22

Mental Models and the Maintenance of Complex Problem-Solving Skills in Old Age

David A. Walsh
University of Southern California
Los Angeles, California

Douglas A. Hershey
George Mason University
Fairfax, Virginia

I. Introduction

Over the last decade, research studying age-related differences in complex problem-solving performance has seen an increase (Charness, 1981a,b,1982, 1983; Denney & Palmer, 1981; Denney, Pearce, & Palmer, 1982; Hartley, 1989). These studies have important applied and theoretical motivations. From an applied perspective, knowing whether societies are wise to entrust their older members with some of their most important problem-solving responsibilities is important, given the large amount of literature showing age-related declines in the basic abilities believed to underlie decision making. May societies work against the common good by allowing older adults to occupy positions of responsibility, or do the findings of widespread declines of basic cognitive abilities in laboratory studies lack external generalizability to the everyday world of human cognitive tasks? Clearly, either conclusion, if supported by complex problem-solving research, will have important implications.

From a theoretical perspective, understanding how older adults could maintain competent, complex, cognitive performance in the face of declines in basic cognitive abilities is important, if indeed they are able to do so. Does the heavy research focus on basic abilities overestimate their importance in many human cognitive tasks? Is the quality of one's performance in many complex cognitive tasks primarily dependent on knowledge of the domain, rather than on basic cognitive abilities such as attention, memory, or information processing speed? Studies of age-related differences in complex problem solving could provide some important theoretical insights into the probable impact of aging on cognitive performance.

ADULT INFORMATION PROCESSING: LIMITS ON LOSS

Researchers studying age-related differences in problem solving have emphasized the quality of problem solutions. The work of Cornelius and Caspi (1987) exemplifies this outcome approach. These investigators constructed an inventory to assess the response modes that people reported they would use to solve problems in a variety of everyday situations. Subjects of various ages were tested to see if they would report (1) taking overt action to solve problems, (2) intellectually analyzing problems, (3) attempting to avoid the situation, or (4) denying that a problem exists. The investigators found that increasing age was associated with improvements in the response modes that subjects reported they would use when confronted with everyday problem situations. This line of research provides some evidence to support society's trust in older decision makers and some insight into how modes of problem solving may vary with age, but tells us very little about the adult development of processes that underlie performance because it does not examine the substance of problem solving (i.e., the specific solutions people would propose and the cognitive processes that lead to those solutions).

In contrast, the work of Arenberg (1974), Charness (1981a,b,1983) and Hartley and Anderson (1983a,b) pays more attention to the process underlying problem solving, but still emphasizes the quality of outcomes. Arenberg's work, for example, has examined age-related differences in tasks that require subjects to decide which of a set of foods composing hypothetical meals is poisonous. These studies show that older adults perform more poorly than young adults, as measured by the number of errors they make and the number of trials to solution. However, the two major processing demands of this laboratory task (and of those used by others) are, we believe, atypical of many everyday problem solving tasks. First, tasks such as these require subjects to use one (or a few) logical decision rules to generate a solution (the rule of deductive elimination, in the case of Arenberg's work). Second, they require subjects to encode and retain novel episodic information (e.g., which food combinations lead to death and which to survival).

This chapter draws on research in expert problem solving and cognitive psychology to propose a mental model-based interpretation of problem solving in complex, informationally rich, and ill-defined domains (Gentner & Stevens, 1983). Legal judication, financial planning, and medical diagnosis are three examples of domains in which people are required to solve complex information-rich problems. Problems in these domains are complex because, to generate a solution, an individual often is required to integrate information from dozens, or even hundreds, of variables. Problem solving in these domains is informationally rich because one's knowledge of the domain specifies what variables are relevant and how to interrelate those variables to arrive at a solution. Finally, problem solving within these domain is ill defined because the situation-specific characteristics of a particular problem may play an important role in determining which variables should be considered and how they can be combined to arrive at a solution.

We have chosen personal financial planning for study because it presents problems faced by all adults in American society. We will have more to say about the complex, informationally rich, and ill-defined aspects of financial planning problems later. Within the context of our theoretical framework, we offer an explanation of the paradoxical relationship between an age-related decline in basic cognitive processing resources and some empirical evidence for age-related improvement in real-world problem-solving performance. Two investigations of age-related differences in the way in which individuals solve complex financial planning problems are reported as support for our theoretical position.

A. Theoretical Framework

The theoretical framework that has guided our studies suggests that past research has neglected some important features of the complex cognitive performance people exhibit in real-world situations. The major tenet of our theoretical framework is that most complex problem solving is guided by a person's mental model of the problem area. Further, we propose that people solving complex problems in the real world bring *established* mental models to the problem situation. A mental model is a person's conceptual understanding of (1) the relevant variables to consider in solving a particular problem and (2) how these variables are interrelated. We believe that mental models develop gradually through exposure to a problem domain. This exposure may include formal or informal study or attempts to solve a few problems in the topic domain (cf. Gentner & Stevens, 1983; Hershey, Walsh, Read, & Chulef, 1990).

Our theoretical framework leads to the prediction that increasing experience with a problem domain should lead to more efficient problem-solving processes and higher quality solutions. If age is associated with increasing experience in a problem area, then age also should be associated with increasing problem-solving efficiency and higher quality solutions, that is, older, more experienced people should have better developed mental models than younger, less experienced adults. Further, people who are inexperienced in a problem area should have to invest cognitive effort to develop a mental model of the problem space. Thus, we predict that older subjects, who are likely to be more familiar with the financial planning problem domain we have chosen for study, should show more efficient information selection and search profiles than younger, less experienced subjects. Further, we predict that older adults should produce higher quality solutions to these financial problems.

Our general theoretical framework presupposes that adult development is associated with increasing knowledge in a variety of problem-solving domains, and that this acquired knowledge is responsible for most of the variability seen in everyday reasoning situations. Further, although we believe basic abilities such as working memory and attention are critical for the successful acquisition of information from the environment, we believe their contribution to everyday performance becomes less important as an individual gains problem-solving experience within a domain.

Charness (1981a,b,1983) provides supporting evidence for the hypothesis that knowledge associated with expertise can remove age-related differences in cognitive performance. He found that old adults continued to perform problem-solving tasks in chess and bridge as well as their younger counterparts (matched in rated expertise), despite measurable declines in many simple task-related memories. This investigation seeks to extend our understanding of age-related differences in the use of knowledge in a complex problem-solving task, and represents a special effort to focus on age-related differences in the type of information that is selected to solve complex problems, and how that information is used to reach a solution.

B. Task Selection

Some studies have demonstrated that task selection has a profound effect on the information search and selection strategies of problem solvers. The complexity, novelty, and structure of tasks all have been shown to impact information search. Cognitively complex tasks elicit problem-solving strategies that minimize search, thereby emphasizing efficiency (Huber, 1980; Payne, 1976). Novel tasks eliminate the subject's knowledge from playing a role in generating solutions (Charness, 1982). Well-structured tasks leave little room for the subject to apply problem-solving strategies they have developed on their own (Simon, 1973; Voss, Tyler, & Yengo, 1983). Since the goal of this study is eliciting the individuals' unique mental model for problem solving and examining how these attributes are related to age, we chose a task that is sufficiently complex to encourage search efficiency, sufficiently familiar that prior knowledge and experience of the subject, contribute to the solution, and sufficiently ill defined to allow subjects the opportunity to apply their own mental models of the problem domain.

II. Study 1

The first study examines differences in the information search strategies of young, middle-aged, and old adults on a complex personal financial planning problem. This study re-examines data reported by Hershey et al. (1990) in their study of problem-solving differences between expert and novice financial planners. One-third of the data is new, using subjects not included in the Hershey study. The major difference, however, is that subjects have been grouped by age rather than by expertise in this study.

A. Method

Our task required subjects to decide whether a hypothetical couple should open an Individual Retirement Account (IRA). The IRA task was chosen because it meets the criteria described and because it can be analyzed logically into a

prescriptive sequence of "proper" steps. A task analysis was carried out to identify the conceptual elements required to reach a solution. A pilot study (N = 12) queried subjects about the variables they considered important to deciding whether to open an IRA account. Their reports were combined with guidance from retirement planning literature and used to design the IRA problem.

The task analysis identified three higher-order issues that should be addressed when deciding whether or not to open an IRA account. One should first consider if a need exists for additional retirement funds (NEED). Second, if a need exists, one should determine if an IRA account is a suitable investment vehicle (ACCOUNT). Finally, the affordability of an IRA account should be considered (AFFORDABILITY). A complete consideration of any one of these factors requires calculating the interplay between a number of variables. For example, projecting a person's retirement need requires that we know their annual expenses in retirement, how many years they will have to meet those expenses, and what their retirement income will be. We also must factor in the influence of inflation on their various income streams and their expenses to arrive at a plausible approximation of their future need in retirement. A thorough analysis of the IRA problem revealed 43 variables related to the problem solution. The variables for each factor (NEED, ACCOUNT, and AFFORDABILITY) have been arranged into the three hierarchical structures shown in Figures 1, 2, and 3.

1. Subjects

A group of 16 men and 5 women varying in age from 23 to 73 years served as participants.[1] Subjects were recruited to ensure that the sample included a wide range of age and expertise. Approximately half the subjects were chosen because they were experienced financial planners. To address the issue of whether age differences occur in problem-solving abilities, the continuous range of ages was divided into three groups of 7 subjects (young: M = 28, s = 5.3; middle aged: M = 44, s = 3.4; and old: M = 62, s = 7.1). Previously, we examined differences in the problem-solving processes of expert and novice financial planners using 14 subjects from this same pool of 21 individuals (Hershey et al., 1990). The expert and novice subgroups were formed using subject scores on a measure of financial knowledge, in combination with their occupational histories. Participation was voluntary and no one was paid for their time. All subjects appeared to be highly motivated and interested in the task. The educational background was comparable across the three age groups; the young, middle-aged, and old groups have an average of 14.6, 17.3, and 17.4 years of education, respectively.

[1]This research effort began in 1985 with the plan of carrying out a replication subject sampling design. We planned to sample 21 more subjects after the initial data collection. This plan was motivated by the explorative nature of our research—we were not sure if we could develop methods to analyze our subjects' "on-line" performance. By the time we had developed the PSPM approach and coded the data on our first 21 subjects, the U.S. tax laws had changed. The new laws governing IRAs made it impossible to use our IRA decision task with an additional 21 subjects.

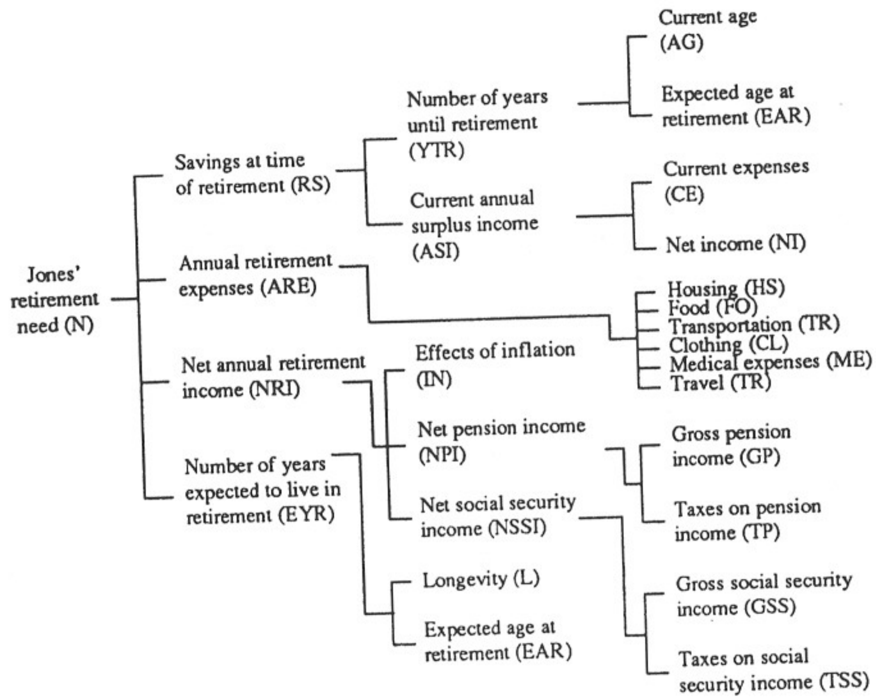

FIGURE 1

Retirement need hierarchy. Variables and concepts related to the issue of the Jones' additional financial need in retirement. Variables and concepts were generated through a logical task analysis of the Individual Retirement Account problem. Abbreviations in parentheses are used in the process tracing maps of Figures 3, 4, and 5.

2. Documenting Expertise

After finishing the experimental problem-solving task, participants completed a 26-item questionnaire measuring knowledge of retirement planning and finance. This financial knowledge test served as our objective index of expertise.

3. Materials

A complete set of plausible values for all 43 variables identified in the task analysis was constructed to create a realistic scenario involving a hypothetical couple. Both the name of the variable and the selected value were printed on 4″ × 6″ index cards; the name of the variable was typed on the back side of the card. Separate cards were printed for each of the variables shown in Figures 1, 2, and 3. A large information board was used to hold the cards that subjects requested to solve the problem.

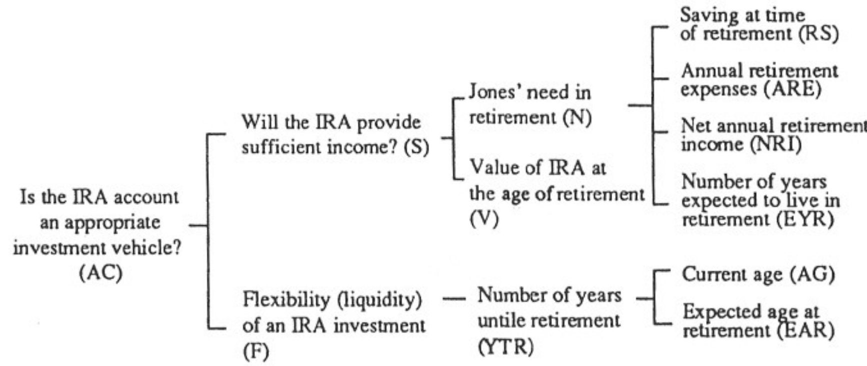

FIGURE 2

Account hierarchy. Variables and concepts related to the issue of the adequacy of an Individual Retirement Account as an investment vehicle for the Jones couple. Variables and concepts were generated through a logical task analysis of the Individual Retirement Account problem. Abbreviations in parentheses are used in the process tracing maps of Figures 3, 4, and 5.

4. Procedure

Subjects were informed that the purpose of the study was to investigate the thought processes people use to make complex real-world decisions. They were told their answers would not be scored as right or wrong. Instead, they were told the purpose of our research was to examine the step-by-step processes used to reach the decision. Further, they were instructed that the experimental session would be conducted in two phases. In the first phase, they were asked to specify the information they thought was necessary to reach a decision. In the second phase, they were required to use that information to decide how much money the hypothetical couple should contribute to an IRA account. At the start of the first phase, subjects were asked to read the following instructions and scenario:

> Described below is a decision facing a young working couple. Please place yourself in their situation and describe what things you would consider and the detailed information you would need to know in order to solve the problem.
>
> Bill and Sally Jones met 10 years ago as college students and have been happily married for 8 years. Bill is 32 years old and has been working for 6 years as an electrical engineer. Sally is 33 years old and works full-time as a university professor. They are both happy with their jobs which they hold at large and financially secure institutions. They have a good income, and earn equal annual salaries. Bill and Sally have one child, and live in a pleasant home they purchased 2 years ago. The whole family enjoys excellent health.

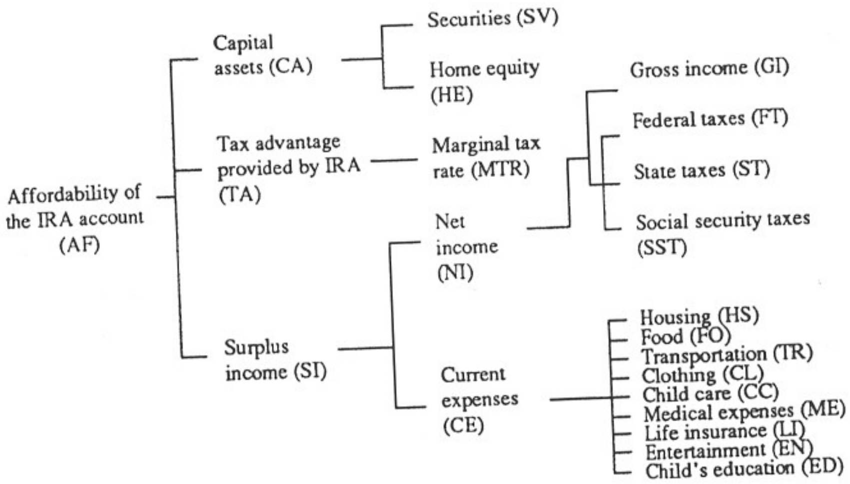

FIGURE 3

Affordability hierarchy. Variables and concepts related to the issue of the affordability of the Individual Retirement Account for the Jones couple. Variables and concepts were generated through a logical task analysis of the Individual Retirement Account problem. Abbreviations in parentheses are used in the process tracing maps of Figures 3, 4, and 5.

> Bill and Sally have recently seen a number of advertisements by banks and brokerage firms about their Individual Retirement Accounts (IRAs). They are wondering whether they should open such an account. If you were Bill or Sally, what factors would you consider in order to solve this problem? Please list the specific information you would want to know if you were going to help Bill and Sally make this decision.

Subjects were asked to list verbally and in writing the information they would need to reach a decision. If their request for a variable was ambiguous, they were further queried to clarify the information being requested. Our conceptual task analysis proved sufficiently exhaustive to anticipate virtually all the variables subjects requested. After they completed listing relevant variables, they were seated in a waiting room. This concluded the first phase of the experimental session. While the subject was in the waiting room, the experimenter placed the requested variable cards on the information board in a random arrangement. Only the back of the cards and the variable names were visible. A simple hand-held calculator, some paper, and a pencil were placed on the table. The subject returned to the room and read the following instructions:

> On the board in front of you are the variables you have named as important in deciding whether or not Bill and Sally should open an IRA. On the other side of each card is a value to help you make that decision.
>
> You may only look at one card at a time, and cards must be replaced on the information board with only the title showing. If at any time you would like information about a variable that does not appear on the board, just tell the experimenter and he will provide you with an additional card(s). If you would like to use the calculator, pencil or paper, please feel free to do so.

Subjects were told they could view cards as often and as long as they wished. There was no time limit on the decision process. Subjects were instructed to continually "think aloud" in their effort to make a decision so that an audio recording of the decision process could be made. A tape recorder was started and the subjects were asked to begin. Subjects were reminded to think aloud if they fell silent for more than a few seconds. The second phase of the session ended when the subject had determined whether or not the couple should open an IRA account. After completion of the task, the financial expertise questionnaire was administered. Finally, subjects were debriefed and thanked for their cooperation.

5. Assessing Decision Quality

In Study 1, the accuracy of subject decisions was measured by comparing their recommended investment in an IRA with the objectively correct amount specified by our conceptual model. The correct amount was determined by combining the 43 variables for the IRA problem to arrive at a specific investment amount, given the retirement need of Bill and Sally Jones, limits on contributions to an IRA, and their ability to afford a contribution. The measure of decision quality was the absolute value of the deviation of the subject's recommended investment from the correct amount (which was $4000). Thus, recommended investments that were either too large or too small were treated equally, and were not allowed to offset one another in the group mean to create a potentially misleading average solution quality.

B. Results and Discussion

1. Domain Specific Knowledge and Decision Quality

The percentage of questions answered correctly on the financial knowledge test was found to increase with age (means of 43.9, 52.1, and 55.7 for the young, middle-aged, and old, respectively). However, the mean differences were not statistically significant [F (2,18) = 1.13; n.s.].

Moreover, the accuracy of the subjects' solutions to the IRA problem were not found to change as a function of age. The average absolute deviation of each groups' solution from the correct amount was $1714.30, $285.70, and $1742.90 for the young, middle-aged, and old, respectively. Although the solutions of the middle-aged were, on average more accurate than those of the young and old, these differences were not statistically significant [$F(1,\ 13) = 2.73$; n.s.].

Our two major predictions, that both financial knowledge and financial problem-solving accuracy would increase with age was not confirmed in Study 1. We think two problems with Study 1 may explain the failure to support this hypothesis. First, the subjects in Study 1 were not selected to be representative of the various age groups sampled. Instead, they were selected to create two extreme groups of expertise for the Hershey et al. (1990) investigation. Some of the subjects were included because they had the credentials of experts; others were selected because they reported vast ignorance about financial planning. Perhaps this nonrepresentative mix, regrouped by age, fails to reflect more general age-related differences in financial knowledge that may exist in the general population.[2] Thus, our sampling procedure may be masking stronger age-related differences in financial knowledge in the general population. This problem provided one of two major motivations to conduct Study 2.

The second limitation to the first study was the restricted range of possible solutions (the IRA problem allowed contributions of $0 to $4000). Assuming that many of the subjects were either familiar with the widely advertised limits on contributions or had specifically requested this information to solve the problem is not unreasonable. The net result appears to have been a dependent measure of problem-solution quality that had limited range and high variability, thereby masking group differences. Thus, the need for a more sensitive measure of solution quality was a second impetus to Study 2.

2. *Process Measures*

The dynamic nature of subject problem-solving processes was represented with the use of Problem Solving Process Maps (PSPMs). A PSPM is a graphic presentation of the sequence of steps a subject took to arrive at a solution. PSPMs were constructed by abbreviating the nodal elements contained in the problem hierarchies (NEED, ACCOUNT, and AFFORDABILITY; see Figures 1, 2, and 3 for the abbreviation legend) and arranging them on a single page (see Figure 4). In addition to the three hierarchies, information related to the IRA account was represented on the PSPM (the rectangular block of eight variables shown on Figures 2, 4, 5, and 6).

The actual step-by-step process an individual used to arrive at a solution was obtained from that person's think-aloud protocol and our records of their variable card usage. If a subject first considered the couple's gross income (as was the case for the subject represented in Figure 4), that node was labeled "START,"

[2]The correspondence between the age and expertise groupings of these 21 subjects follows. Three young, two middle-aged, and two old subjects fell into the novice group, whereas three middle-aged and four old subjects fell into the expert group as reported in Hershey et al. (1990).

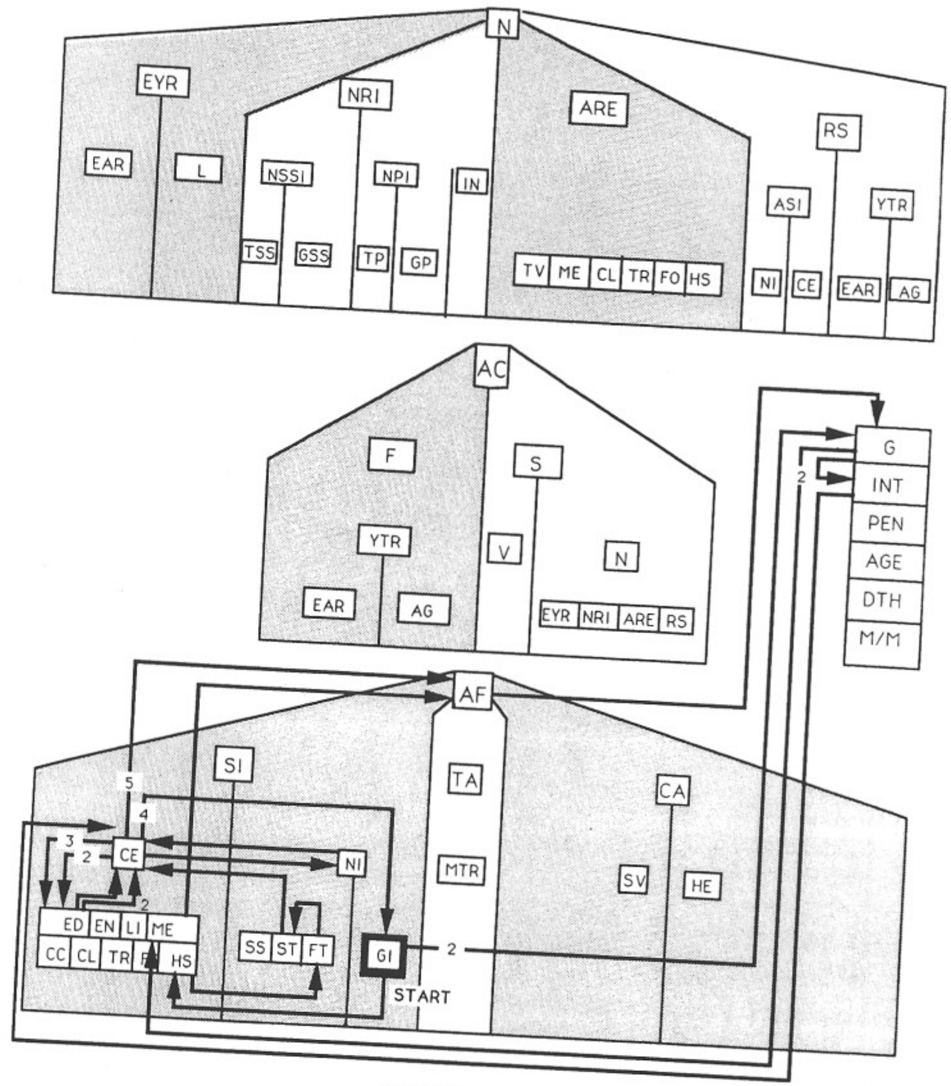

FIGURE 4

The Problem Solving Process Map (PSPM) of a young adult whose performance is representative of the average of the young group. The three hierarchies—need, account, and affordability (ordered from top to bottom) are represented in the conceptual model of the problem found in Figures 1, 2, and 3. Shaded areas in the hierarchies represent different information "branches" in the conceptual model. The beginning of the subject's solution path is labeled "START"; the directional arrows show the successive sequence of variables they considered to arrive at a solution. IRA account information variables: G, general information about IRAs; INT, interest rates; PEN, penalties for early withdrawal; AGE, age-related account policies; DTH, distribution of funds in the event of death; M/M, minimum and maximum deposits. See Figures 1, 2, and 3 for nodal abbreviations.

and an arrow was drawn to the subsequent node considered. We judged a node to be "activated" once the variable was removed from the information board and a calculation or qualitative assessment of the parameter was made. For example, accessing the Current Expenses card and subtracting this amount from the Net Income value was judged to be a computation sufficient to activate the current expenses node. Likewise, if a subject viewed the Gross Retirement Income card and commented, "$8000 isn't going to be enough to live on during retirement," that node would be activated since a qualitative assessment had been made. Merely explaining how a problem should be solved, or describing the importance of a particular piece of information without viewing the parameter was not sufficient to activate a node. In the analyses reported here, we distinguish between "total steps" and "unique nodes" used to reach a decision. Unique nodes are the number of different pieces of information used to reach a decision whereas total steps are equal to unique nodes plus the number of recursions (repetitive considerations of the same piece of information).

If a node was activated more than once during the decision making process, second and third arrows emanating from the node were distinguished from the original (first) path from the node in that subject's PSPM. (These recursions are indicated in the PSPMs by numbers embedded in the arrows interconnecting the conceptual nodes.) No particular node was considered more than five times by a subject (i.e., four recursions).

Figure 7A presents the group data of our young, middle-aged, and old subjects on our dependent measures of information processing. Newman–Keuls procedures were used to assess differences between groups when an F test was significant. The results of these comparisons are shown in Figure 7A for each dependent measure.

The results for age comparisons will be contrasted with the differences reported by Hershey et al. (1990) as a function of expertise.[2] We believe these expertise analyses provide a valuable framework in which to view the age differences. The expertise comparisons use the data of the seven most expert and the seven least expert subjects, as described earlier. Figure 7B presents the results of these analyses.

The most striking age-related trend in PSPMs is that the decision paths of older adults are more goal directed than those of young adults. (Figures 4, 5, and 6 are actual PSPMs for young, middle-aged and old subjects, respectively. These PSPMs were selected for display because they are representative of the "average" for each group.) One way to quantify goal directedness is simply to count the number of times subjects reconsidered the same information (recursions). On average, the seven old adults, made .7 recursions, compared with 1.6 for the middle-aged group and 5.4 for the young group. This difference was statistically significant [$F(2, 18) = 4.12$; $p < .05$]. Figure 7A shows individual comparisons between groups using Newman–Keuls contrasts. The differences between the young and middle-aged and the young and old groups were statistically

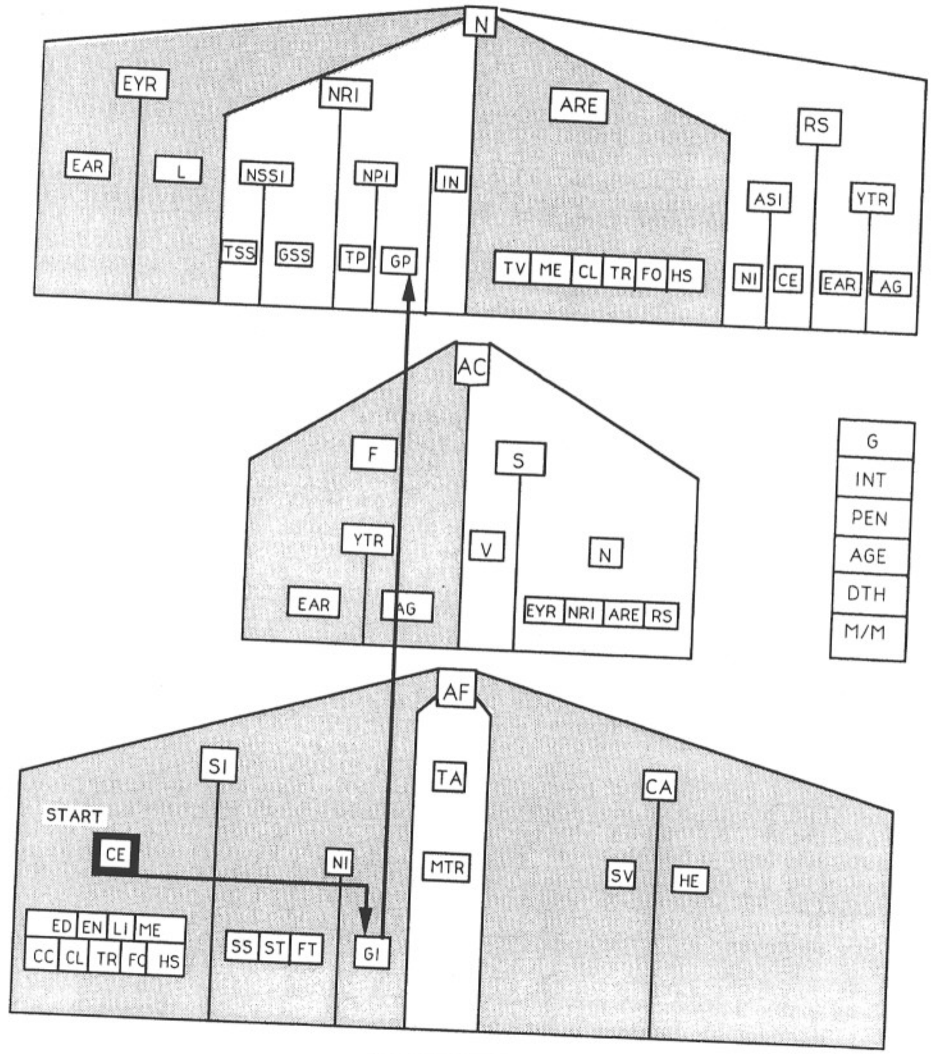

FIGURE 5

The PSPM of a middle-aged adult whose performance is representative of the average of the middle-aged group. The three hierarchies—need, account, and affordability (ordered from top to bottom)—are represented in the conceptual model of the problem found in Figures 1, 2, and 3. Shaded areas in the hierarchies represent different information "branches" in the conceptual model. The beginning of the subject's solution path is labeled "START"; the directional arrows show the successive sequence of variables they considered to arrive at a solution. See Figure 4 for IRA account information variables. See Figures 1, 2, and 3 for nodal abbreviations.

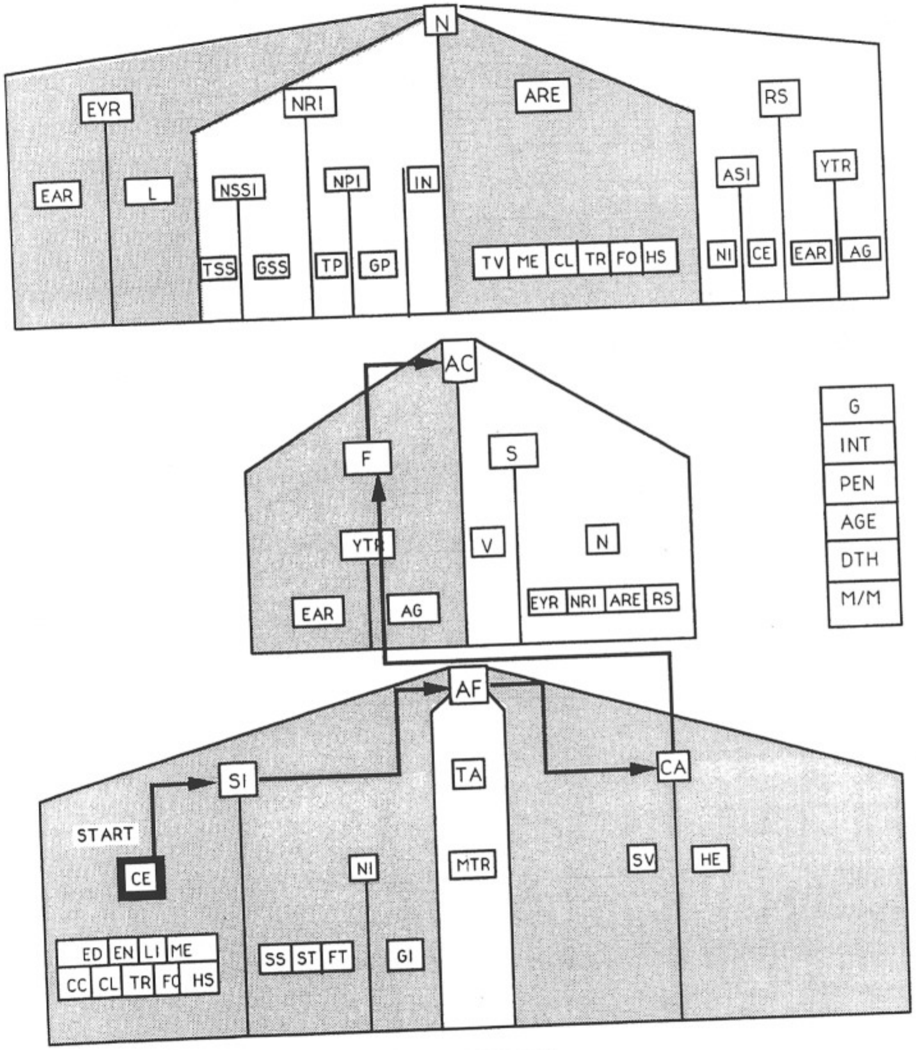

FIGURE 6

The PSPM of an old adult whose performance is representative of the average of the old group. The three hierarchies—need, account, and affordability (ordered from top to bottom)—are represented in the conceptual model of the problem found in Figures 1, 2, and 3. Shaded areas in the hierarchies represent different information "branches" in the conceptual model. The beginning of the subject's solution path is labeled "START"; the directional arrows show the successive sequence of variables they considered to arrive at a solution. See Figure 4 for IRA account information variables. See Figures 1, 2, and 3 for nodal abbreviations.

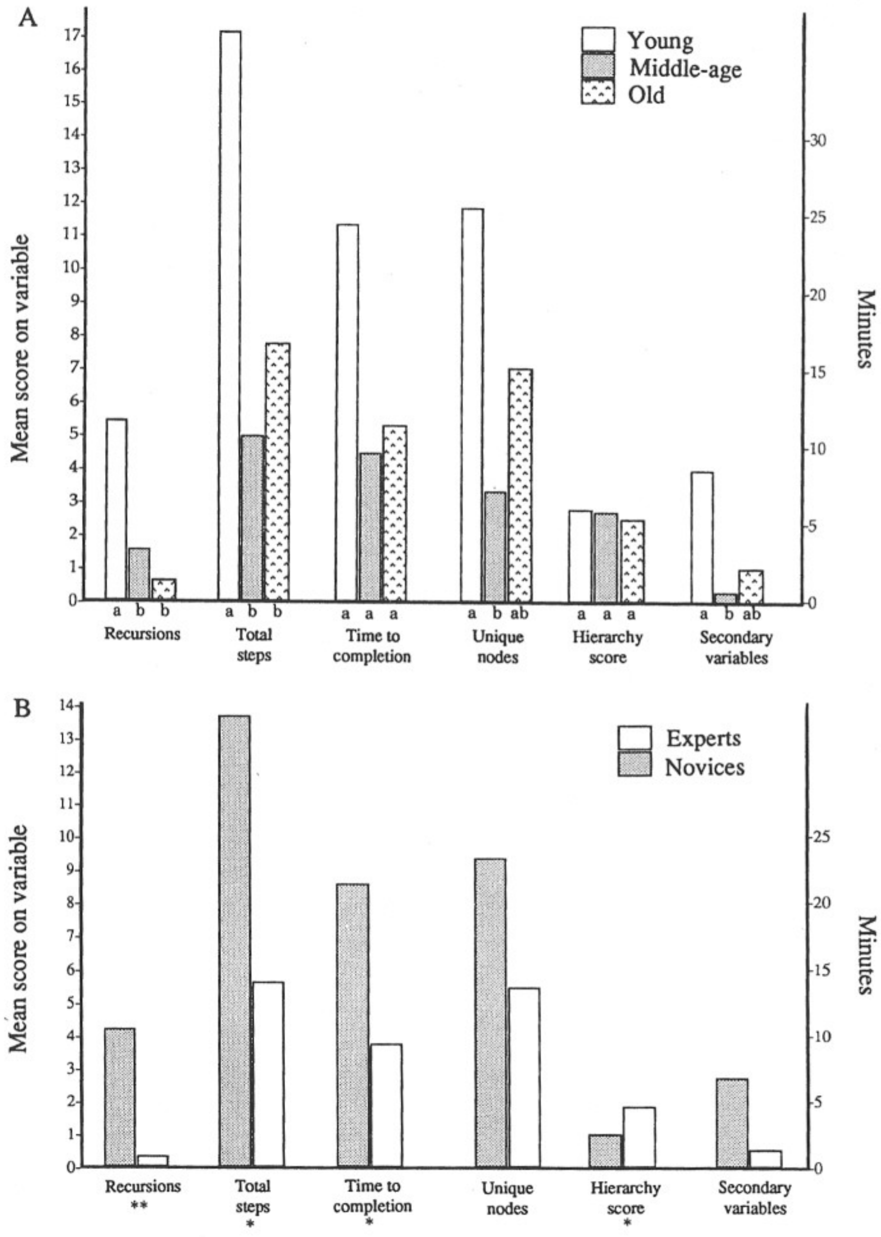

FIGURE 7

(A) Differences in the problem solving processes used by young, middle-aged, and old adults to solve the IRA problem. The three age groups were created by resorting the expert and novice subjects studied by age by Hershey et al. (1990) and adding an additional seven subjects not included in that report. The letters below the bars indicate the results of Newman–Keuls comparisons. Groups showing different letters beneath the bars are significantly different from one another ($p < .05$). (B) Differences in the problem solving processes used by experts and novices to solve the IRA problem. The expert and novice groups are composed of the seven most and the seven least knowledgeable subjects, respectively, from the pool of 21 sampled in this research (*, $p < .05$; **, $p < .01$).

significant. The difference between the old and middle-aged groups was not statistically significant.[3]

Age-related differences in the total number of steps used to reach a decision were found also. On average, old and middle-aged adults completed the task in significantly fewer steps than young adults [7.9, 5.0, and 17.3 steps, respectively; F (2, 18) = 6.41; $p < .01$; see Figure 7A for individual comparisons]. In addition, young adults required over twice as much time as middle-aged and old adults to solve the problem, requiring an average of 20.6, 9.2, and 12 minutes, respectively. However, because of the large variability within each age group, these mean differences were not found to be statistically significant [F (2, 18) = 1.94; n.s.].

Another analysis was conducted to determine if age was associated with differences in the total number of unique nodes activated in reaching a decision (i.e., total steps minus recursions). The young, middle-aged, and old groups used an average of 11.9, 3.4, and 7.1 unique nodes to reach a decision; this difference was statistically significant [F (2, 18) = 6.74; $p < .01$]. Contrasts indicated that the difference between the young and middle-aged group was statistically significant; however, differences between the old group and the other two groups were not (see Figure 7A). Thus, middle-aged adults used fewer variables more efficiently to arrive at quicker solutions than did young adults. The old adults performance was intermediate to the performance of the other two age groups.

The pattern of differences found when these subjects were grouped into experts and novices is strikingly similar to that seen as a function of age. Figure 7B shows comparisons of the seven most and seven least knowledgeable subjects from our sample. The experts made fewer recursions, used fewer total steps, and took less time than novices to arrive at a solution. Although not significant, the experts also used fewer unique nodes, on average, then the novices. Although these comparisons are confounded by the modest association of age and expertise in this small sample, they do offer some useful information. The finding that three young, two middle-aged, and two old "novices" are less goal directed and efficient in their information search than three middle-aged and four old "experts" suggests that expertise (knowledge about the problem domain as represented in a subject's mental model of personal financial planning) may be a more important determinant of these performance characteristics than age. Since the data of Study 1 were inadequate to resolve this issue, Study 2 (described subsequently) was designed to address it directly.

[3]The count of recursions for each subject was based on their reinspection of information cards. Subjects were allowed to use paper and pencil to keep notes. Possibly, some subjects consulted their notes, thus masking recursions to data that were not counted and could not be counted given our experimental procedure and arrangements. However, we doubt this happened with much frequency. Few subjects recorded the values of data cards, since they could look at them again if needed. The notes that were taken were sketchy and poorly organized.

Since each of the hierarchies in the problem space contains four levels, the average hierarchical level of information used by an individual can be calculated by summing the "level scores" of each node considered and dividing by that number of nodes (a score of 4 indicated high level information; a score of 1, low level information). The hierarchy scores are interesting because they reflect the conceptual level of information that was used to solve the problem. The hierarchy scores show no indication of varying as a function of age [F (2, 18) = .22; n.s.].

However, we did find statistically significant age-related differences in Phase 2 information requests (secondary variables) [F (2, 18) = 3.67; $p < .05$]. Recall that subjects could request additional information not requested in Phase 1 if they chose to do so in Phase 2. On average, the young, middle-aged, and old groups requested 4.0, .3, and 1.0 additional variables during the second phase of the task. As Figure 7A shows, the difference between the young and middle-aged groups was statistically significant. Although the results for the old group were not significantly different from either the young or the middle-aged, the mean value for the old was more similar to the middle-aged than to the young. This pattern of results is consistent with the hypothesis that middle-aged and old adults have developed mental models of the problem space they use to direct their decision processes. If a mental model were guiding the selection of information, enumerating the relevant variables prior to starting the task should be easy. On the other hand, if a subject was operating without a well-defined mental model (as appears to be the case for the young adults), then enumerating all the relevant variables during Phase 1 would be difficult (if not impossible). Many of the secondary variables requested by the younger group appear to have been afterthoughts, that is, pieces of information they found they needed only after reaching an advanced stage in their decision process.

Once again, similarity exists between the information search and selection processes of our subjects when considered as groups varying in age and groups varying in expertise. As Figure 7B shows, the expert subjects in this sample requested fewer secondary variables than the novices, just as old and middle-aged subjects requested fewer secondary variables than the young. However, some dissimilarity is seen between the age and expertise comparisons because the old and middle-aged subjects used information from the same hierarchical level as the young to arrive at their solutions. In contrast, the experts used information from the upper levels of the task hierarchy, whereas novices selected lower level information.

A striking feature of these results is how little of the total problem space subjects considered in arriving at a solution of the Jones' financial problem. On an individual basis, 14 of the 21 subjects considered 7 or fewer of the 43 parameters identified by our conceptual model as relevant to a solution. The young subjects considered the largest number of variables. One explanation for this outcome is that older, more financially experienced subjects had mental models that specified that only a few important variables need to be considered to produce a reasonably good solution. This explanation is similar to the principle of "satisficing" (Simon, Guetzkow, Kozmetsky, & Tyndall, 1954). When satisficing, problem solvers simplify their deliberations to arrive at satisfactory (rather then ideal) solutions. In some respects, this suboptimal behavior is adaptive because a cost–benefit analysis between cognitive effort and decision quality favors a cognitive "easy" satisfactory solution over one that is near optimal, however cognitively "difficult" to produce. Although the explanation may sound counterintuitive, the young subjects' attention to *more* variables could, therefore, be explained by a lack of knowledge that would enable them to reach a simple and reasonably high quality solution. This explanation is also consistent with the finding that young subjects made more recursions and requested more secondary variables than the middle-aged and old subjects.

On the other hand, age differences in number of variables considered also could be explained by cognitive limitations on the part of the old and middle-aged subjects. Perhaps these age groups could not keep as many issues and variables in mind as the young and thus, either consciously or unconsciously, limited their use of problem information. Although this possibility is not ruled out by the data of Study 1, we think it unlikely because of the similar pattern between expects and novices. Experts considered fewer variables than novices and, although all the experts in this comparison were middle-aged or old, four of the seven novices were also middle-aged or old. Thus, knowledge of the problem domain seems to be a more likely predictor of the use of a small number of variables than does age. Study 2 was designed to further examine this possibility.

A third possible explanation for the observed findings was that our subjects had different levels of interest in the retirement investment problem and, therefore, invested different levels of effort on the task. The age differences might be explained by the young subjects finding the plight of the Jones family more interesting than would the older subjects because of its greater similarity to their own life situations. Study 2 also examines this possibility.

III. Study 2

The results of the first study provided some support for the idea that domain-specific knowledge is important to determining how efficiently one uses information to solve complex problems. These results are also consistent with the hypothesis that, in domains in which age is correlated with the acquisition of knowledge (for example, in financial planning), age also is likely to be related to increases in problem-solving efficiency. The primary evidence for an association between age, knowledge, and problem-solving efficiency is the similarity of performance between middle-aged and old adults and the more expert third of the same sample—a group that was composed primarily of middle-aged and old adults. However, confounds and missing information in the first study limit the force of any conclusions. The sample was small (because of changes in federal tax laws midway in our data collection effort) and restricted in age range (because the sample was selected on the basis of task knowledge, not age). In Study 2, we sampled three groups of adults who were more homogeneous in age and knowledge of financial planning. Subjects were chosen to create two homogeneous age groups, separated in age by 40 years, and a third independent group of highly trained experts. In addition, we changed from an IRA investment problem to a 401K problem that required more variables to solve, had limits and options that were not generally known, and offered a wider range of solution values.

Another difference was that the second study used five different versions of the financial planning task. The five versions of the task were constructed to create a range of hypothetical life situations that might be of greater interest to each of the age groups sampled.

A. Method

Subjects decided whether one of five different hypothetical individuals should take advantage of a supplementary retirement savings program offered by their employer. The retirement savings plans used in this study were 401K plans (named for the federal tax section that regulates them). In most ways, the decisions about participating in an employer-sponsored 401K plan are identical to the IRA decision used in the first experiment. A conceptual task analysis identified the same three higher-order issues outlined for the IRA problem (see Figures 1, 2, and 3). The main differences between the task are in the ACCOUNT hierarchy (Figure 2) and include differences in the legal limits of how much an individual can contribute to the plan on an annual basis, as well as the possibility of employer contributions. Switching tasks from the IRA to the 401K problem was necessitated by the 1986 tax law that dramatically complicated the nature of the IRA decision.

1. Design

Two factors were crossed in a between-subjects experimental design. Three different groups (young, old, and expert) solved five different problems in which the life situation of the hypothetical person varied. A random start with rotation counterbalancing technique was used to assign subjects to the five different 401K problems.

2. Subjects

The two age groups in this study were composed of 14 young subjects (7 men, 7 women; average age of 19 years; average education of 14 years) and 18 old subjects (10 men, 8 women; average age of 69 years; average education of 16 years). The expert group was composed of 16 financial planners working in the personal tax and financial planning department of a nationally recognized accounting firm (11 men, 5 women; average age 29 years; average education of 16 years).

3. Materials

In contrast to Study 1 in which a single scenario was used to depict the life situation of a hypothetical young couple facing an IRA problem, Study 2 presented subjects with one of five scenarios describing people of different ages and life situations facing a 401K investment decision. The five scenarios used follow:

> Bob and Judy O'Keefe are a middle-aged couple that have been married for a number of years. They have a teenage son and own a small pleasant home in the San Fernando Valley. Bob is a supervisor at the Gas Company and Judy runs a small but profitable home-based business.
>
> Alan Twain is a young successful computer engineer living in Los Angeles. His commitment to his career prevents him from marrying; however, he leads a full social life with friends from work. Alan recently bought his first house just a few minutes drive from his place of employment.
>
> Denise and Mark Thompson are a young couple busy raising two growing boys. Denise works for Pacific Bell and Mark is a machinist at an auto parts shop. The family of four lives in a comfortable two-bedroom home that they have been renting for a number of years.
>
> Frank and Betty Benson are an older couple who will soon enter the golden years of retirement. Frank is a high level executive at IBM and Betty keeps busy as a housewife and volunteer for a local charitable organization. They have paid off the mortgage on their home and plan to live there during retirement.
>
> Rhoda Sims is a young energetic woman working as a manager at Denny's Restaurant. She was divorced from her husband three years ago and is raising a pair of twins on her own. Together, the family of three lives in a small two-bedroom apartment which she rents in a nice neighborhood.

These scenarios exclude many of the details about job stability, health, adequacy of income, and specific ages that were given in the Jones scenario of Study 1. This change was made because of our concern that subjects may have requested so few variables in Study 1 because many of the necessary pieces of information had been given in the scenario description.

The conceptual task analysis carried out for the 401K problem yielded 73 variables that were potentially relevant to solving each of the five problems. In general, the IRA problem analysis shown in Figures 1, 2, and 3 provides a clear

idea of what these variables were and how they were interrelated. We constructed a complete hypothetical profile for each of the five scenarios, yielding 73 variables that were available to subjects in their efforts to solve the problems. The name of the variable and the selected value were printed on 4″ × 6″ index cards; only the name of the variable was typed on the back side of the card.

4. Procedure

The procedure followed in Study 2 was almost identical to that used in the first study. In summary, the major features were a two-phase task in which subjects (1) specified the information they thought was necessary to reach a decision and (2) used that information to decide if the person(s) in the 401K scenario should open an account. The information subjects requested (printed on index cards) was placed on an information board in a random arrangement. Subjects were encouraged to ask for additional information that might come to mind during the second phase. They also were told they could look at cards repeatedly, but could turn over only one card at a time. No time limit was placed on either phase of the task; the experimental session did not end until the subject reached a decision about whether an investment should be made and how much money (if any) should be contributed. Finally, subjects took a 32-item financial knowledge test. This test measured their information about current financial trends, tax issues, social security, employer pension plans, and 401K plan characteristics.

5. Assessing Decision Quality

As in Study 1, the accuracy of subject decisions was measured using the absolute value of the deviation of their recommended 401K investment from the correct solution. The "correct solution" for each of the five scenarios was determined by combining the 73 variables for each problem to arrive at a specific investment amount. This amount was based on (1) the retirement need of the person(s), (2) the characteristics of the employer's 401K plan, and (3) the target employee's ability to afford an investment. The complexity of these calculations for each of the five problems necessitated the validation of these criteria by having three senior financial planners from a "big-eight" accounting firm study all 73 variables for each of the five problems. All three consultants arrived at the same "correct" answer for four of the five problems; two of the three agreed on a correct answer for the fifth problem. These values were uses as the criterion against which subject solutions were evaluated.

B. Results and Discussion

The dependent variables for Study 2 were measured in the same fashion described for the first study. Written records of each subject's step-by-step decision process were used to create individual PSPMs. The PSPMs were constructed from an abbreviated template of our conceptual analysis of the 401K problem and, for the most part, resembled the PSPMs for the IRA problem shown in Figures 4, 5, and 6 (except for major modifications of the ACCOUNT hierarchy and minor modifications of the NEED and AFFORDABILITY hierarchies, noted previously).

First, we carried out a series of 2 (age group) × 5 (problem scenario) analyses of variance (ANOVAs) to test whether age differences found on the various dependent measures in the first study might be explained by an interaction of subjects' own life situation and the situation of the hypothetical couple described in the scenario. To test this hypothesis, the two-way interactions of age group × problem scenario were examined across all our dependent measures. None of these interactions was found to be statistically significant for the seven dependent measures of problem-solving processes nor for our measure of decision quality (F values ranged from .3 to 1.6, but five of the seven fell within the range of .92 to 1.3). We also examined the main effects of problem scenario. None of the main effects approached statistical significance (F values ranged from .4 to 1.8 for the seven tests). Because the different 401K scenarios had no effect on any of our dependent measures and did not interact with age, we were able to collapse our data across scenarios in the discussion that follows.

1. Domain Specific Knowledge and Decision Quality

The young, old, and expert group levels of financial knowledge differed from one another as measured by the 32-item test described earlier (scores of 39, 49, and 74% for young, old, and expert groups, respectively). Consistent with our argument that aging is associated with increasing knowledge about financial planning, a planned comparison showed that the old group knew more about financial planning than the young group [t (26) = 3.08; $p < .01$]. A second contrast between the old and expert groups showed that this difference was also statistically significant [t (25) = 9.80; $p < .01$].

The accuracy of the young, old, and expert group solutions on the 401K problems also differed from one another (absolute errors of $4892, $3344, and $1033, respectively). Based on the findings of the Hershey et al. (1990) study, we had hypothesized that greater knowledge of financial planning would be associated with higher quality solutions. In fact, experts were found to make more accurate financial decisions than the young [t (14) = 2.88; $p < .05$] and old groups [t (15) = 2.57; $p < .05$], thereby supporting this hypothesis. Although the old adults were, on average, $1547 closer to the correct answer than the young, this difference was not found to be statistically significant [t (23) = .98; n.s.].

The pattern of outcomes of the financial knowledge and decision accuracy measures, considered together, provide support for two conclusions. First, higher levels of financial knowledge (i.e., richer, more elaborate mental models of financial planning) are associated with more accurate solutions to the complex 401K investment problems. Second, a sample of healthy, well-educated, older adults knows more about financial problem solving and provides more accurate,

average solutions to financial problems than a comparable group of young adults (although the average difference was not statistically significant). The importance of one's mental model in determining the quality of problem-solving performance is documented further by findings from the experts who, as a group, demonstrated the highest levels of knowledge and the most accurate problem solutions.

2. Process Measures

Figure 8 shows the outcome for the seven dependent variables used to measure the problem solving process. Figure 8 shows that few differences were found among the young, old, and expert groups tested in Study 2 on any of the dependent measures derived from the PSPMs. In fact, univariate ANOVAs failed to detect any statistically significant group differences on any of our measures of information use or problem-solving efficiency.

Before embarking on a discussion of age differences in the content-specific

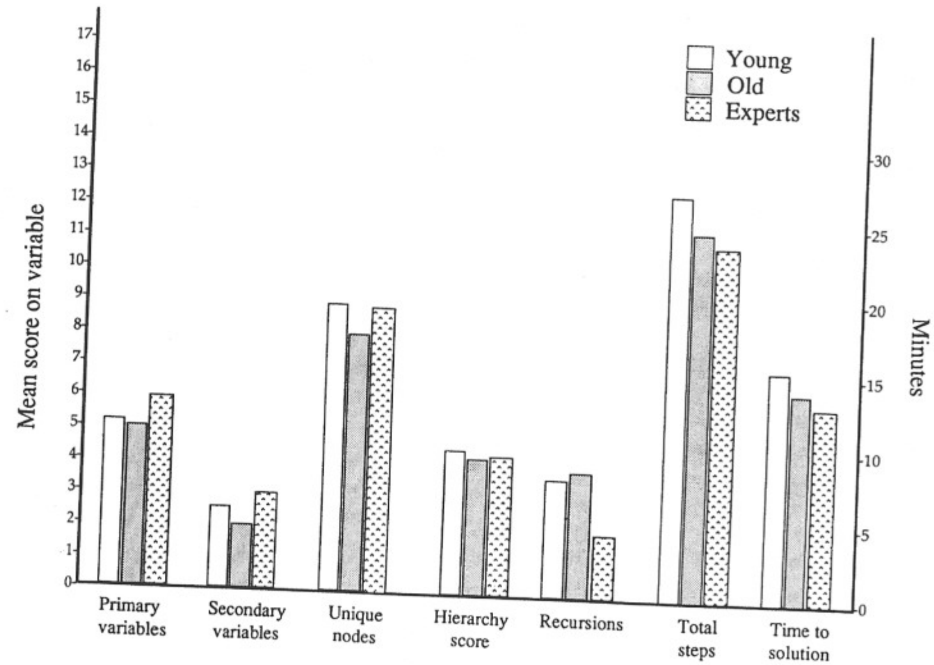

FIGURE 8

Differences in the problem solving processes used by young, old, and expert groups to solve the 401K problems. The dependent measures were taken from PSPMs constructed from our conceptual model of the 401K problems. These were similar to the PSPMs shown in Figures 4–6.

variables that the various groups used to solve our financial problems, a few more thoughts on the general pattern of results seen in Figure 8 will be offered. The following discussion pertains only to the small mean differences shown in Figure 8, having already acknowledged that these differences are not statistically significant. In contrast to Study 1, experts in Study 2 used as much information or more than the young and old to reach their problem solutions (as seen in their larger mean number of primary variables, secondary variables, and unique models). However, as was the case in Study 1, the experts appeared to be slightly more efficient than the young and old. They made fewer recursions, used fewer total steps, and solved the problems in less time than the young and old groups.

We think the differences seen among the information processes used by the expert and old groups of Studies 1 and 2 are probably the result of the different problems used. In Study 1, we presented much relevant information about the life situation of the target persons in the IRA problem description. In Study 2, only a brief description of the targets was given. Therefore, in Study 2, subjects specifically had to request information that was provided as part of the problem description in Study 1. A second important difference between the two tasks was that the IRA problem offered fewer and simpler possibilities for saving than the 401K problems. Federal regulations stipulated that the maximum amount any couple could invest annually in an IRA account was $4000. In contrast, for the 401K problems, contributions could range from $0 to $7500 and, in any given scenario, the ceiling on contributions to the plan might be limited by a federal regulation, the employer's contributory limits, the worker's wages, or the amount of the employer's matching contribution. Thus, even the most knowledgeable subjects had to request a good deal of information about the specifics of a target person's 401K plan to make an informed investment decision. We think these differences in the problems forced the older subjects and experts of Study 2 to request more information than their counterparts had requested in Study 1.

3. *Information Use Patterns*

Figures 9, 10, and 11 show the information-use patterns of the young, old, and expert groups on the 401K problems. The figures are each abbreviated representations of the complete conceptual model of the 401K problem we developed for this research. In this sense, they are structurally identical to the PSPMs shown in Figures 4–6. However, Figures 9–11 do not reproduce the sequence of variables considered by an individual subject, as was the case for the PSPMs, but show the percentage of subjects within a group that used each variable. A visual comparison of the young and old shows much similarity and few differences. The differences are primarily in the Account Characteristics hierarchy in the center of Figures 9 and 10. Specifically, more older subjects than younger subjects considered the total value (V) of the 401K investment at retirement. A visual comparison of the information-use patterns of the experts with those of the young and old groups shows greater differences. As a group, the experts considered more of the

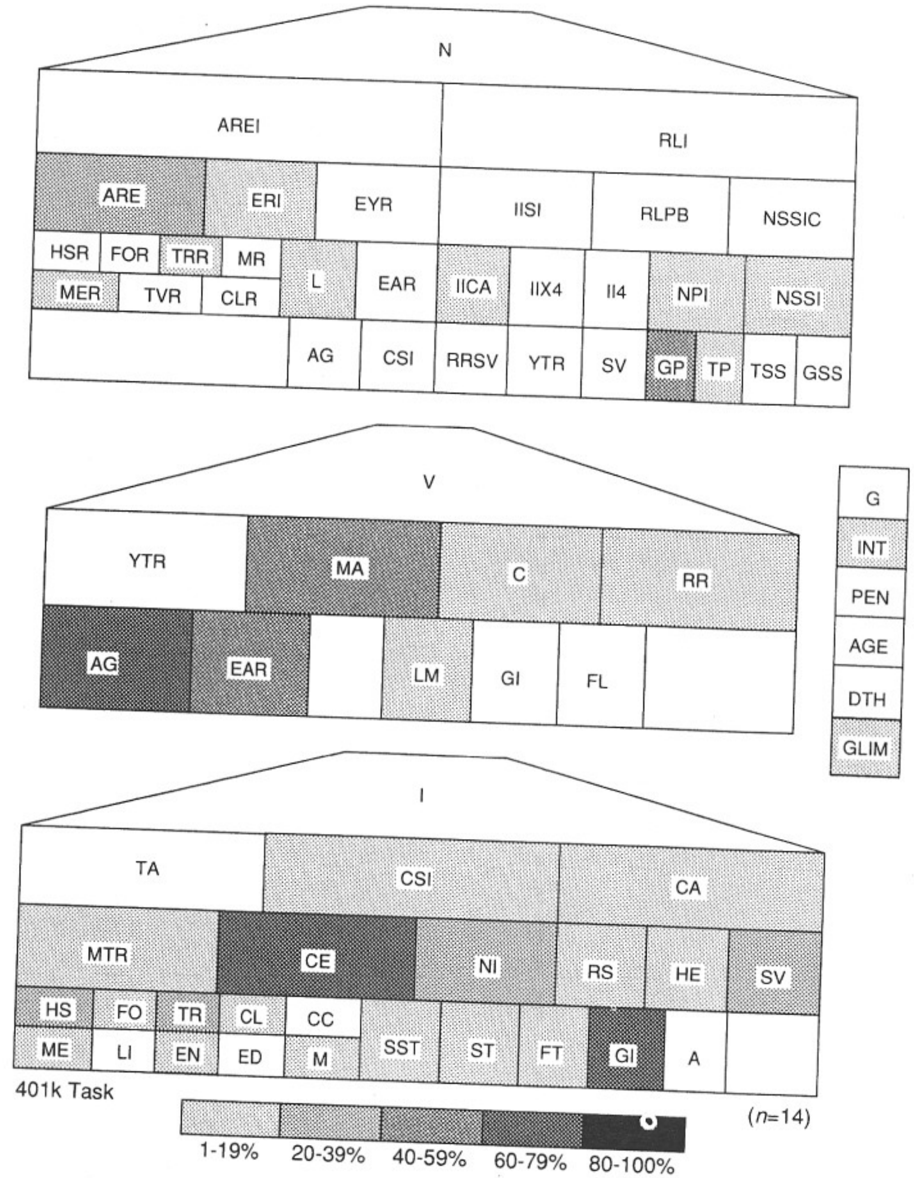

FIGURE 9

The Information Use Density Plot for the young subjects of Study 2. The structure of the plot corresponds to the conceptual model of the 401K problem. The top hierarchy represents future need in retirement, the middle represents future value of the 401K account, and the bottom represents information relevant to determining if an investment in a 401K is affordable. The six variables located to the right of center specify characteristics of a particular 401K plan. Different levels of shading found in the nodes correspond to the proportion of subjects in the group who selected a particular variable (see bar at bottom of figure).

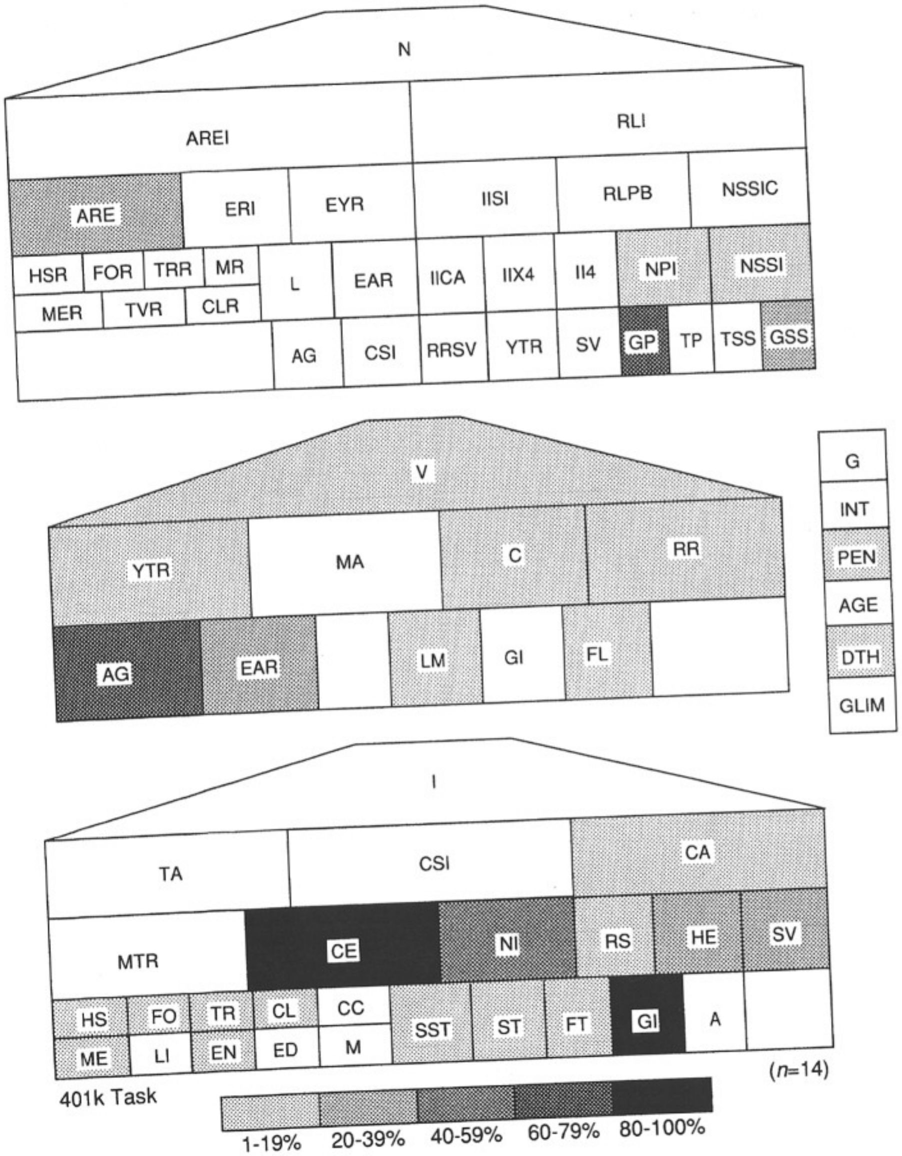

FIGURE 10

The Information Use Density Plot for the old subjects of Study 2. The structure of the plot corresponds to the conceptual model of the 401K problem. The top hierarchy represents future need in retirement, the middle represents future value of the 401K account, and the bottom represents information relevant to determining if an investment in a 401K is affordable. The six variables located to the right of center specify characteristics of a particular 401K plan. Different levels of shading found in the nodes correspond to the proportion of subjects in the group who selected a particular variable (see bar at bottom of figure).

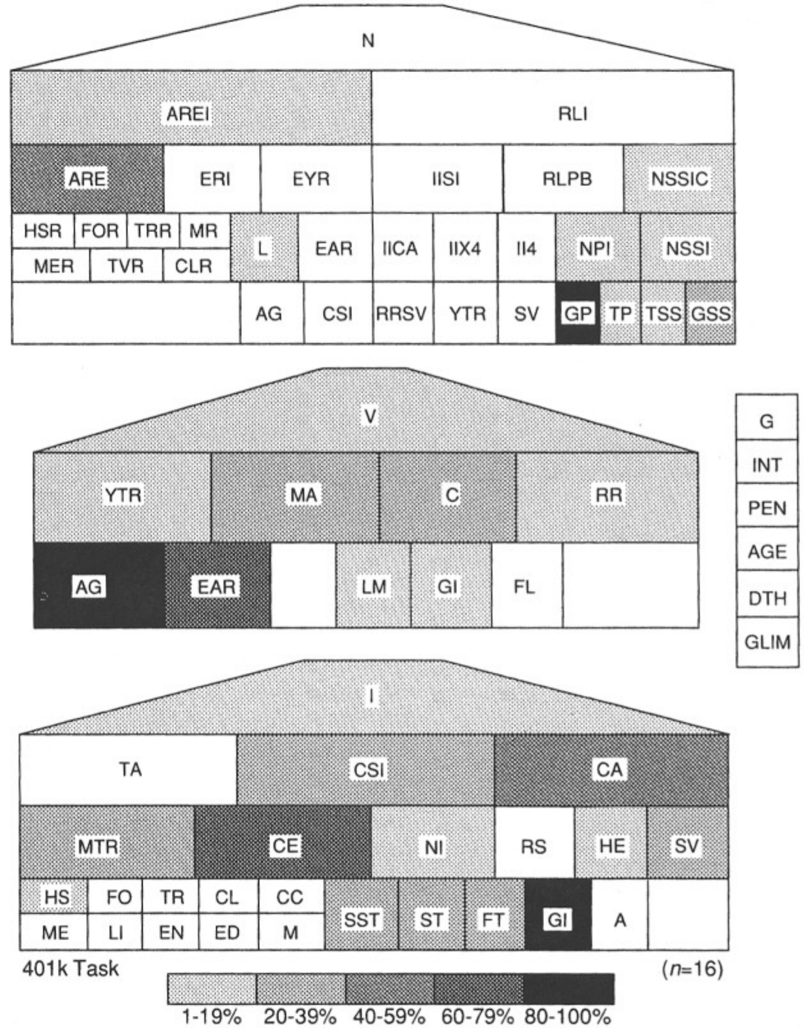

FIGURE 11

The Information Use Density Plot for the expert subjects of Study 2. The structure of the plot corresponds to the conceptual model of the 401K problem. The top hierarchy represents future need in retirement, the middle represents future value of 401K account, and the bottom represents information relevant to determining if an investment in a 401K is affordable. The six variables located to the right of center specify characteristics of a particular 401K plan. Different levels of shading found in the nodes correspond to the proportion of subjects in the group who selected a particular variable (see bar at bottom of figure).

variables in the Account Characteristics hierarchy shown in the middle of Figure 11. Not only did they consider more of these variables, but a larger percentage of expert subjects considered these variables, relative to the young and old groups.

Our interpretation of the import of these differences in information-use patterns relates back to differences in financial knowledge. The experts, who showed the highest measured level of financial knowledge, showed more consistency in the variables on which they focused. They also paid more attention to the Account Characteristics hierarchy. Thus, relative to the other two groups, the experts paid more attention to the future value of 401K accounts in arriving at their recommended investment. The old group, in turn, attended to these issues more than the young, and also produced more accurate solutions. Thus, we believe one reason the old and expert subjects were able to produce higher quality decisions than the young was that their greater knowledge (better mental models of financial planning) led them to pay more attention to the future value of the 401K account, given various investment amounts.

IV. General Discussion

We began this chapter with a speculative discussion of why societies continue to entrust their older members with important problem-solving responsibilities when many basic cognitive abilities are well known to decline with age. Our argument was that performance on real-world problem-solving tasks depends as much on one's mental model about the problem domain as on one's cognitive resources. Individual mental models specify what information to use and how to combine the information to reach a solution. The further point in our argument was that mental models of complex problems, such as financial planning, take years to acquire; therefore, one might expect age to be associated with improved problem-solving performance.

Figures 1–3 present a conceptual model of the relevant information to solve the retirement savings problems we presented to our subjects. Our hypothesis was that financial planning experts and older adults would have more detailed mental models of these problems than novice financial planners and young adults and would, therefore, solve these problems in a more thorough and efficient fashion. This hypothesis was borne out only partially by the results of Studies 1 and 2. The experts and older adults were somewhat more efficient in their use of information to solve financial planning problems. They made fewer recursions to reconsider previously considered information in both Studies 1 and 2. They also were able to request more of the information they needed to solve the problems at the outset in Study 1, compared with the young and novice groups who requested more secondary variables while attempting to solve the problems. However, the old adults and experts were not found to be more thorough than the young adults

and novices in their selection and use of problem information. In Study 1, the middle-aged, old adults, and experts used only half as much information as the young individuals and novices to reach their solutions. In Study 2, the young, old, and expert groups considered approximately equal amounts of information. Therefore, these mixed findings do not support the hypothesis that older adults and experts carry out a more thorough search of the problem space.

The most unexpected finding in both Studies 1 and 2 was how little information the typical subject used to reach a solution. Of the 21 subjects in Study 1, 14 considered 7 or fewer variables from the pool of 43 our conceptual model suggested as potentially relevant to a solution. A similar proportion of subjects in Study 2 considered 9 or fewer variables from the pool of 73 in our conceptual model of the 401K problem. We might have predicted this result if we had paid more attention to the relevance of research by Miller (1956) and Simon et al. (1954) to our own work. Miller (1956) first extolled the virtues of the "magical" number seven (plus or minus two) as a statement of human limitations in processing information. The research by Simon et al. (1954) found that adults confronted with complex information-rich problems simplify and economize in their decision processes or, to use Simon's term, they "satisfice." Collectively, the research of Miller (1956) and Simon et al. (1954) and the results of Studies 1 and 2 suggest that adults faced with complex financial planning problems may satisfice by considering seven or fewer variables to avoid exceeding their cognitive resources, although they have unlimited time and external hard-copy memory to support their problem-solving efforts.

An interesting developmental question is how satisficing occurs. We think that people unfamiliar with complex problems, such as the IRA and 401K tasks, initially must carry out a more exhaustive and exploratory analysis of the potentially relevant variables to build a mental model of the task. The logic behind this argument assumes that a "satisficing" problem solver intentionally selects a small subset of important variables to attend to. However, knowing which variables are important, and the optimal sequence in which to consider them, requires experience. Two sources of evidence provide support for this speculation. In Study 1, 5 of the 7 subjects who considered eight or more variables came from our youngest age group. Further, when the 7 expert and 7 novices from our pool of 21 subjects are grouped for analysis (Hershey et al., 1990) a statistically significant negative relationship is found between expertise and the number of variables considered—experts considered an average of 5.6 variables, compared with 9.4 for novices.

This discussion leads directly to the idea that one's mental model of a problem domain will determine, to a large extent, the quality of the solution produced. If an individual's cognitive limitations and proclivity to satisfice limit the number of variables considered in reaching a solution, knowing which are the most relevant variables to a solution becomes critical. The knowledge and solution quality data from Study 2 support this idea. Those data show that older adults and experts who knew more about financial planning did, indeed, provide more accurate solutions than young adults who had significantly less knowledge. Also, the information density plots (see Figures 9–11) show that the old adults and experts used somewhat different variables than the young to solve the problems. Further, the old and expert groups provided better quality decisions, despite the fact that they considered no more information than the young to reach a solution.

In summary, we think the findings of this study, considered in the context of the ecology of complex real-world problem solving, offers some useful insights into society's trust of older adults to decide important matters. The current findings suggest that adults confronted with complex problems consider only a small subset of the variables potentially relevant to a solution, possibly because of cognitive limitations that all humans share. Further, the problem-solving data seem to indicate that older adults and experts consider a small set of variables in a more linear and efficient fashion than do young adults or novices. We interpret these findings as evidence for the hypothesis that problem solving in complex domains is guided by an individual's mental model, a cognitive structure that specifies which variables to consider in a particular problem solving situation. Further, we speculate that mental models develop over time as a result of learning about, and solving problems in, a particular problem domain.

This analysis suggests that older adults, who are probably more experienced with many real-world problem areas than young adults, are likely to be better qualified to solve problems in their areas of expertise because (1) they have developed mental models to direct their decision processes efficiently and (2) their mental models are likely to include variables that are better predictors of problem solutions. Further, we speculate that the ecology of the modern human world combines with a picture of complex problem solving that emerges from our research to suggest that age typically should be associated with improvements in real-world decision performance. Specifically, we propose that most adults devote their professional, intellectual, and social lives to relatively constrained and consistent interest areas. These patterns of living should produce increasingly efficient mental models for problem solving, that is, knowledge structures that specify the few important variables that must be considered in a particular problem-solving situation.

Many questions are raised by our research for which we currently have no answers. Although we have speculated that mental models develop with increasing exposure to a content area, and that the typical mode of adult existence is to attend to consistent content areas across the life-span, direct empirical support for these hypotheses awaits future research. Further, we have contributed little or nothing to understanding the relationship between age and the ability to acquire mental models for complex problem. Walsh and Hershey (1990) reported that young adults (who supposedly have better attention, memory, or fluid intelligence abilities than older adults) seem better able than old adults to acquire complex mental models. Although we wish to stress that this chapter does not address the question of age-related differences in the development of mental models, we also wish to be clear that this one is not the only question that a cognitive psychology of aging should address. We believe our research makes an important contribution by suggesting why age-related decrements in many basic cognitive processes may not translate into decrements in everyday complex problem-solving performance.

Acknowledgments

This work was made possible by a Faculty Research and Innovation Fund Grant awarded by the University of Southern California and a research grant from the National Institute on Aging (R01 AG08106) awarded to David A. Walsh. Additional support was provided through a traineeship awarded to Douglas Hershey by the National Institute on Aging (#5-T32-AG00037-09).

References

Arenberg, D. (1974). A longitudinal study of problem solving in adults. *Journal of Gerontology, 29*, 650–658.

Charness, N. (1981a). Aging and skilled problem solving. *Journal of Experimental Psychology: General, 110*, 21–38.

Charness, N. (1981b). Search in chess: Age and skill differences. *Journal of Experimental Psychology: Human Perception & Performance, 7*, 467–476.

Charness, N. (1982). Problem solving and aging: Evidence from semantically rich domains. *Canadian Journal on Aging, 1*, 21–28.

Charness, N. (1983). Age, skill, and bridge bidding: A chronometric analysis. *Journal of Verbal Learning & Verbal Behavior, 22*, 406–416.

Cornelius, S. W., & Caspi, A. (1987). Everyday problem solving in adulthood and old age. *Psychology and Aging, 2*, 144–153.

Denney, N. W., & Palmer, A. M. (1981). Adult age differences on traditional and practical problem-solving measures. *Journal of Gerontology, 36*, 323–328.

Denney, N. W., Pearce, K. A., & Palmer, A. M. (1982). A developmental study of adults' performance on traditional and practical problem-solving tasks. *Experimental Aging Research, 8*, 115–118.

Gentner, D., & Stevens, A. L. (1983). *Mental models*. Hillsdale, New Jersey: Erlbaum.

Hartley, A. A. (1989). The cognitive ecology of problem solving. In L. Poon, D. C. Rubin, & B. A. Wilson (Eds.), *Everyday cognition in adulthood and late life* (pp. 300–329). Cambridge: Cambridge University Press.

Hartley, A. A., & Anderson, J. W. (1983a). Task complexity, and problem-solving performance in younger and older adults. *Journal of Gerontology, 38*, 72–77.

Hartley, A. A., & Anderson, J. W. (1983b). Task complexity, problem representation, and problem-solving performance by younger and older adults. *Journal of Gerontology, 38*, 78–80.

Hershey, D. A. (1990). *The role of knowledge and experience in structuring problem solving performance*. Doctoral dissertation. University of Southern California. (*Dissertation Abstracts International, 51*, Section 7B.)

Hershey, D. A., Walsh, D. A., Read, S. J., & Chulef, A. S. (1990). The effects of expertise on financial problem solving: Evidence for goal directed problem solving scripts. *Organizational Behavior and Decision Processes*, *46*, 77–101.
Huber, O. (1980). The influence of some task variables on cognitive operations in an information-processing decision model. *Acta Psychologica*, *45*, 187–196.
Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.
Payne, J. W. (1976). Task complexity and contingent processing in decision making: An information search and protocol analysis. *Organizational Behavior and Human Performance*, *16*, 366–387.
Simon, D. P., & Simon, H. A. (1978). Individual differences in solving physics problems. In R. Siegler (Ed.), *Children's thinking: What develops?* (pp. 325–348). Hillsdale, New Jersey: Erlbaum.
Simon, H. A. (1973). The structure of ill-structured problems. *Artificial Intelligence*, *4*, 181–201.
Simon, H. A., Guetzkow, H., Kozmetsky, G., & Tyndall, G. (1954). *Centralization versus decentralization in organizing the controllers office*. New York: The Controllership Foundation.
von Winterfelt, D., & Edwards, W. (1986). *Decision analysis and behavioral research*. Cambridge: Cambridge University Press.
Voss, J. F., Tyler, S. W., & Yengo, L. A. (1983). Individual differences in the solving of social science problems. In R. F. Dillion and R. R. Schmeck (Eds.), *Individual differences in cognition* (pp. 205–232). New York: Academic Press.
Walsh, D. A., & Hershey, D. A., (1990). The effects of training and practice on age-related differences in solving complex financial problems. Paper presented at the Cognitive Aging Conference, Atlanta.

IX
CONCLUSION

ADULT INFORMATION PROCESSING: LIMITS ON LOSS

John Cerella
Research Service
Veterans Administration Outpatient Clinic
Boston, Massachusetts

John Rybash
Psychology Department
Hamilton College
Clinton, New York

William Hoyer
Psychology Department
Syracuse University
Syracuse, New York

Michael L. Commons
Department of Psychiatry
Harvard Medical School
Boston, Massachusetts

ACADEMIC PRESS, INC.
A Division of Harcourt Brace & Company
San Diego New York Boston
London Sydney Tokyo Toronto