need even more temporal historical information to quickly update or recover their situational awareness. To provide useful time information, temporal proximity should display the historical changes of the variable over time.

Although the term temporal proximity was not used specifically, one of the few studies that examined the tracking of dynamic information over time was Buttigieg and Sanderson's (1991) study that examined failure detection in 3-types of displays with and without emergent features. They found that emergent features that changed over time could be as effective as displays that changed over space (the majority of previous research) to represent the changes in a dynamic environment. The presence of emergent features did not interfere with the performance of separable tasks and, in some cases, even enhanced performance. The emergent features allowed the operator to perceive directly the distinctions among perceptual cues with less need for higher cognitive processing.

Application of Temporal Proximity in this Experiment

In this study, temporal proximity was defined as the changing of variables in the same task that occur over time. Tasks that change dynamically over time have higher temporal proximity and tasks that do not change over time have lower temporal proximity. Temporal proximity was examined on a continuum of high and low time-based information rather than a component of only *when* information should be displayed. *How* time-based information was displayed was also significant. Temporal proximity was a component of both the properties of the task, display proximity, and processing proximity. It was hypothesized that a task that required comparison of variables or trends over time would benefit from a graphical format that was more integrated across time. Similarly, a task that required recalling specific cue information was predicted to benefit from a display with lower display and processing proximity.

Although this study expanded the definition of temporal proximity from previous PCP research, it seemed reasonable to keep the proximity terminology to maintain consistency with the other types of compatibility proximity terms (e.g., processing, color, etc.). In this study temporal proximity referred to both *when* (sequential, simultaneous, and animated) and *how* (bar graph or rectangle) the information was displayed. Age differences in performance were based on the format of the graphical aid and the type of temporal proximity condition displayed. The temporal proximity hypotheses used in this study are explained in more detail in the following section.

Temporal Proximity Hypotheses

The current experiment was based, in part, on the Barnett and Wickens (1988) study that examined display proximity for multicue information and the benefit they found for information displayed as rectangles rather than bar graphs in a static integrated task. They examined integration and differences in display proximity in terms of time, space, and object configuration for a military supervising task. They found that the rectangular display was more beneficial than the bar graph for the integration task and displaying information simultaneously was better than sequentially displaying it. Surprisingly, Barnett and Wickens did not find the typical or expected PCP cost associated with the object display on the focused attention task. Participants were able to perceive the rectangle object as a whole, but were also able to discriminate specific cue values. They suggested that the emergent feature (i.e., area of the rectangle) supplied the relevant information for the integration task without disrupting the memory for the separable features (i.e., height and width of the rectangle).

This experiment assessed the influence of using different types of graphical aids to display temporal information in a dynamically changing multiple cue probabilistic decision-making task. The hypotheses in this study were designed to test temporal proximity in terms of age and individual differences in performance and response time based on the type of task, requiring either integration or individual processing of cue information.

There were 8 hypotheses tested in this experiment. These were 1) performance that required integrating information was predicted to be best for the animated rectangle condition, 2) older adults were predicted to benefit more than younger adults from the integration provided by the animated rectangle format, 3) participants with lower scores on the spatial ability test were predicted to perform better using the animated graphics display, 4) the sequential displaying of dynamically changing information was predicted to hurt performance for older adults more than younger adults, regardless if the rectangle or bar graph format was displayed, 5) no cost was predicted to be associated with the rectangle format for remembering the distinct probe information, 6) response time in the integrated task was hypothesized to be fastest in the animated rectangle condition for both age groups, 7) the response time for more separable information was predicted to be faster for the bar graph than the rectangular format, and 8) response time was predicted to be slower for the older adults across conditions.

In hypothesis 1, performance in a high temporal proximity task was predicted to improve using an animated rectangle graphic, because it incorporated higher display and processing proximity. Animation was believed to aid recall in communicating changes over time better than static graphics by reducing the level of abstraction and integration

required to make a time-based decision. It was expected to provide more environmental support and combining of the cues than the static graphics and as a result, improve performance.

In hypothesis 2, older adults were hypothesized to benefit more from the use of animation, because it was believed that it would supplement and aid their decision making more than younger adults. Westerman, Davies, Glendon, Stammers, and Matthews (1995) found that interfaces that emphasize spatial processing, that are complex, or place heavy demands on working memory are more disadvantageous to older adults. Furthermore, when there are large amounts of information that require integration, the judge's capacity to combine the information may be strained (Stewart, Heideman, Moninger, & Reagan-Cirincione, 1992). This was predicted to be especially true for older adults. Although younger adults' performance was predicted to benefit from the use of animation and the rectangle format, the benefit of using an animated rectangle to combine information was predicted to be greater for older adults.

In hypothesis 3, differences in spatial ability were used as a control variable for examining differences in temporal proximity. Hays (1996) found that animation was more beneficial for learners who lacked some of the skills for creating their own visualizations (i.e., low-spatial ability learners). Low-spatial ability participants that used animated graphics were able to make significantly greater gains in understanding than low-spatial ability participants not receiving animation. The participants in his study were seventh and eighth graders, so it was not clear whether the same gains would be seen in low-spatial ability college-age students and older adults. It was hypothesized that younger and older adults with lower scores on the spatial ability test would benefit more

from the use of animated graphics because it would aid them in combining the cue information over time. High-spatial ability participants were not expected to gain as much from the animated cues, because they were predicted to more easily combine the cues in the static display formats.

Due to screen space constraints, information often needs to be displayed in the same physical space in an interface. In the sequential display, updates were made to the information by replacing older information (e.g., time 1) with newer information (e.g., time 2). The participant was required to temporarily store the older information in working memory, which imposed a rehearsal load because the cue information needed to be integrated and compared (Hess et al., 1999). The use of a sequential format was predicted to hurt performance for older adults more than younger adults, because of resource limitations and working memory deficits associated with aging and because the sequential format violates the PCP matching of high display proximity for an integrated task (Carswell & Wickens, 1987; Wickens & Andre, 1990; Wickens & Carswell, 1995).

The retrospective memory probes required the participant to recall information at random intervals without the cue information displayed on the screen (see Bennett & Flach, 1992; Elvers et al., 1993). The finding of a no-decrement in performance in the rectangle condition found by Barnett and Wickens (1988) was an exception to the PCP framework, in that processing separable information in an integrated graphic typically hurt performance because of the low processing proximity required. Although information was dynamically changing over time in this study, the focused attention tasks using the rectangle format were predicted to not have a decrement in performance compared to the bar graph format.

Bennett, et al. (1993) found that participants responded more quickly (and more accurately) to a task requiring integration with a configural display than with a separable display. Similarly, Buttigieg and Sanderson (1991) and Carswell and Wickens (1987) found that response time was faster for integrated information in a configural display because it allowed for more rapid holistic processing. Based on these findings, it was predicted that the response time for integrated information would be fastest in the animated rectangular condition compared to the static conditions, because there was a match of higher temporal, processing, and display proximity in the animated rectangle condition.

Correspondingly, Bennett et al. (1993) found that the response time pattern was reversed when the task required recalling low-level specific information. Carswell and Wickens (1987) also found that response time was significantly faster in a separable task when information was displayed as a bar graph rather than an object format. The response time for the more separable information in the probe questions was predicted to be faster for the bar graph than the rectangular format, because this type of information required remembering isolated information (i.e., lower processing and display proximity). Performance (i.e., correct value) was not predicted to suffer, but response time was predicted to be slower in the rectangle than the bar graph condition for the specific cue-value information.

Older adults have consistently been found to take more time to perform a variety of tasks in experimental and real-world settings (Johnson, 1997; Kelley & Charness, 1995; Morrell & Echt, 1996; Westerman et al., 1995). The response time information provided needed information on the time difference between older and younger adults'

decision-making in a complex, dynamic probabilistic task. As found in most studies with older adult participants, response time was predicted to be slower for the older adults across conditions.

To summarize the hypotheses: there were three hypotheses pertaining to performance in the integrated task, one concerning performance in the separable task, one regarding spatial ability, and three relating to response time in the integrated and separable tasks.

CHAPTER 2

METHOD

Design

The design was a mixed between-group age (younger adults and older adults) x between graphical aid (bar graph or rectangle format) x within temporal proximity condition (static sequential, static simultaneous, and animated). The dependent variables were the mean correlation (over subjects) of actual versus optimal predictions for the mission outcome, response time, and correct cue value on probe questions for separable information.

Participants

Seventy-five undergraduate psychology students ages 17-28 ($M=20.35$, $SD= 2.22$) from The University of Georgia Psychology research pool and 67 older adults ages 60-78 ($M= 70.07$, $SD= 3.38$) from the Athens, GA area participated in this study. Students received credit hours toward fulfillment of a class research participation requirement and older adults were compensated \$25.00 for their time. Three older adult participants' data were excluded because of a power outage, one accidentally exited the program, two left before the experiment was finished, and two failed to indicate a decision during the computer portion of the experiment.

Based on corrected vision, over 90% of the older adults and all of the younger adults passed the near vision test. Seventy percent of the older adults and 99% of the younger adults performed 20/30 or better on a far vision test. The majority of older

adults (72%) and all of the younger adults had between 2-10 years computer experience. Ninety-two percent of the older adults and 97% of the younger adults described their health as good or better. No gender differences in performance were found in the temporal proximity task.

Materials

The Temporal Proximity decision-making tool and the Temporal Proximity response-training tool were custom created using Visual Basic (Taylor, 2002a, 2002b). A 17-inch color monitor was used to present the program and a standard two-button computer mouse was used to record decision responses.

Temporal Proximity Task

In a complex and dynamic environment the exact cue values are often not available. In this task the participants were learning how to evaluate the reliability and diagnosticity of the information, not the true state of the cues. The reliability variable was constant, but the diagnosticity value was not (see Table 2.1). Each trial consisted of a random sub-set of four cues (out of eight) changing over three time periods. The participants learned what and how to weight the information based on the feedback they received during the practice sessions. The information was worth more or less depending on how accurate or relevant it was, not the actual value of the cue. For example, the participants did not see how empty or full the fuel gauge was but rather, how reliable or informative the fuel gauge information was to making the optimal decision.

The participants were asked to complete two tasks. The primary task was to decide whether to continue or abort the pilot's mission. The secondary task was to answer probe questions at random intervals regarding specific cue values at different time

periods. There was some initial concern about the difficulty of the task and the ability of the older adult participants to perform the task. The pilot tests and the majority of feedback from the participants indicated that the older adults were able to perform the task.

Table 2.1

Example of Reliability, Diagnosticity, and Information Worth Values for the Cues

Cue	Reliability	Diagnosticity	Information Worth
Fuel	5	1-5	5-25
Headwinds	5	1-4	5-20
Oil	4	1-4	4-16
Temperature	3	1-4	3-12
Navigational Aids	3	1-3	3-9
Weather	2	1-4	2-8
Enemy Intent	2	1-2	2-4
Pilot Fatigue	1	1-2	1-2

Note. Cues are based on Barnett & Wickens (1988) diagnostic and reliability cues.

Similar to Barnett and Wickens (1988) study, the primary task was dichotomous in that the cues were either in support of continuing (green) or aborting (red) the mission. The colors green and red were chosen for their symbolic meaning and the population stereotype of green indicating continue or go and red signifying stop or danger (Wickens & Hollands, 2000). The cue values were weighted by each cue's information worth and combined according to the algorithm

$$\text{Optimal decision} = \sum_{i=1}^3 [(\text{Avg}(WC_i) - \text{Avg}(WA_i)) \times 0.137]$$

where $\text{Avg}(WC)$ is the sum of the weighted cues in support of continuing the mission at time i , $\text{Avg}(WA)$ is the sum of the weighted cues in support of aborting the mission at time i , and 0.137 is a constant for converting scores to the appropriate scale values. By requiring participants to average cues for each time period, participants could not simply add up the cues for continuing or aborting the mission at any time period to reach the optimal decision. The participants instead had to integrate and average each cue set as it was presented over time to reach the optimal decision; thus, requiring higher processing and temporal proximity to perform the task.

Participants completed practice sessions consisting of 30 trials for each temporal proximity condition. Participants received outcome feedback during the practice sessions based on the optimal decision for that cue trial. The experimental session consisted of 3 blocks of 60 trials each. There was no feedback provided during the experimental session. The simultaneous and animated cues displayed for 12 seconds and the sequential format displayed each time period for 4 seconds. The participant had 10 seconds to respond to whether the mission should be continued or aborted. There was a 2 second delay between the participants' response and the next trial. During each test block, five probe questions were randomly presented.

Procedure

Participants were tested individually or in groups of two to three. Participants were randomly assigned to the bar graph or rectangle condition before arriving at the laboratory. Upon arrival, participants completed two copies of the consent form and a

demographic-health questionnaire. After completing the paperwork, participants completed a near and far vision test. Next, individual abilities were assessed for vocabulary, spatial visualization, processing speed, and working memory (in that order) using the Shipley Vocabulary Test (Shipley, 1986), the Paper Folding Test – VZ-2 (Ekstrom, French, & Harman 1976), Digit Symbol Substitution Test (Wechsler, 1981), and the Alphabet Span Test (Craik, 1986).

The instructions for the Temporal Proximity tool were then placed in front of each participant and read aloud by the experimenter. The experimenter showed an example of the response box and probe questions on a computer while reading that section of the instructions. The instructions for the task were

This is a study examining how you *learn* to perform a decision-making task. You are to imagine that you are a military supervisor that must decide to continue or abort a pilot's mission based on the information you are receiving from an on-board intelligent decision support system (i.e., the computer display). The information will be presented as snapshots of different information over three time periods: time 1, time 2, and time 3. The information will remain constant over the time trial, but the values for each will change between time periods. The value of information ranges between 1 and 5 with 1 being worth less information than a 5. The information is color-coded: the color green indicates information for continuing the mission and red is for aborting the mission. You will need to combine the information from the three different time periods to reach your decision of whether you think the pilot should continue or abort the mission.

- The “R” in the display refers to the reliability of the information – or how accurate the information is in terms of representing the true state of the system – how much can it be trusted?
- The “D” refers to the diagnosticity of the information – or how relevant the information is to aborting or continuing the mission.

(Note: Depending on the experimental condition, the participants were then told either that they would see the information as a bar graph labeled “R” and “D” or that they would see a rectangle with the width labeled “R” and height labeled “D.” See Figure 2.1 and 2.2)

- There are 2 steps to indicating your decision (this was shown on the computer):
 - (1) You need to indicate how confident you are the pilot should continue or abort the mission by moving the marker along a 10-point continuum with anchors of *definitely continue* and *definitely abort* the mission.
 - (2) Click on the “OK” button after you have made your decision and the next trial will begin. During practice sessions the correct decision, continue or abort, will be displayed at the bottom of the response box. Please make your decision as fast as you can. If you have not clicked “OK” after 10 seconds the next trial will begin.
- In addition, 5 times during the test sessions, a question (example shown on computer) will randomly appear asking you about the specific value of a piece of information e.g., what is the reliability of

oil at time 2? The answer will be a value between 1 and 5. If you know the answer, click on that value and then click “OK.” If you do not know the answer, there is a box labeled “I have no idea” – click on it and then “OK.”

There will be three different approaches to presenting the information. If you need to take a break, please wait until you have been prompted that a new session is about to begin.

After the instructions were read and any questions answered, participants were asked to enter the experimental laboratory and choose a computer station. Individuals with less computer experience were given an opportunity to use a Temporal Proximity response-training tool (Taylor, 2002b). When participants indicated that they were ready to begin the computer experiment portion, the experimenter started the Temporal Proximity tool (Taylor, 2002a). The order of temporal proximity condition displayed and individual trials was randomized. Following completion of the Temporal Proximity program, participants were debriefed and thanked for their participation in the study.

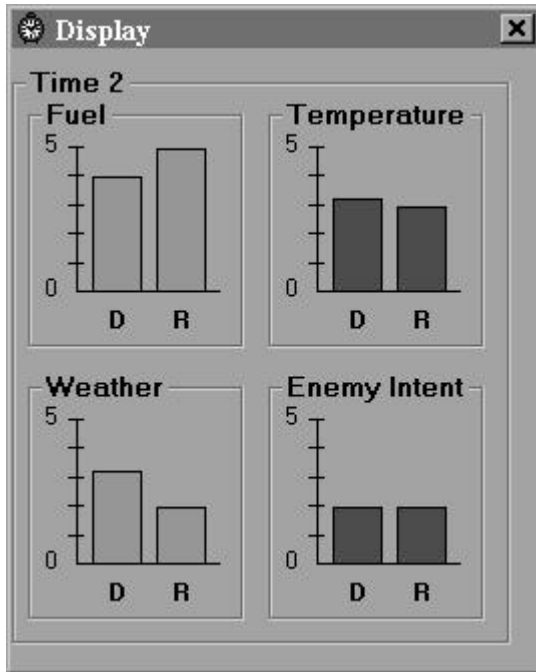


Figure 2.1 Example of Bar Graph Display

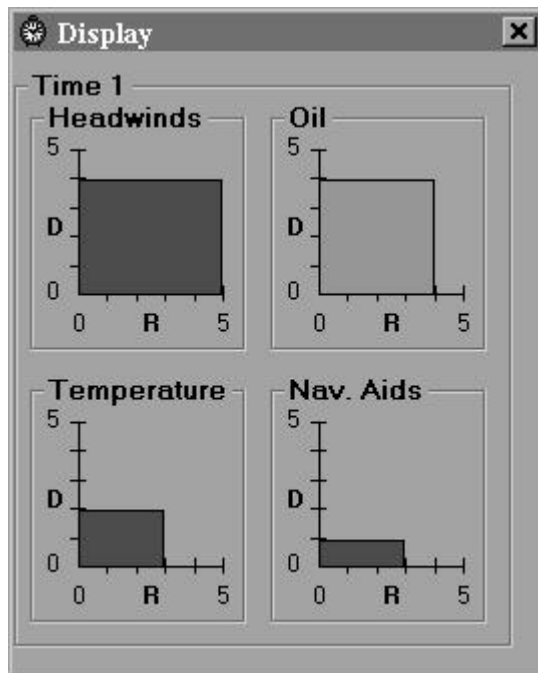


Figure 2.2 Example of Rectangle Display

CHAPTER 3

RESULTS

An omnibus mixed ANOVA performed on the Fisher Z transformation of the correlated performance measures indicated a significant 3-way interaction (age x temporal proximity condition x graphical aid), $F(2, 276) = 6.27, p < .01$. For ease of interpretation, Figure 3.1 and Figure 3.2 display the interaction between temporal proximity condition and graphical aid by age. A table of the means and standard deviations is provided in Table 3.1. All of the means and standard deviations reported in this section are for the correlations and not the transformed z-scores. The only overall significant main effect was for age, $F(1, 138) = 21.58, p < .001$ (older adults $M=.20, SD=.16$; younger adults $M=.29, SD=.14$).

Based on the 3-way interaction and to examine the age difference further, four complex comparisons were computed and revealed significant differences for older adults' temporal proximity performance in the bar condition, $F(1, 34) = 5.16, p < .05$ (static $M=.23, SD=.13$, dynamic $M=.16, SD=.19$) and in the rectangle condition, $F(1, 31) = 5.05, p < .05$ (static $M=.18, SD=.13$, dynamic $M=.23, SD=.16$). The significant difference found in the older adult rectangle condition is described further in the hypothesis 2 results. The younger adults temporal proximity performance in the bar condition, $F(1, 37) = 2.32, p > .05$ (static $M=.26, SD=.11$, dynamic $M=.29, SD=.14$) and rectangle condition, $F(1, 36) = 1.18, p > .05$ (static $M=.33, SD=.14$, dynamic $M=.31, SD=.14$) were not significant.

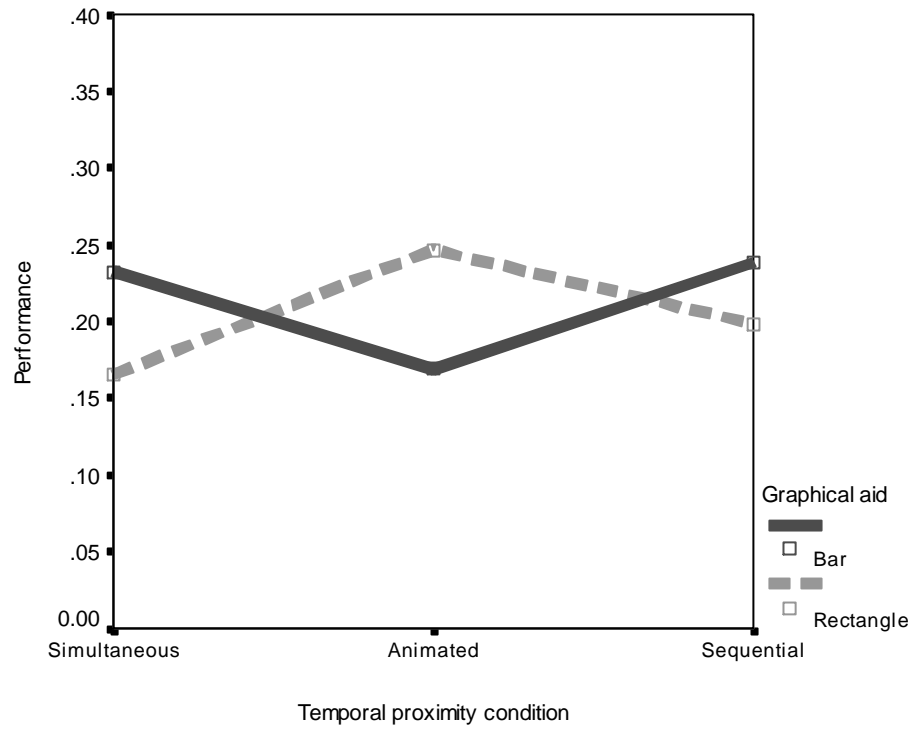


Figure 3.1 Older adult performance based on graphical aid and z-transformed mean performance in the temporal proximity condition.

Table 3.1

Correlation Mean and Standard Deviation by Age and Temporal Proximity Condition

Temporal Condition	Younger Adult				Older Adult			
	Bar		Rectangle		Bar		Rectangle	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Simultaneous	.26	.13	.32	.16	.22	.15	.16	.15
Animated	.29	.14	.31	.14	.16	.19	.23	.16
Sequential	.26	.13	.33	.15	.23	.15	.19	.16

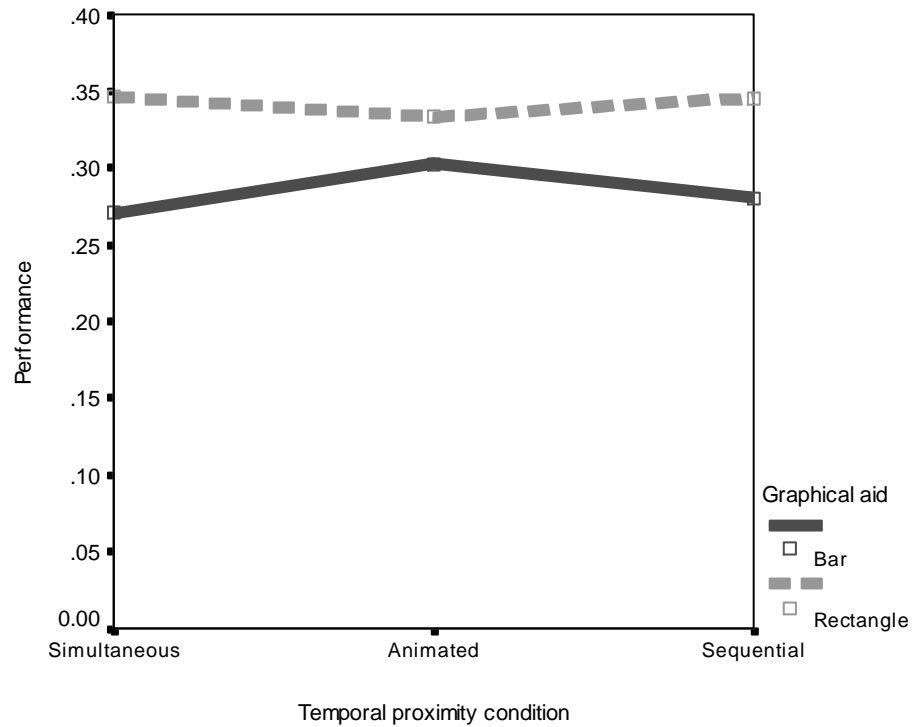


Figure 3.2 Younger adult performance based on graphical aid and z-transformed mean performance in the temporal proximity condition.

Qualified by the 3-way interaction, performance in the integrated task for the animated ($M=.28$, $SD=.15$) rectangle condition was not found to significantly differ from the sequential ($M=.26$, $SD=.17$) and simultaneous ($M=.25$, $SD=.17$) conditions, $F(2, 136) = 1.08$, $p > .05$. Thus, hypothesis 1 was not supported.

As described in the 3-way interaction complex comparisons, hypothesis 2 was supported. Older adults benefited more from the integration provided by the animated rectangle format than the static conditions, $F(1, 31) = 5.05$, $p < .05$. Younger adults did not significantly differ in the animated rectangle condition, but there was a significant difference in performance for the younger adults in the simultaneous condition between

bar ($M=.27, SD=.15$) and rectangle ($M=.35, SD=.18$) conditions, $F(1, 73) = 3.96, p < .05$. Animation did not benefit low spatial ability participants performance more in the animated ($M=.20, SD=.17$) condition than the simultaneous ($M=.20, SD=.15$) and sequential ($M=.22, SD=.15$) conditions as predicted in hypothesis 3, $F(2, 146) = .69, p > .05$.

In Hypothesis 4, the sequential displaying of dynamically changing information (regardless of graphical aid) was predicted to hurt older adults' performance more than younger adults. This was supported in that performance of the older adults ($M=.21, SD=.15$) was more adversely affected than that of the younger adults ($M=.29, SD=.14$), $F(1, 140) = 6.84, p < .01$.

Although there were floor effects in the participants' performance on probe questions, as predicted in hypothesis 5 there was not a significant difference between bar ($M=10.08, SD=10.05$) and rectangle ($M=10.73, SD=9.84$) format for recalling the distinct probe information in the separable task, $F(1, 140) = .78, p > .05$. Hypothesis 5 predicted no difference between the formats in the separable task and was therefore supported. Part of the floor effects can be explained by the older and younger adults frequently responding "I have no idea" to the probe questions rather than a value 1-5; approximately half the younger (56%) and older (49%) adults responded no idea 7 or more times out of 15 probe questions.

The last three hypotheses examined response time information in the integrated and separable tasks. All response time information was recorded in milliseconds. Hypothesis 6 posited that response time would be fastest in the animated rectangle ($M=4165.06, SD=1207.43$) condition for both older and younger adults, as compared to

the respective old and young participant performance in the static rectangle ($M=4028.77$, $SD=1273.40$) condition. Although significant, this hypothesis was not supported, $F(1, 67) = 4.36$, $p < .05$, the animated condition response time was significantly slower rather than faster than the static condition. Hypothesis 7 predicted that response time for the probe questions in the bar condition would be significantly faster than response time for the probe questions in the rectangle condition. This was not supported; analyses showed no significant difference between response times in the probe questions for the bar condition ($M=5257.30$, $SD=1425.34$) than for the rectangle condition ($M=5669.95$, $SD=1622.47$), $F(1, 139) = 3.22$, $p > .05$. Hypothesis 8 predicted that older adults would be significantly slower than younger adults across conditions. This was supported; F-test results indicated that younger adults ($M=3392.95$, $SD=671.39$) answered questions significantly faster than older adults ($M=4664.47$, $SD=1154.58$), $F(1, 140) = 16.26$, $p < .001$.

Additional age differences were found in the performance on the cognitive ability tests. For the most part younger adults performed better than the older adults on the ability tests. The only exception was the vocabulary task, where older adults performed significantly better than younger adults, $F(1, 140) = 15.6$, $p < .001$. Younger adults performed significantly better than the older adults on all of the other ability tasks: processing speed ($F(1, 140) = 22.98$, $p < .001$), working memory ($F(1, 140) = 16.74$, $p < .001$), and spatial ability ($F(1, 140) = 19.84$, $p < .01$). See Table 3.2 for means and standard deviations of all the ability tests.

Table 3.2

Means and Standard Deviations for Ability Tests

Ability Test	Younger Adult		Older Adult	
	Mean	SD	Mean	SD
Vocabulary	30.9	3.4	35.0	3.4
Processing Speed	70.1	10.8	49.2	10.7
Spatial Visualization	12.6	3.7	6.9	3.0
Working Memory – Absolute Span	37.9	11.7	23.4	8.4

CHAPTER 4

DISCUSSION

The interaction between age, graphical aid, and temporal proximity condition indicates that there is a significant age difference in performance based on how and when temporal information is displayed. Although the performance of older adults was worse overall than the younger adults, there are some interesting differences between their performances.

Hypotheses and Implications

Hypothesis 1

The rectangle with animation was predicted to provide more decision support for both age groups by reducing the effort required to combine the cues. Although this was found for the older adults, it was not supported for the younger adults. The younger adults' performance did not differ as much within temporal proximity conditions. The only statistically significant difference in performance for the younger adults was better performance on the rectangle than bar graph in the simultaneous condition. For the younger adults, the simultaneous rectangle provided better cognitive support and performance than the simultaneous bar graph condition. The PCP predicts this finding for an integrated task because of higher processing and display proximity in the simultaneous rectangle condition, but the predicted benefit of adding animation (i.e., higher temporal proximity) was not found for the younger adults.

Hypothesis 2

When the age differences are examined further, it is clear that the older adults are performing differently than the younger adults based on the temporal proximity condition and graphical format displayed. For the older adults the rectangle with animation provides more decision support than the static rectangle conditions. By integrating the information in an animated display, the self-initiated processing required to integrate the information was reduced and performance for the older adults improved. Morrell and Echt (1996) suggested that the addition of animation might facilitate understanding for older adults, because the use of animation required fewer inferences in learning the material. However, it is important to note that the animation was not beneficial when added to the bar graphs in the integrated task. The static bar graph condition resulted in significantly better performance than the animated bar graph. The type of graphic that animation is added to is critical. As predicted in hypothesis 2, the animation in the rectangle condition did benefit older adults decision-making in the integrated task more than the younger adults, but adding animation to the bar graphs hurt performance.

Hypothesis 3

It was hypothesized that younger and older adults with lower scores on the spatial ability test would benefit more from the use of animated graphics. However, there was not a significant difference in performance based on whether the participant scored high or low on the spatial ability task. Although there was a significant difference in performance between older and younger adults on the spatial ability task, no other performance differences were found based on the participants' score on the spatial ability test. Hays (1996) found that low-spatial ability participants' benefited more than high-

spatial participants from an online animated lesson in diffusion, but these differences were not found in this dynamic, decision-making task. The type of task, learning versus decision-making task, may account for some of this difference in findings.

Hypothesis 4

The sequential displaying of dynamically changing information was predicted to hurt performance for older adults more than younger adults, because of processing deficits and working memory problems associated with aging. As predicted, the increased rehearsal load in cue integration for the sequential display did significantly affect older adults' performance compared to younger adults in the sequential condition (Hess et al., 1999). The PCP predicts worse performance for a sequential display compared to a simultaneous display in an integration task, because of the lower display proximity in a sequential display (Carswell & Wickens, 1987; Wickens & Andre, 1990; Wickens & Carswell, 1995) and as found, this was especially true for older adults. When information needs to be combined from different sources (i.e., higher processing proximity), there needs to be a match of higher display proximity.

Hypothesis 5

In complex systems the role of the human is often to monitor or supervise the system in terms of overall status. Probe questions were used in this experiment to simulate an abnormal state of the system that would require the supervisor to redirect attention resources to the discrete cue information quickly and accurately. Similar to findings in the Barnett and Wickens (1988) study, the rectangle format was predicted to have no cost associated with responding to separable information. Although the hypothesis was supported and there were not significant differences between the

rectangle and bar graph in performance on the probe questions, there was poor performance in the task that may have caused floor effects.

Specific cue information was only required 8% of the time during each display test session. Participants may have found it more advantageous to ignore the specific cue value information in favor of the overall integration task because of the low percentage of cue specific information required. In addition, because participants were given the option of responding “I have no idea” to the probe questions, the requirement to give a specific cue value was eliminated. The participants may have viewed this secondary task as merely an interruption to the primary task of deciding whether the pilot should continue or abort the mission.

Another concern with the probe questions is the recall methodology used. Bennett et al. (2000) suggested that a visual methodology (probe questions asked with display available) offers a more representative test than a recall methodology (display not available), because a primary goal of interface design should be to minimize the decision-makers’ reliance on memory. As a result, the performance decrement in probe question responses may be an artifact of the recall task and the attention strategy that the participant employed (Bennett et al., 2000; Elvers, et al., 1993). More research is needed to determine if the rectangle display allows the processing of separable cue information in a dynamic environment. The results from this study suggest that this may be the case, but research using more probe questions and incorporating a visual rather than recall methodology is needed.

Hypothesis 6

Based on the PCP regarding integrated tasks, a match of high temporal, processing, and display proximity was predicted to generate a faster response time in the animated rectangle condition over the static condition. Although there is a significant difference in response time, it is in the opposite direction than predicted. The participants responded significantly faster in the static conditions than the animated. Why this happened is not entirely understood. One possible explanation is that people are more familiar with static displays than animated displays and the novelty of the animated display may have added to the overall response time in this condition.

Hypothesis 7

Response time for probe information was hypothesized to be faster in the bar graph condition than rectangle, because the task required recalling a more separable task, specific cue values. Previous research has found faster response time for the bar graph compared to the rectangle (Bennett et al, 1993; Carswell & Wickens, 1987). Although response time in the bar condition was slightly faster than in the rectangle condition, this hypothesis was not supported. As discussed earlier, the difficulty of the probe questions in this task may have effected the participants' overall response time. Participants' ability to respond "I have no idea" also may have produced differences in response time not found in previous studies lacking this no-response option.

Hypothesis 8

As found in most studies examining age differences in response time, older adults responded significantly slower than younger adults across conditions (Johnson, 1997; Kelley & Charness, 1995; Morrell & Echt, 1996; Westerman et al., 1995). The general

pattern of older adults taking longer to respond in this type of temporal decision-making task is consistent with age differences found in a variety of other tasks. Some of the response time age differences found in this study may be attributed to older adults' strategy differences in controlling the mouse (e.g., more conservative movements) and taking longer to move the mouse (Mead, Batsakes, Fisk, & Mykityshyn, 1999; Rogers & Fisk, 2000). Examining different input devices may reduce some of the response time differences found in this study, but it is reasonable to presume that there would still be some age differences found in response time.

Future Studies

One area for future study based on these findings is to manipulate the type of feedback provided during training. Outcome feedback, provided in the practice sessions, may have only made the participants aware of the inadequacy of their strategy in terms of the optimal decision, but it may not have helped them to change their strategy to the correct one. For example, Chasseigne et al. (1997) found that older adults could not change their default strategy to the correct strategy when given just outcome feedback in a decision-making task with inverse relations between cues. Age differences in applying a new strategy based on the type of feedback needs to be explored further to determine if different types of feedback can improve performance in this type of decision-making task.

In addition to changing the feedback, changing the format of the instructions could improve performance. For example, an online tutorial could help reduce some of the cognitive demands of the task by providing specific instructions and practice on task components on the computer (Morrell, 1997). Perhaps listening and reading to the

experimental scenario and then having to perform the practice sessions introduced more of an extraneous cognitive load. Having the scenario and instructions online may improve performance because participants would not have to divide their attention as much during training (see Sweller & Chandler, 1994). Further studies that address the format and type of instructions would be useful.

Even though age declines are found in most laboratory cognitive ability tasks, this does not explain how the majority of older adults are able to successfully perform most everyday tasks. Fisk and Rogers (2000) suggested that the novelty of the task accounts for the age-related pattern of decline found in most laboratory studies. When the task was more familiar, they found that decision-making capabilities were maintained across various complex tasks and well-learned skills (e.g., typing, visual search) into old age. A valuable follow-up study would be to develop a probabilistic decision-making task that incorporates temporal proximity and animation in more of an everyday context that younger and older adults would be equally familiar with and examine if performance is different than in this more artificial military context. Although a military context was thought to be equally unfamiliar to both age groups, a study examining a more familiar context would be valuable.

Applied Implications

Learning to make probabilistic judgments is an important part of life. From medication adherence to driving a car, ways to aid and support decision-making through instruction and presentation of information is essential. Results from this study suggest that the memory support provided by the graphical components of the display as it changes over time is linked to performance. For example, designers of a system

primarily used by older adults should avoid sequentially displaying information that needs to be combined or compared. Given that older adults benefited more from the use of animation in this complex dynamic decision-making task, other types of procedural and spatial tasks with known age differences in performance may also benefit by incorporating animation in training or in the design of the task.

Several ability tests were included in this study to assess cognitive differences within and between participants. There was a significant difference in processing speed, spatial ability, and working memory between older and younger adults and this difference provides some explanation regarding why age differences are found in temporal proximity performance. Evidence from this study suggests that age differences in the abilities of the decision-maker and the design of the display affect performance. Interface design can benefit by incorporating these types of differences in individual abilities in the design of new technology (Hess et al., 1999).

In summary, computers are only going to become more pervasive in older adults' lives and ways to positively introduce and support the use of technology need to be found. The evidence suggests that older adults need to be considered as an important user group in the design process (Czaja, 1996). Age differences in both how and when temporal information is displayed were found. There is some evidence that temporal proximity could provide a viable guideline to follow for the display of dynamic information. Differences in performance based on the type of display or graphical aid used in a temporal proximity task could provide guidelines for the design of other types of monitoring, tracking, and complex decision-making tasks that are time based.

Animation may provide part of the answer, but more investigation is needed examining temporal proximity and display design.

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APPENDIX

Perceptual Factors in Viewing Animation

Perceptual factors involved in perceiving animation include the phenomenon of apparent motion, or perceiving motion when there is no physical movement of an object in the visual field (Ramachandran & Anstis, 1986). In order to perceive animation as a single object in motion, the visual system must detect correspondence between the separate images and apply one organized and meaningful pattern (Ramachandran & Anstis, 1986; Rieber & Kini, 1991). Three factors of apparent motion are especially relevant to creating animation: 1) time between display of separate objects, 2) light intensity of display, and 3) spatial distance between each of the objects. Additional factors (e.g., spatial frequency, color, size, shape, depth, etc.) influence the perception of apparent motion, but the impact is considered minor compared to the previous three factors (Rieber & Kini, 1991).

For the purposes of this study, the rate of image presentation to be perceived as moving smoothly and continuously was the most critical component. Although there is some controversy concerning how the visual system detects correspondence between static images, how this is completed is not as important as the end result. For a person to perceive motion as continuous, the minimal requirement for displaying the graphic is at least 15 frames per second (Rieber, 1991a). Pilot testing was used to confirm that the animation was perceived as smooth and continuous using a sample of younger and older adult participants. Although research had shown that animation may need to be slowed down for older adults, this was not found to be necessary in this study.