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Effects of Age and Concurrent Verbalization on Cognitive Task Performance

Mark Carver Fox

FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

EFFECTS OF AGE AND CONCURRENT VERBALIZATION ON COGNITIVE TASK PERFORMANCE

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Mark Carver Fox

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The members of the Committee approve the thesis of Mark C. Fox defended on February 11th, 2008.

Neil Charness
Professor Directing Thesis

K. Anders Ericsson
Committee Member

Joyce Ehrlinger
Committee Member

The Office of Graduate Studies has verified and approved the above named committee members.

This thesis is dedicated to my parents, Robert Carver Fox and Grace Fox.

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ABSTRACT

Few studies have examined the impact of age on reactivity to concurrent think-aloud (TA) verbal reports. The aim of this project was to test whether older adults exhibit greater negative reactivity to concurrent verbal reports than younger individuals. In Experiment 1, 31 older (mean age = 72.3) and 30 younger (mean age = 19.0) adults performed four cognitive tasks -- paired associates with instructions to form mediators, cube-comparison, a shortened version of the Raven's Matrices, two-digit mental multiplication -- while either thinking aloud or remaining silent. An age group by condition interaction emerged as older adults performed more accurately and took longer on the Raven's Matrices while thinking aloud. Condition did not affect performance on the other tasks. In Experiment 2, 30 older adults (mean age = 73.0) performed the Raven's Matrices, mental multiplication, and two modified matrix reasoning tasks in four varied orders while thinking aloud or remaining silent. Modified matrix reasoning tasks were used to test the hypothesis that older adult facilitation while thinking aloud is due to reduced effects of age-related inhibitory deficits. Once again older adults performed significantly better only on the Raven's Matrices while thinking aloud, however, the hypothesized explanation for the effect was not supported.

INTRODUCTION

Concurrent verbal reports (or "think-aloud" reports; TA) are among several verbalization methods used by researchers to study the mental processes underlying cognitive task performance. TA allows for a more detailed analysis of cognitive processes than do traditional behavioral measurements, providing information that can be used to infer specific strategies and identify the characteristics of a task that give rise to errors in problem solving (Ericsson & Simon, 1980, 1993). TA has been used to study the reasoning processes involved in general problem solving (e.g., Duncker, 1945; Fleck & Weisberg, 2004; Newell & Simon, 1972) and expert performance in domains such as chess (Charness, 1981). In recent decades TA has been employed in human factors research to pinpoint the impasses potential users may face when encountering a new technology (e.g., Van den Haak, de Jong, & Schellens, 2004; Wright & Monk, 1991). Few studies, however, have examined whether older adults—a population characterized by general declines in reasoning ability and processing speed—react differently to TA. Moreover, the existing studies focus on single tasks, limiting the extent to which conclusions about older adult reactivity can be drawn. Among the factors involved in cognitive decline, the literature on processing speed and dual-task performance suggest that older adults may be expected to exhibit additional reactivity when thinking aloud in the form of lower performance and increased reaction times.

Age and TA

Although the TA method has been criticized (e.g., Nisbett & Wilson, 1977; Schooler, Ohlsson, & Brooks, 1993), few studies have demonstrated that concurrent verbal reports change cognitive processes when performed in adherence to the guidelines of Ericsson and Simon (c.f., 1980, 1993). Several authors, however, have argued that TA could impact task performance even under these restrictive conditions as participants may modify their strategies to match the presumed demands of the experimenter, perform better because of enhanced working memory resulting from auditory rehearsal, or suffer decrements in performance as a result of processing resources lost to verbalizing (Biehal & Chakravarti, 1989; Russo, Johnson, & Stephens, 1989). Johnson (1993) suggested that the latter two possibilities may be especially relevant to older adults, given the extent to which this group exhibits deficits on a variety of cognitive tasks. However, she found that with the exception of increased decision times TA did not impact performance on an apartment-search decision task in older or younger adults. Moreover, it was younger adults giving verbal reports showing some degree of reactivity in the form of increased rechecking of information. Johnson's null findings are unlikely due to type II error given the substantial size of her sample (116 participants total) and suggest that TA does not alter decision processes in older or younger adults.

Only two other studies have included silent control groups and younger groups to test for age-related differences in reactivity. In attempting to study the role of encoding strategies on recollection of encoding context, Perfect and Dasgupta (1997) had groups of younger and older adults think aloud while encoding either words or non-words. In addition, a control group of older adults encoded the items silently. The authors found that older adults in the TA group did not differ from older silent participants in familiarity judgments. This study could not, however, test for the possibility of reactivity differences between age groups, as there was no silent younger group. Gilhooly, Phillips, Wynn, Logie, and Della Salla (1999) reported that verbalization did not impact older or younger adult performance on a five-disc version of the Tower of London except with respect to planning time and movement time. Sample sizes in the Perfect and Dasgupta, and Gillhooly et al. studies were relatively small (20 participants per group in both studies), leaving open the possibility that minor TA effects went undetected. However, reactivity unobserved in a 40 participant, between subjects design is unlikely to pose a methodological concern to researchers interested in employing TA. The findings of Johnson, Perfect and Dasgupta, and Gillhooly et al. suggest that there are at least some higher level cognitive tasks in which older adults exhibit little or no reactivity.

Despite these null findings, it remains to be seen whether such results apply to other tasks entailing a wider variety of processing requirements. Because neither study revealed reactivity, it is difficult to identify the characteristics of tasks that may elicit reactivity in older individuals based on these results. It is possible that specific cognitive deficits experienced by older adults may inform the question of which tasks are most likely to elicit reactivity in this group.

Age-Related Cognitive Decline

Age-related cognitive decline has been attributed to several mechanisms including deficits in general processing speed (Salthouse, 1996), inhibitory processes (Hasher & Zacks, 1988), capacity for controlled processes (Craik & Byrd, 1982), and working memory (Salthouse, 1990). Declines in general processing speed could lead to longer latencies as increasing the complexity of a task results in greater additional reaction times for older adults than younger adults (Cerella, Poon, & Williams, 1980). In addition, slower reaction times have been theorized to cause lower accuracy as task complexity increases (Salthouse, 1996). Moreover, previous studies suggest that under certain conditions older adults suffer more from performing simultaneous tasks than younger individuals, suggesting that older adult performance may be disrupted by the concurrent task of giving verbal reports.

Aging and Processing Speed. Older adults experience declines in processing speed that lead to slower performance on many cognitive tasks and experience lower accuracy on more complex tasks (Salthouse, 1996, 1992). Salthouse (1996) has theorized that declines in processing speed disrupt performance on complex tasks because information in working memory decays as additional information processing occurs. Assuming the rate of decay does not change with age, the probability of successfully retrieving information from working memory is a function of how long it takes to process additional information. That is, in a multi-step task, temporarily unused information decays during the longer processing durations of newer information, decreasing the likelihood of later retrieval in older adults. The theory accounts for why older adult accuracy decreases on complex cognitive tasks in addition to increased reaction times. Task complexity is not easy to measure although numerous investigators have undertaken this burden (e.g., Crawford, 1991; Raykov & Stankov, 1993; Verhaeghen, Cerella, & Basak, 2006). The definition provided by Stankov (2000) measures complexity in terms of the number of steps required to arrive at a solution. By this definition, multi-step tasks such as items from fluid intelligence tests are more complex than simple memory tasks such as digit span. While little evidence exists that TA actually increases task complexity, it is possible that a marginal increase in complexity due to verbalization would not be enough to impair younger adult performance. Such increases should be more likely to impact older adult performance, especially on initially more complex tasks, yielding longer reaction times and lower accuracy in older TA groups.

Dual-task Performance and Levels of Verbalization. Because TA is essentially a concurrent task it is conceivable that the issue of older adult reactivity can be informed by previous studies of older adult dual-task performance. A substantial body of literature has addressed the impact of aging on dual-task performance and revealed that in many cases older adults show greater performance decrements than younger individuals (Broadbent & Alastair, 1962; Inglis & Caird, 1963; McDowd & Craik, 1988). However, Somberg & Salthouse (1982) found that older adults did not exhibit additional declines under dual-task conditions. Tun and Wingfield (1993) suggest that older adult deficits may depend on the nature of the tasks and that those tasks involving automatic processes may be less disrupted. In a meta-analysis on age differences in dual-task performance Riby, Perfect, and Stollery (2004) concluded that controlled and automatic processes differentially affect dual-task performance of older adults relative to younger individuals. Dual-tasks involving controlled processes tend to lead to greater age-related decrements than those involving automatic processes. The seemingly low linguistic demands of TA (i.e., admittance of phrases, single words, long pauses, etc.) would seem to require little or no controlled processing under most circumstances, however, the need to translate abstract information into words—what Ericsson and Simon (cf., 1980, 1993) have dubbed "level 2 verbalizations"—may be more akin to controlled processing and necessary when thinking aloud on abstract reasoning tasks such as the Raven's Advanced Progressive Matrices.

Ericsson and Simon refer to the number of times a mental process needs to be recoded between the time information is apprehended and verbalization occurs as level of verbalization. The authors identify three levels of verbalization that vary along this continuum. Level 1 verbalization occurs when information is merely verbalized in the form it was originally apprehended and need not be recoded into verbal form. Level 2 verbalization involves recoding nonverbal representations into verbal information but requires no additional information to produce a verbal report. Level 3 verbalizations occur when it is necessary to attend to the verbalization itself. For example, if only certain types of information are to be verbalized it may be necessary to filter some information. Presumably, as the verbalization level for tasks increase the cognitive workload shifts from automatic to controlled processes. Thus tasks that elicit level 3 verbalizations are most susceptible to altering cognitive processes.

Level 1 verbalizations would seem to depend almost exclusively on automatic processes while level 2 verbalizations would seem to require additional control processes. While the extent to which automatic versus controlled processes differentially underlie these levels of processing is not directly measurable, a conservative conclusion is that level 2 relies more on controlled processing than does level 1. Based on the aforementioned studies suggesting that age decrements on dual-tasks increase with the amount of controlled processing involved, older adults should be more likely to exhibit additional reactivity when thinking aloud on tasks that elicit level 2 verbalization.

Although it is not possible to record the content of the mental representations underlying task-performance in their original form, it is possible to manipulate the content of the stimuli that need to be processed. For example, the symbols involved in problem solving may be represented propositionally (Anderson, 1978), pictorially (Kosslyn, 1981), or they may be embodied (Barsalou, Simmons, Barbey, & Wilson, 2003). However, a TA participant given a problem that involves reasoning about spatially presented stimuli must translate what is presented into a verbalization. For familiar stimuli such as pictures of everyday objects the translation into a verbal code may remain relatively automatic. However, more abstract spatial stimuli are likely to increase the degree of controlled processing necessary to perform the translation. Meanwhile, problems in which the spatial properties of the presentation are less relevant, such as mentally multiplying numbers, may be processed without regard to the spatial features of the stimulus. Consequently, problems presented in a spatially-relevant form, especially those containing abstract elements, should elicit level 2 verbalization more frequently than problems in which the spatial elements of the stimulus are irrelevant. Spatially irrelevant problems will more frequently evoke level 1 verbalization. Because level 2 verbalization requires more controlled processing it is hypothesized that problems presented in a spatially relevant fashion will elicit more reactivity in older adults relative to younger adults whereas problems presented in a spatially-irrelevant fashion will show less of a difference.

EXPERIMENT 1

The purpose of Experiment 1 was to test the extent of reactivity in older adults relative to younger adults on variety of tasks that are assumed to differ systematically in processing requirements. Four tasks were chosen that varied with respect to the verbalization level they were presumed to elicit. Older adults are expected to have greater difficulty with abstract, spatially relevant tasks when thinking aloud.

Method

Participants

Thirty-one older (mean age 72.3) and 30 younger (mean age 19.0) adults participated in the study. Older adults were recruited from the community and were paid $10 to participate. Older participants were screened for dementia with the Wechsler Memory Scale III and the Short Portable Mental Status Questionnaire. Younger adults were recruited from the department subject pool and were compensated with course credit.

Materials

The tasks used were paired associates with instructions to generate mediators, Cube Comparison, an abbreviated set of the Raven's Advanced Progressive Matrices (Bors & Stokes, 1998; Raven, 1965), and mental multiplication. In the paired associates task participants must generate an association between two words to facilitate later recall of one of the words when the other is presented. Cube Comparison is a spatial task in which pictures of two cubes with markings on each face must be compared to determine if they are the same cube in different orientations or different cubes altogether. The Raven's Matrices is and inductive reasoning test in which the goal is to decide which of eight possible choices best completes a matrix of abstract figures. In mental multiplication two two-digit numbers are presented that must be multiplied mentally. Paired associates and mental multiplication were assumed more likely to elicit level 1 verbalization as the spatial properties of the stimuli are likely less relevant to how they are carried out. Cube Comparison and the Raven's Advance Progressive matrices were expected to yield more level 2 verbalization because the spatial qualities of the stimuli are intrinsic to the solutions.

Cube Comparison and the Raven's Matrices were administered in paper and pencil format, while other tasks were administered on the computer. On tasks other than Cube-Comparison, participants were given as long as necessary to complete each task so that the effect of verbalization condition on solution times could be assessed. Because Cube Comparison was timed (according to instructions), solution times were determined by the number of problems attempted in each of two-three minute sessions.

Procedure

Each experimental session began with a warm-up procedure from Ericsson and Simon (1993) to acquaint participants with providing concurrent verbal reports. Next, participants performed the tasks in the following fixed order: paired-associates, Cube Comparison, Raven's Matrices, and mental multiplication. Each participant completed two tasks silently and two tasks while thinking aloud. Four overall verbalization orders were used to vary the order in which participants performed silent or while thinking aloud.

Results

Paired associates were scored in terms of total number of words recalled. Cube Comparison dependent variables were total number of items correct and total number of items attempted in two three-minute sessions. Raven's Matrices and mental multiplication were scored with respect to overall scores and solution times. A multivariate analysis of variance (MANOVA) revealed no differences between the four verbalization orders on any of these dependent variables, $p > .05$. The order in which participants verbalized or remained silent on the four tasks did not affect scores or the speed at which tasks were performed.

A series of 2(verbalization condition: TA/silent) x 2(age group: older/younger) analyses of variance (ANOVA) were used to test for differences between groups on task performance and speed. Means and standard deviations for Experiment 1 tasks are presented in Table 1. ANOVA revealed a main effect for age on paired associates, $F(1,57) = 23.18$, $p < .01$., as younger adults recalled more words than older adults. However, verbalization condition did not affect number of words recalled and did not interact with age group, $p > .05$. Younger adults had higher scores on Cube Comparison in both sessions, $F(1, 57) = 17.05$, $p < .01$; $F(1, 57) = 12.24$, $p < .01$, but did not attempt more problems in either session, $p > .05$. Verbalization condition did not impact performance or solution speed on Cube Comparison, and did not interact with age, $p > .05$. Younger adults scored higher than older adults on mental multiplication, $F(1, 57) = 10.57$, $p < .01$, but these groups did not differ in the amount of time spent solving the problems, $p > .05$. Verbalization condition did not impact scores or solution times on this task and did not interact with age group, $p > .05$. No significant reactivity emerged on paired associates, Cube Comparison, or Mental multiplication.

An age group by verbalization condition interaction occurred on the Raven's Matrices as older adults scored higher, $F(1, 57) = 5.64$, $p < .05$, and took longer, $F(1, 57) = 4.28$, $p < .05$, when thinking aloud relative to younger adults (see figures 1 and 2). Simple effect contrasts revealed that differences in score, $F(1, 57) = 4.12$, $p < .05$, and solution time, $F(1, 57) = 11.77$, $p < .05$ between TA and silent older adults were significant. Notably, a one-sample t-test revealed that silent older adult scores on the test were not significantly different from chance performance of 1.5, $p > .05$. Contrary to predictions, TA older adults actually performed better than the silent group on this task. This finding was not predicted as the Raven's Matrices is a complex task presumed to elicit level 2 verbalization.

Discussion

Thinking aloud had little impact on total scores and the amount of time needed to complete the tasks. The only task in which reactivity was observed was the Raven's Matrices as older adults performed better when thinking aloud. Aside from this facilitation effect on the Raven's, these findings are consistent with previous studies (Gillhooly et al.; Johnson, 1993; Perfect & Dasgupta, 1997) in showing older adults do not exhibit negative reactivity on a variety of tasks. Moreover, older adults, if anything, may benefit from TA under certain conditions as their performance was better on the Raven's Matrices when thinking aloud. Superior TA performance on this task among older adults was not attributable to trivial factors such as subtle experimenter cues or random differences in age between the older groups. These findings seem to show that any additional processes involved in concurrent verbalization are resistant to cognitive decline, even on complex tasks with spatially-relevant stimuli.

While Experiment 1 suggests that in most cases older adults do not react to TA with lower performance, the finding that scores on the Raven's Matrices actually increased is not consistent with the theory proposed earlier. The Raven's Matrices were assumed to elicit level 2 verbalization and are more complex than the other tasks. Therefore, TA older participants should have performed worse than controls on this task if the theory was correct. An explanation for superior performance on the Raven's Matrices for TA older adults must account for the absence of reactivity on other tasks in both age groups as well as the finding that younger adult performance does not differ with condition on the Raven's Matrices. The theories outlined by Biehal & Chakravarti, (1989) and Russo, Johnson, & Stephens, (1989) for why reactivity should be expected to occur in general are not consistent with these results as these theories would not predict better performance when thinking aloud on only one of the tasks and there is no reason to assume that any of these hypothetical modes of reactivity would apply more to older adults. The most likely of the three—facilitation resulting from auditory rehearsal—is an unlikely explanation given that TA performance was not improved on other tasks that taxed working memory such as mental multiplication and Cube Comparison.

TA and Visual Distraction

Results suggest that TA may compensate for an age-related deficit that impairs performance on tasks that entail processing a substantial quantity of visual information, as this is one characteristic of the Raven's Matrices that distinguishes it from the other tasks used in the study. The Raven's Matrices differ from the other primarily visual task (Cube Comparison) in that matrix reasoning items consist of more visual information and are solved incrementally (Carpenter, Just, & Shell, 1990). The tests require test-takers to identify rules describing the relationships between figures arranged in a 3X3 array as shown in figure 3. The figure in the lower right-hand corner of the array is absent, and the objective of the test is to determine which of eight possible figures best completes the array. In order to solve the problems test-takers must identify and then apply one or more rules to identify the characteristics of the missing figure.

To solve matrix-reasoning problems, selected visual information must be heeded and processed (e.g., one of the three rows), while other visual information is ignored. Hasher and Zacks (1988) proposed that many performance declines in older adults can be explained by an age-related inability to inhibit information that is irrelevant to task performance, leading to a lower signal-to-noise ratio during information processing. Older adults perform worse than younger adults on tasks involving visual distractors (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991, Scialfa, Kline, & Lyman, 1987). A possible explanation for the pilot findings is that the instruction to think aloud forces older adults to attend to more specific cues during matrix reasoning as it is not possible to simultaneously verbalize information that is both relevant and irrelevant to task performance.

An inhibition account of the pilot findings would lead to several predictions about performance on matrix reasoning problems and the think-aloud method. If concurrent verbalization helps older adults to attend more selectively to relevant information, control and TA participants should perform more similarly when less irrelevant information is present in the matrix. For example, matrix reasoning problems consisting of two rows by two columns should elicit less facilitation for TA participants than conventional problems consisting of three rows by three columns because they contain less visual information. Moreover, if a third row and column containing information that will never be useful, are added to a two-by two matrix, TA participants should perform better than control participants, even if participants are informed that these rows and columns are irrelevant. An inhibition account of the findings would be consistent with an interaction between verbalization condition (TA/silent) and visual attention condition (distraction/control), such that TA and silent groups perform more similarly in the control condition, but TA participants perform better in the distraction condition.

EXPERIMENT 2

The aim of Experiment 2 is to replicate the findings of Experiment 1 and test whether TA facilitation on the Raven's Matrices in older adults is due to reduced effects of age-related deficits in inhibiting visual distraction as a result of concurrent verbalization.

Method

Design

The design of Experiment 2 is a 2 (verbalization condition: TA/control) X 2 (visual distraction condition: visual distraction/control) mixed factorial. The between-subjects variable is verbalization condition and the within-subjects variable is visual distraction condition. In addition to this experiment participants perform the same 12 Raven's Matrices items from Experiment 1 and mental multiplication. Verbalization condition is a between-subjects variable on these tasks. Dependent variables of interest are total scores and solution times on each of four tasks. In addition to these dependent variables, retrospective verbal reports are collected from participants in TA and control groups during the Raven's Matrices.

Participants

Thirty older adults (mean age 73.0) were recruited from the community to participate in a study lasting approximately 1 hour were compensated $10 for participating. All participants were screened for dementia with the Wechsler Memory Scale III and the Short Portable Mental Status Questionnaire.

Materials

Testing materials include the abbreviated Set II of the Raven's Advanced Progressive Matrices used in Experiment 1, two sets of modified matrix reasoning problems, and the mental multiplication task from Experiment 1. The control set of modified matrix reasoning problems consists of 2 x 2 matrices as opposed to the 3 x 3 design of traditional matrix reasoning problems as shown in figure 4. In the visual distraction sets an additional row and column of irrelevant information was added as demonstrated in figure 5. Participants in the visual distraction condition are instructed to ignore the additional row and column. A total of 20 problems were developed for both sets that always appear in the same order. Each set was split in half, yielding a total of two control sets and two distraction sets so that participants would not encounter the same set of problems as each performed both control and distraction tasks. A two-digit by two-digit mental multiplication task consisting of five problems is used to replicate the null finding of Experiment 1. The Raven's Matrices are administered in paper and pencil format while all other tasks are administered on a computer.

Procedure

Each experimental session began with the warm-up procedure outlined by Ericsson and Simon (1993) to acquaint participants with providing concurrent and retrospective verbal reports. The four tasks were completed in four different orders to test whether the pilot findings generalize beyond the fixed ordering of tasks in Experiment 1.

1. Modified Matrix: Control, Ravens, Modified Matrix: Distraction, Multiplication
2. Ravens, Modified Matrix: Distraction, Multiplication, Modified Matrix: Control
3. Multiplication, Modified Matrix: Control, Ravens, Modified Matrix: Distraction
4. Modified Matrix: Distraction, Multiplication, Modified Matrix: Control, Ravens

The use of two control and two distraction tasks means there are a total of eight conditions in which the experiment is run. Manipulation of TA consists of dividing participants into two groups: One group thinks aloud on the Raven's Matrices and mental multiplication and remains silent on the modified matrix reasoning tasks and another group completes the matrix reasoning tasks aloud and remains silent on the Ravens and mental multiplication. All tasks were administered without a time limit so the impact of TA on solution times could be assessed. Additionally, participants provided retrospective reports for four of the 12 problems (problem numbers 3, 15, 22, and 34).

Results

MANOVA revealed no difference between the four orders on accuracy or solution time for any tasks, $p > .05$. Dependent variables were not influenced by the order in which participants performed the tasks. A one-way ANOVA revealed a significant difference between TA (M = 3.94, SD = 2.62) and silent (M = 1.93, 1.64) participants on Raven's Matrices Scores, $F(1, 28) = 6.12$, $p < .05$, $d = .92$, but not solution time, $p > .05$. Once again, a one-sample t-test revealed that silent participants did not perform above chance level of 1.5, $p > .05$. This finding partially replicates Experiment 1 as TA participants had higher scores. Contrary to Experiment 1, TA participants were not found to have longer solution times, however, this null finding may be due to lack of power. A trend toward replication of longer solution times for TA participants was observed, however the effect size was smaller than before ($d = .45$ as opposed to $d = .78$ in Experiment 1), resulting in less power ($1 - \beta =$

.22) and thus a high probability of Type II error. Mean scores and overall solution times are depicted in figures 5 and 6 respectively. Null findings for mental multiplication were also replicated as scores and solution times were unaffected by verbalization condition, $p > .05$. Once again, the Raven's Matrices were the only task impacted by thinking aloud. Table 2 shows the means and standard deviations for Experiment 2 tasks and Table 3 depicts the correlations among these tasks.

Two versions of a modified matrix reasoning task were used to test the hypothesis that thinking aloud may lead to reductions in decline of age-related inhibitory processes. It was hypothesized that participants would perform better in the visual distraction condition while thinking aloud whereas verbalization condition would have less impact on performance of the control task. A 2(verbalization condition: TA/silent) x 2(visual distraction condition: distraction/control) repeated measures ANOVA revealed no interaction between these factors on overall scores or solution time, $p > .05$, (see figure 8). Moreover, a main effect for visual distraction was not observed, implying that the distraction manipulation was not successful. However, it is not possible to dismiss the possibility that the distraction task was more difficult as the observed power for this factor was low, ($1 - \beta = .15$). Nevertheless, the visual distraction condition should have elicited lower scores than were observed if the distractors had actually made the task more difficult. The analysis revealed no main effect for verbalization condition as TA participants did not perform significantly better on the tasks than silent participants. The failure of this manipulation leaves open the possibility that an inhibition account of improved matrix reasoning with TA could be uncovered in future experiments, but no support for such a theory was provided by these data.

Post hoc analyses were conducted in an attempt to understand why verbalization condition did not significantly impact modified matrix reasoning. Correlations between Raven's and both modified matrix reasoning tasks were substantial for distraction, $r(28) = .70$, $p < .01$, and control, $r(28) = .51$, $p < .01$, suggesting these tests were measuring similar abilities (see Table 3). One possibility is that individuals who thought-aloud on the Raven's just prior to performing a modified matrix reasoning task would "retain" the TA benefit into the new task. For this analysis distraction and control matrices were treated as one because of their high intercorrelation ($r = .72$). However, participants thinking aloud on the Raven's just prior to performing either of these tasks did not perform differently than those in other conditions, $p > .05$, suggesting that modified matrix reasoning tasks used in Experiment 2 are not influenced by TA on the Ravens.

Discussion

Experiment 2 partially replicated Experiment 1 as older participants performed better on the Raven's Matrices while thinking aloud, but not the other tasks. However, unlike in Experiment 1, TA participants did not take longer to complete the task. Total scores and solution times were unaffected by verbalization condition on the mental multiplication task and either of the modified matrix reasoning tasks. Experiments 1 and 2 provide converging evidence that TA facilitates performance on the Ravens but not other tasks.

It is unclear why TA participants did not have significantly longer solution times in Experiment 2 as they did in Experiment 1. However it is notable that results were trending in this direction. One possibility is that the collection of retrospective reports and variability in task order in Experiment 2 changed the way participants allocated their time during the task.

Experiment 2 findings demonstrate that TA facility on the Raven's Matrices among older adults generalizes to experimental conditions differing from that of Experiment 1. Participants in Experiment 2 performed the Raven's matrices either first, second, third, or fourth among other tasks as opposed to Experiment 1 in which this task was always performed third. Moreover, participants generated retrospective verbal reports in Experiment 2 while not doing so in Experiment 1. It appears that older adult facilitation on the Raven's matrices is not only replicable but robust enough to manifest under a variety of experimental conditions. However, one exception to this generalizability was the modified matrix reasoning tasks, which were unaffected by TA. These tasks may have been too easy or different from the Raven's to elicit the effect.

While the post-Experiment 1 hypothesis that older adult facilitation may be due to reduced effects of age-related inhibitory deficits was not supported, this hypothesis cannot be dismissed entirely as the manipulation of visual distraction was unsuccessful. Participants performed as well in the distraction condition as in the control condition, leaving open several possibilities. For example it may have required more distractors than what were present in the modified matrix reasoning problems to simulate the amount of visual distraction present in Raven's Matrices problems. Another possibility is that the unchanging position of the distractors made them too easy to ignore; all of the figures in Raven's

Matrices problems are eventually relevant as opposed to the distracting figures in the modified matrix reasoning task, which are never relevant to solving the problem. It is possible that further experiments may implicate an inhibition account of why older adults perform better on the Raven's Matrices while thinking aloud.

GENERAL DISCUSSION

Findings from these experiments suggest that age and type of task influence reactivity as it was shown that older adults perform better on at least one task when thinking aloud. This finding was then replicated in a second experiment. Conversely, younger adults did not exhibit reactivity on any task. Older adults appear to generally perform the same on most cognitive tasks whether silent or thinking aloud. Null results on tasks other than the Raven's Matrices provide evidence consistent with previous studies (Gilhooly et al., 1999; Johnson, 1993; Perfect & Dasgupta, 1997) showing that older adults rarely exhibit reactivity to concurrent verbal reports.

The initial hypothesis that older adults would perform worse while thinking aloud due to declines in processing speed and deficits in dual-task performance was not supported. They did not exhibit any negative reactivity and, in fact, showed improved performance on the Raven's Matrices when thinking aloud. While no evidence was provided that facilitation from TA was attributable to age-related inhibitory declines, future studies may reveal this factor to be relevant.

The possibility remains that TA facilitation is explicable without recourse to an age-related explanation. Several studies (Short, Evans, Friebert, & Schatschneider, 1991; Short, Schatschneider, Cuddy, & Evans, 1991) have reported higher performance among TA children but not college-age adults on verbal and spatial analogies. A relationship between these studies and the findings of the current investigation should be interpreted with caution given that Short et al.'s method of collecting verbal reports did not conform to the guidelines established by Ericsson and Simon. Nonetheless, these studies provide some evidence that individuals with lower fluid ability (e.g., children and older adults) may benefit most from thinking aloud. Future studies may reveal that TA older adults benefit on the verbal and spatial analogies tests used in Short et al.'s studies.

Of note were the effect sizes for Raven's scores (d = .73 and d = .92 for Experiments 1 and 2 respectively). Given the standard deviations provided by Bors and Stokes (1998) and those obtained in the present study (all roughly 2.5), on an IQ scale with a standard deviation of 15, these effects (averaged) correspond to an IQ gain of about 11 points. A difference of this magnitude wields significance in both theoretical and applied domains. Previous studies (Bors & Vigneau, 2003; Raven, 1938) have revealed gains of one testing session to be about the same as the facilitation effect described here. Denney and Heidrich (1990) reported that brief training, consisting of an experimenter showing participants how to combine vertical and horizontal patterns within the matrices, comparably improved scores, but that older adults did not benefit more than younger adults from this intervention. Importantly, TA facilitation may be less test-specific than practice or training and thus generalize beyond the Raven's Matrices. It is possible the effect may influence other psychometric tests and have practical applications in training and usability.

Nevertheless, the extent to which the facilitation effect generalizes remains unknown. Participants attempted to solve the same 12 problems in both studies and it is possible that specific characteristics of these problems drove the effect. Post hoc analyses of items from Experiment 2 revealed little about specific problems or groups of problems from the test. Silent and think aloud groups did not score significantly different on any individual problem, $p > .05$, nor did they score differently on a composite of the four retrospective problems, $p > .05$. However, TA participants did score higher on a composite of the eight non-retrospective items, $F(1, 28) = 6.38$, $p < .05$. The finding that scores on retrospective problems were not related to verbalization condition and that non-retrospective problems were is likely due to the latter analysis possessing the greater power of more items. Raven's problems seem to be at least somewhat homogeneous with respect to their reactivity to TA, at least within the sample of 12 used in this study. Additional studies will be needed to determine whether the effect persists with the full set of 36 Raven problems or other matrix reasoning problems. Whether or not TA facilitates real-world tasks remains to be discovered.

The major contribution of this study has been to demonstrate that potential for reactivity is determined in part by age group and task, and to show that negative reactivity among older adults is unlikely to occur on most cognitive tasks. Moreover, older adults have been shown to perform better on at least one task while thinking aloud and future studies will be needed to identify under which conditions these individuals may benefit from verbalizing, whether in the laboratory or out in the world.

Table 1. *Means and Standard deviations for Silent and Think Aloud (TA) conditions by Age Group and Task for Experiment 1.*

Variable	Young Silent Mean (SD)	Young TA Mean (SD)	Older Silent Mean (SD)	Older TA Mean (SD)
Paired Associates	11.1 (4.94)	10.7 (4.40)	5.64 (3.98)	5.18 (4.38)
Cube Comparison 1 Score	10.7 (2.94)	9.21 (3.60)	6.82 (3.06)	5.79 (3.54)
Cube Comparison 1 Attempted	13.6 (3.10)	13.1 (4.47)	11.6 (5.29)	11.2 (4.41)
Cube Comparison 2 Score	11.6 (4.14)	11.2 (3.37)	8.40 (3.54)	7.44 (4.05)
Cube Comparison 2 Attempted	12.9 (5.81)	12.7 (6.24)	11.4 (5.13)	10.3 (5.64)
Raven's Matrices Score	6.67 (2.41)	5.40 (2.70)	2.35 (1.90)	4.07 (2.76)
Raven's Matrices Solution Time	574 (201)	625 (169)	719 (224)	1080 (477)
Mental Multiplication Score	2.00 (1.51)	2.71 (1.59)	1.13 (1.40)	1.20 (1.21)
Mental Multiplication Time	57.8 (26.3)	44.3 (13.3)	58.6 (36.0)	64.0 (44.1)

Note. Paired Associates represents the mean number of items correctly recalled. Cube Comparison 1 represents number of items correct and attempted in session 1; Cube Comparison 2 represents total number of items correct and attempted in session 2. Solution time for Raven's Matrices is time for completing all 12 problems in seconds. Mental multiplication time reflects means times for individual problems in seconds.

Table 2. *Means and Standard deviations for Silent and Think Aloud (TA) conditions by Age Group and Task for Experiment 2.*

Variable	Silent Mean (SD)	TA Mean (SD)
Raven's Matrices Score	1.93 (1.64)	3.94 (2.62)
Raven's Matrices Solution Time	929 (436)	1170 (610)
Mental Multiplication Score	1.50 (1.29)	1.75 (1.65)
Mental Multiplication Time	58.6 (27.9)	48.7 (21.5)
Control Matrices Score	5.29 (2.46)	5.63 (2.75)
Control Matrices Time	39.6 (19.0)	42.2 (16.9)
Distraction Matrices Score	4.64 (2.73)	5.50 (3.52)
Distraction Matrices Time	37.7 (21.0)	48.2 (23.0)

Note. Scores represent the total number of correct items on each task. Solution time for Raven's Matrices is time for completing all 12 problems in seconds. Mental multiplication time, control matrices time, and distraction matrices time represent mean solution time for individual problems and are expressed in seconds.

Table 3. *Correlation Matrix of Tasks for Experiment 2*

	Raven's Total	Raven's Time	Control Matrices Total	Control Matrices Time	Distraction Matrices Total	Distraction Matrices Time	Multiplication Total
Raven's Time	**.41**						
Control Matrices Total	**.50**	.29					
Control Matrices Time	-.40	**.43**	.17				
Distraction Matrices Total	**.70**	.29	**.72**	-.15			
Distraction Matrices Time	-.33	**.39**	-.01	**.44**	-.33		
Multiplication Total	**.59**	.18	.22	-.25	**.47**	-.32	
Multiplication Time	-.09	.03	-.07	**.38**	-.16	**.37**	.01

Note. Bold scores represent values significant at $p < .05$

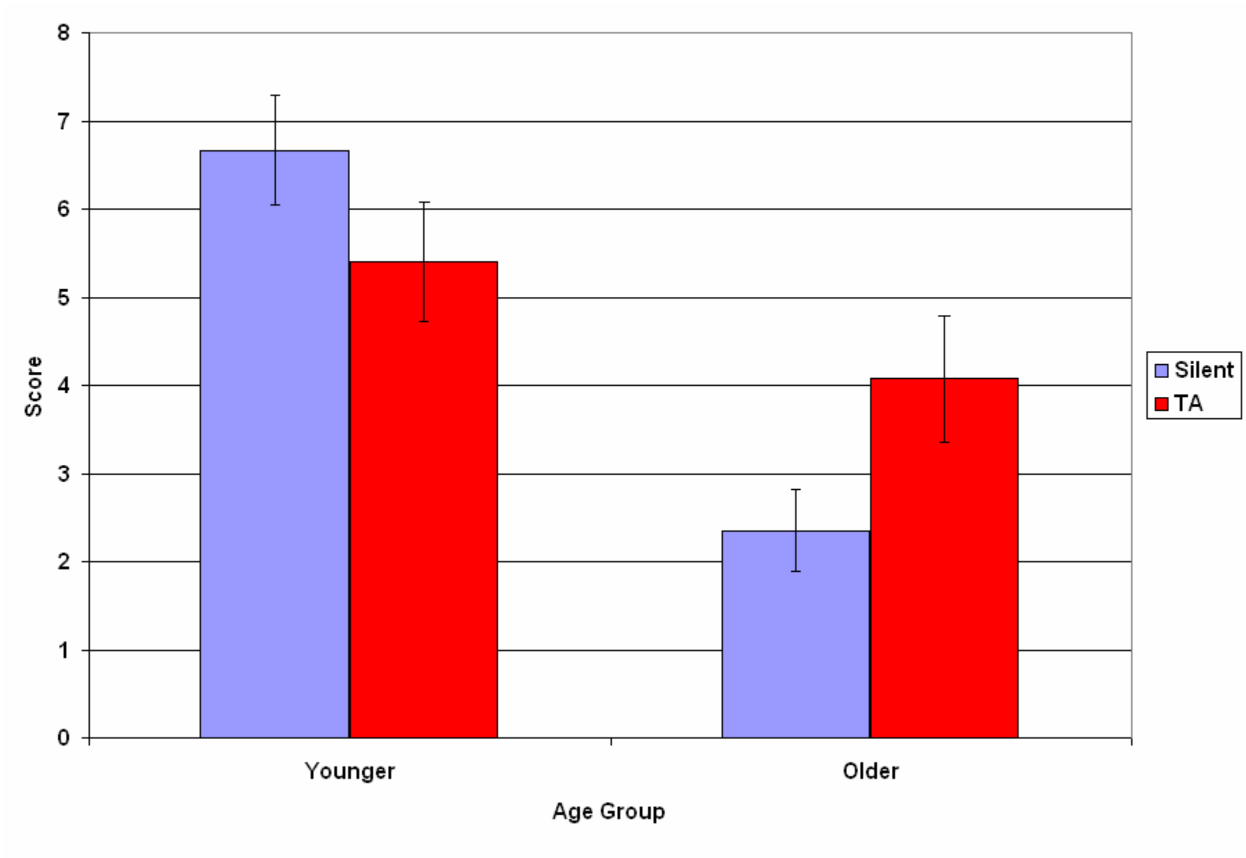

Figure 1. *Graph depicting scores on the Raven's Matrices from Experiment 1 with +/- 1 standard error bars.*

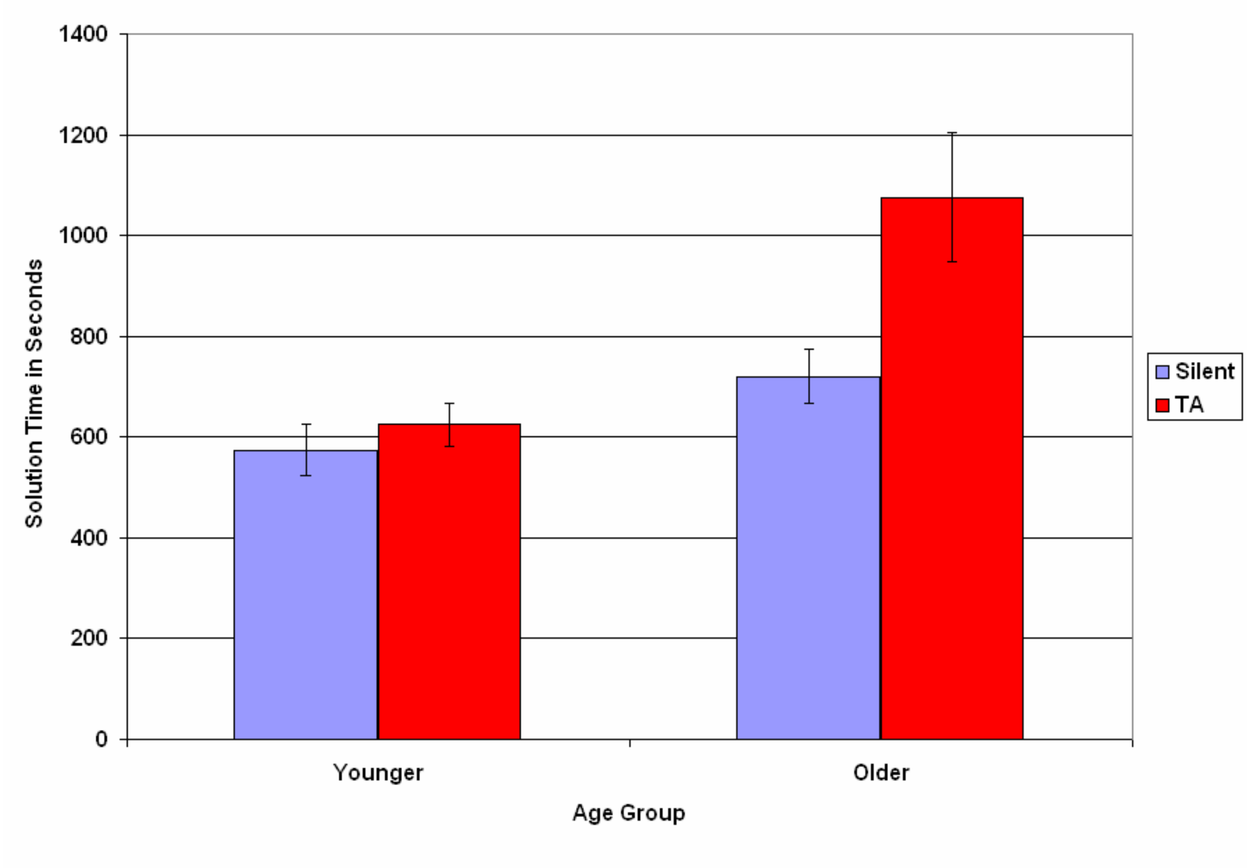

Figure 2. *Graph of Raven's Matrices solution times from Experiment 1 with +/- 1 standard error bars.*

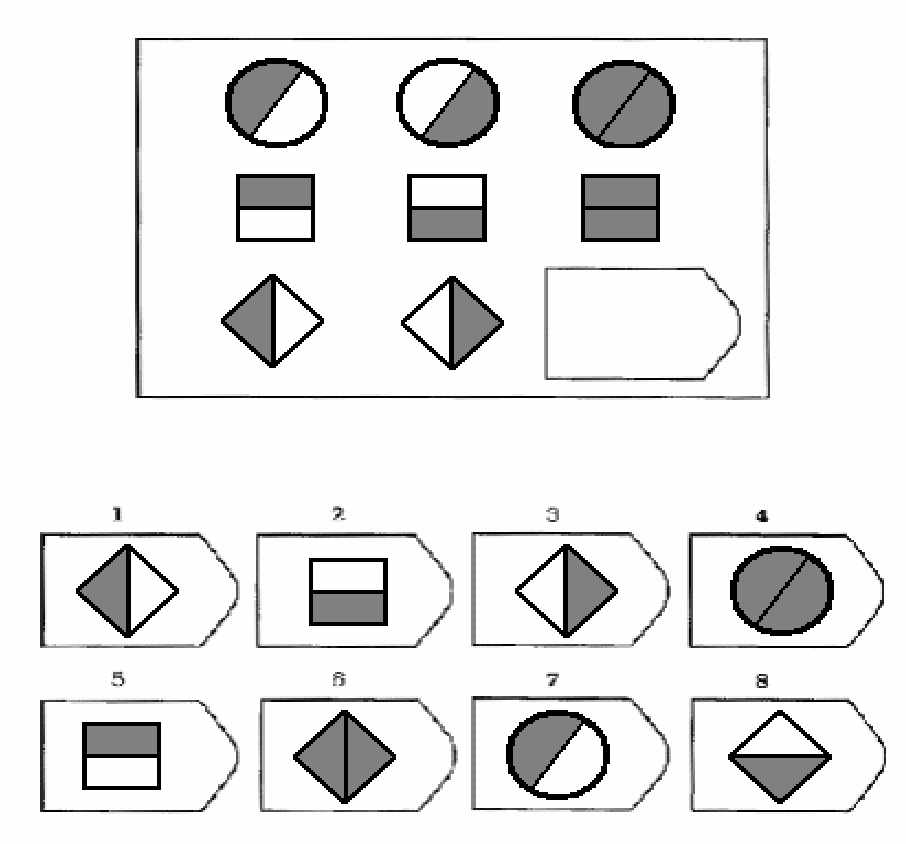

Figure 3. *Example of a problem similar to those found in Raven's Advanced Progressive Matrices.*

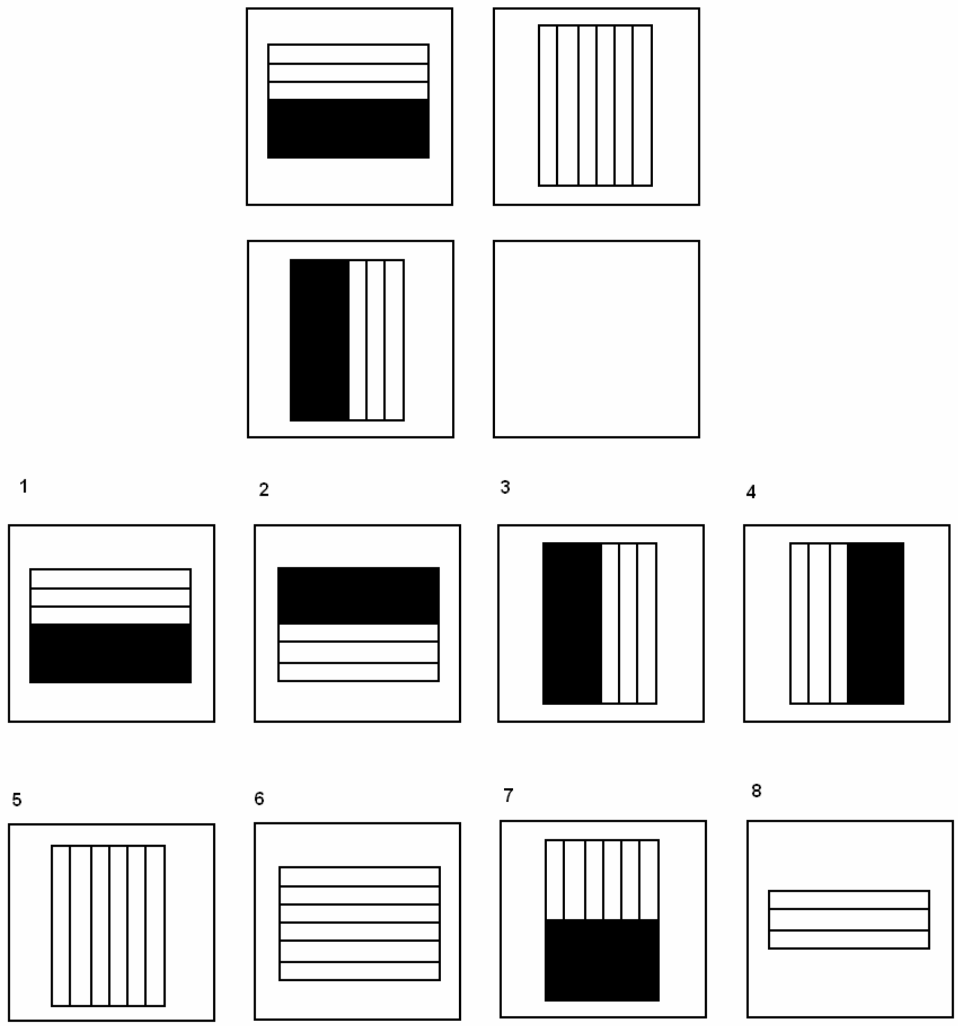

Figure 4. *Example of a control modified matrix reasoning item.*

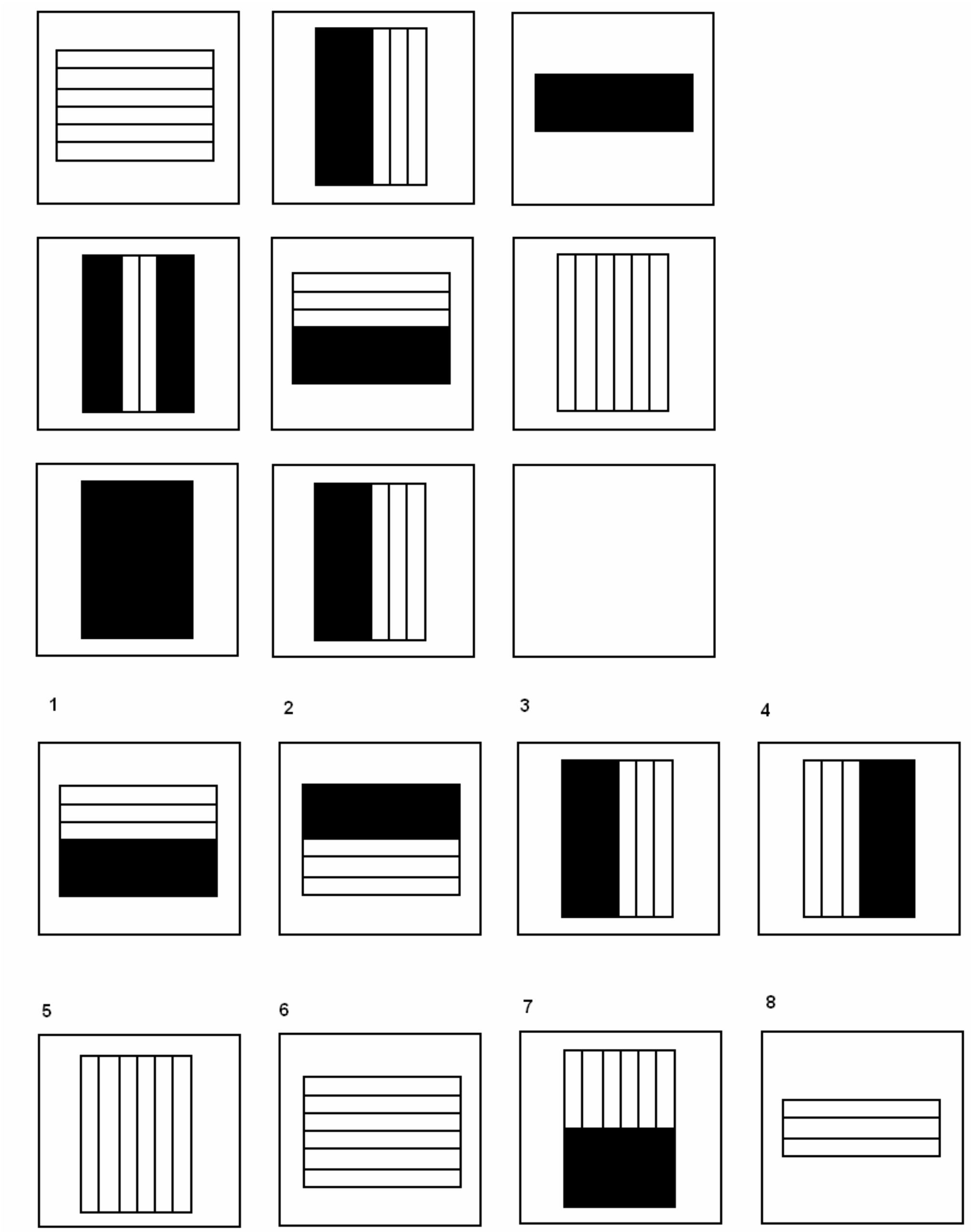

Figure 5. *Example of a visual distraction modified matrix reasoning item.*

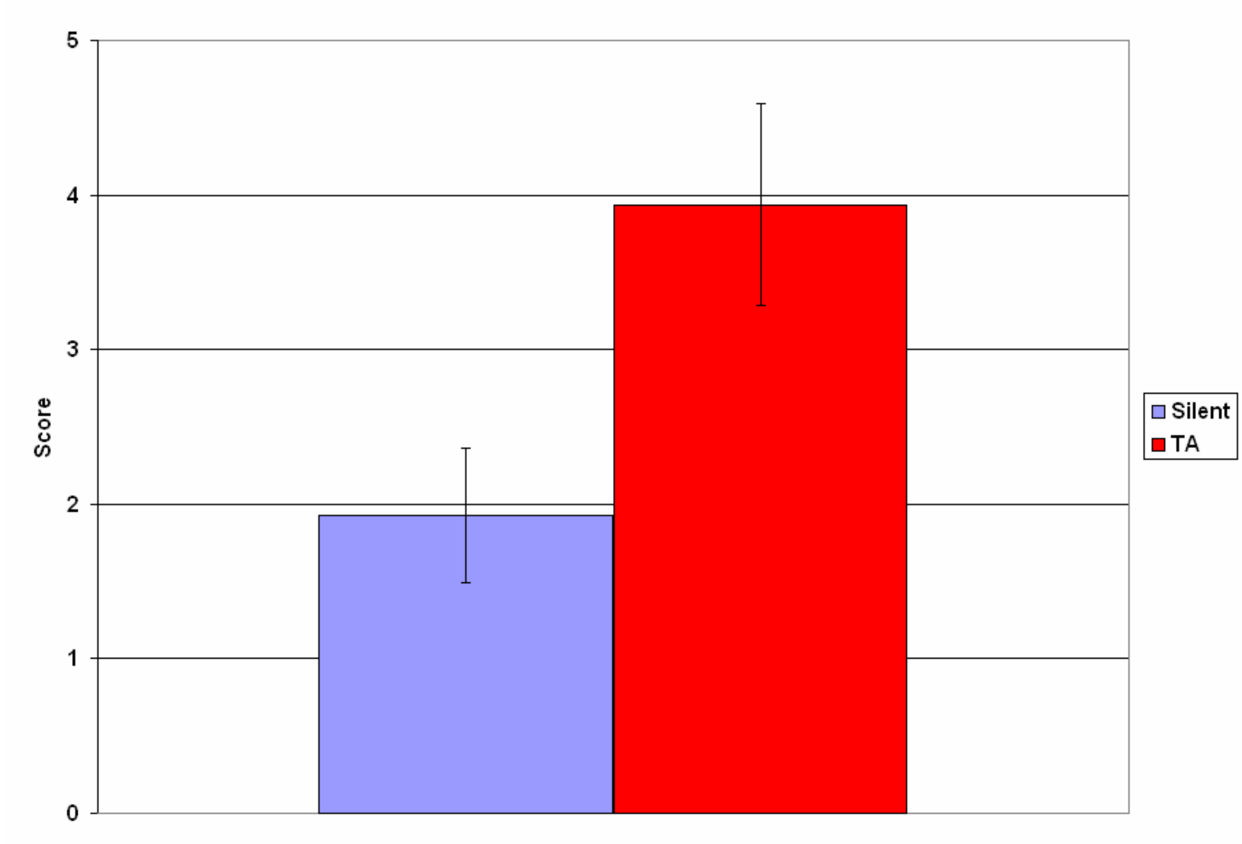

Figure 6. *Graph depicting scores on the Raven's Matrices from Experiment 2 with +/- 1 standard error bars.*

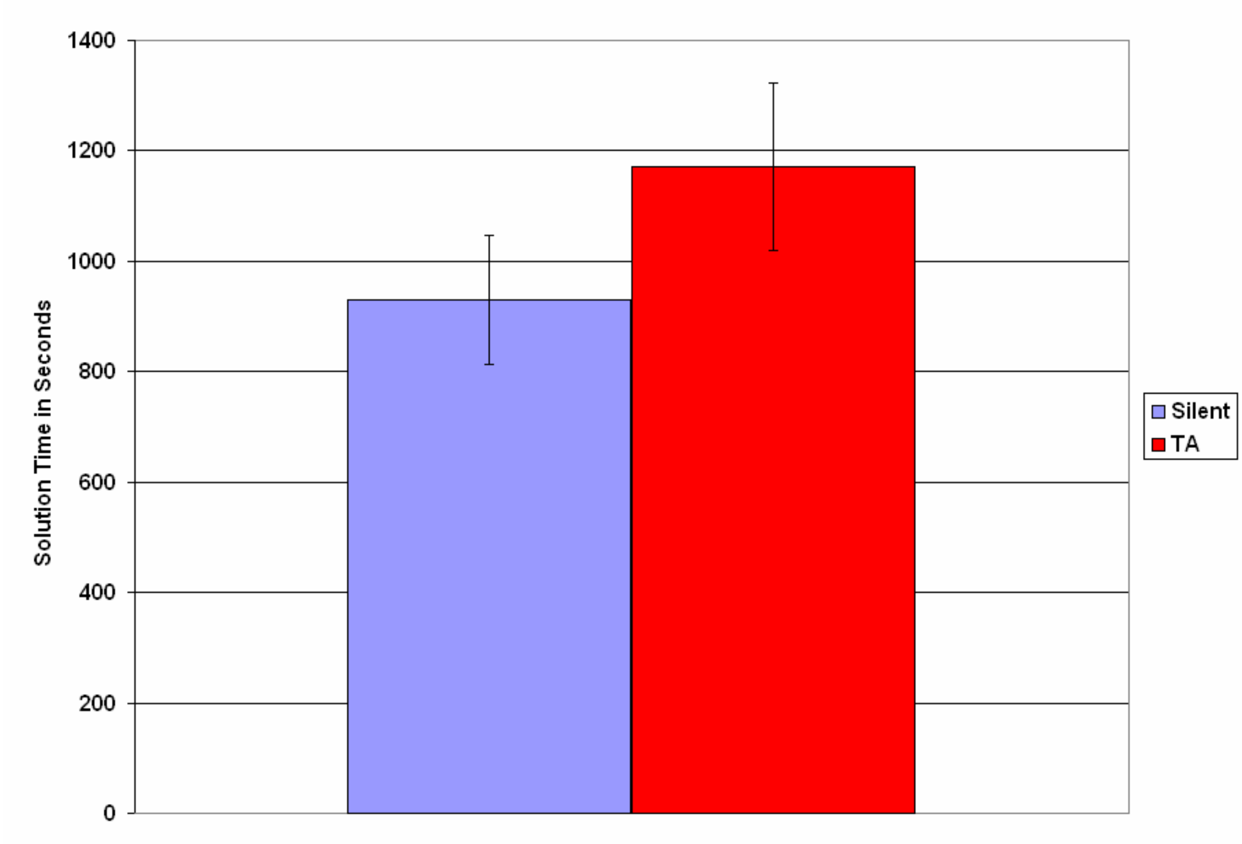

Figure 7. *Graph depicting overall solution times on Raven's Matrices from Experiment 2 with +/- 1 standard error bars.*

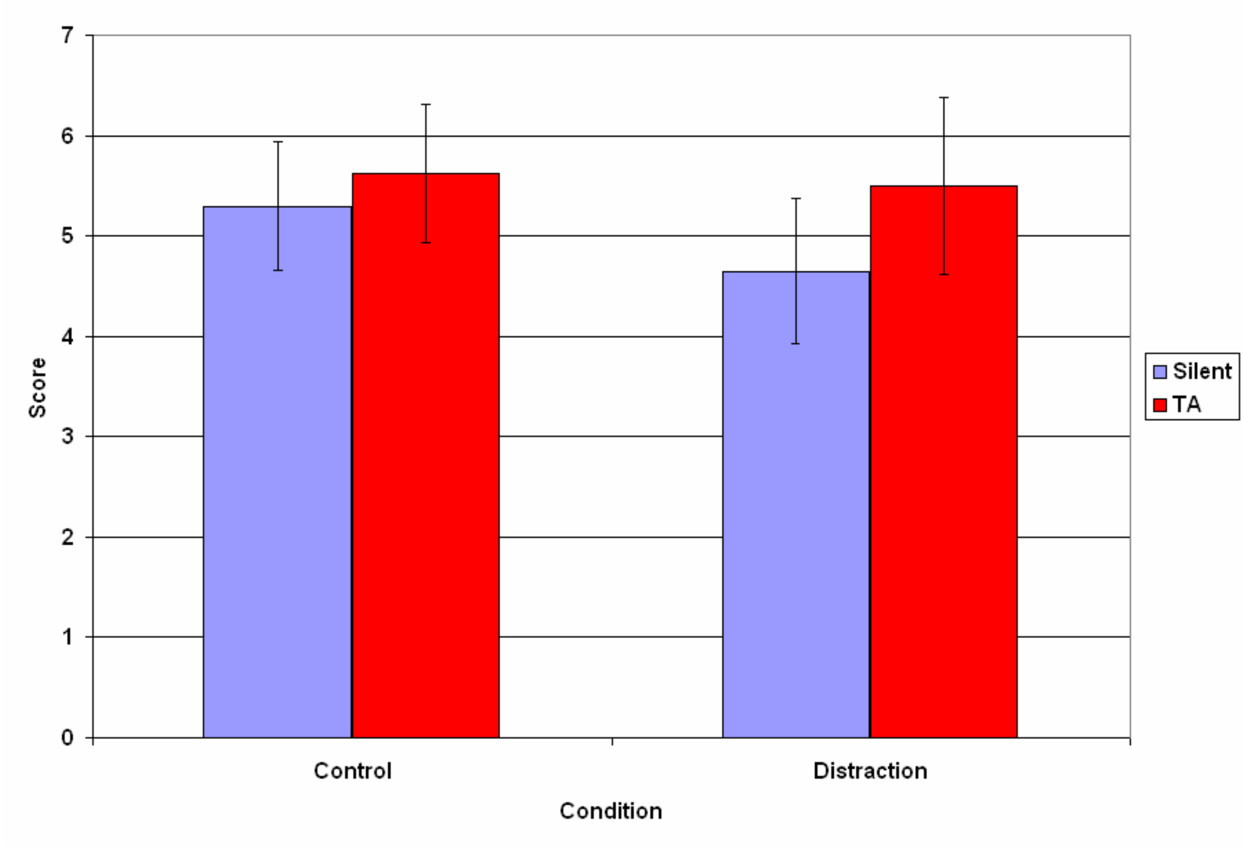

Figure 8. *Graph of scores on control and distraction matrix reasoning problems from Experiment 2 with +/-1 standard error bars.*

APPENDIX A: INSTITUTIONAL REVIEW BOARD APPROVAL

Florida State
UNIVERSITY

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

APPROVAL MEMORANDUM (for change in research protocol)

Date: 5/31/2007

To:
Mark Carver Fox
Department of Psychology
1107 W. Call Street
Tallahassee, FL 32306

Dept: PSYCHOLOGY DEPARTMENT

From: Thomas L. Jacobson, Chair

Re: Use of Human subjects in Research
Project entitled: Aging, Reasoning and the Use of Verbal Protocols

The memorandum that you submitted to this office in regard to the requested change in your research protocol for the above-referenced project have been reviewed and approved. Thank you for informing the Committee of this change.

A reminder that if the project has not been completed by 10/31/2007, you must request renewed approval for continuation of the project.

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

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

cc: Neil Charness
APPLICATION NO. 2006.0902

jth5898

From:	Webmaster [tjiang@magnet.fsu.edu]
Sent:	Wednesday, November 01, 2006 1:58 PM
To:	fox@psy.fsu.edu
Cc:	charness@psy.fsu.edu
Subject:	Use of Human Subjects in Research - Approval Memorandum

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

APPROVAL MEMORANDUM

Date: 11/1/2006

To: Mark Fox

Address: 1107 W. Call St. Tallahassee FL 32306 or Department of Psychology
Dept.: PSYCHOLOGY DEPARTMENT

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
Aging, Reasoning, and the Use of Verbal Protocols

The forms that you submitted to this office in regard to the use of human subjects in the proposal referenced above have been reviewe by the Secretary, the Chair, and two members of the Human Subjects Committee. Your project is determined to be Expedited per 45 CFR § 46.110(7) and has been approved by an expedited review process.

The Human Subjects Committee has not evaluated your proposal for scientific merit, except to weigh the risk to the human participan and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 10/31/2007 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementatio of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

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

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

Cc: Neil Charness, Advisor
HSC No. 2006.123

jth5898

From:	Webmaster [tjiang@magnet.fsu.edu]
Sent:	Wednesday, November 01, 2006 10:07 AM
To:	fox@psy.fsu.edu
Subject:	IRB Chair Review Feedback

Human Subjects Application - For Full IRB and Expedited Exempt Review

PI Name: Mark Carver Fox
Project Title: Aging, Reasoning, and the Use of Verbal Protocols HSC Number: 2006.123

Your application has been reviewed by IRB Chair and will be transmitted to office staff for approval paperwork.

APPENDIX B: INFORMED CONSENT FORM

INFORMED CONSENT FORM

Date:________________________

I freely and voluntarily consent to be a participant in the research project entitled "Aging, Reasoning, and the Use of Verbal Protocols" Dr. Neil Charness will be the principal investigator and Mark Carver Fox will be the research assistant.

I understand that I will be given tests measuring different cognitive abilities. Abilities that will be tested are memory, spatial reasoning, and mental arithmetic. In addition, I understand that I may be observed during a typical session and that this session could be audio taped to capture talk/think aloud information (e.g. speaking my thoughts aloud while I perform) for later protocol analysis. A post session retrospective of my thoughts during my performance may also be recorded for later analysis. I understand that this experiment will last approximately one hour.

I understand that the records of this research which refer to my data will be given a code so that no one except the investigators and their designated assistants will have access to the data, and that no identifiable data, including handwritten information that I have supplied, will be used for publication. In addition, the records of this research, which refer to my performance, will be kept confidential to the extent allowed by law. I understand that any audio tapes used in this project will be retained at the FSU Department of Psychology, and that the tapes will be erased or destroyed within ten years (no later than October 31, 2016). I understand that I will be paid 10 dollars per hour for participation in this project if I am not a student at Florida State University and course credit if I am a student at Florida State University.

This consent may be withdrawn at any time without consequence. Also, I understand that I may stop the experiment at any time without penalty. I have been given the right to ask and have answered any inquiry concerning the foregoing. Questions, if any, have been answered to my satisfaction. I understand that I may contact Dr. Neil Charness, Department of Psychology, Florida State University, Tallahassee, FL 32306, phone: (850) 644-6686, or Mark Carver Fox, phone: (850) 212-0802, for answers to pertinent questions about this research. I have read and I understand the foregoing.

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

Signature of Research Participant________________________

Printed Name________________________

Florida State University Institutional Review Board
Approved: 11/1/2006
Void After: 10/31/2007
HSC # 2006.123

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BIOGRAPHICAL SKETCH

Mark Carver Fox was born on August 24, 1979 and grew up in rural southwest Michigan. As a child, he enjoyed drawing, playing sports, building things, and taking things apart. He graduated with honors from Michigan State University in 2003 while working in the memory and aging lab of Rose Zacks.

In summer of 2005, Mark began working with Neil Charness at Florida State University. Mark's research interests are higher-level cognition and cognitive aging. He is especially interested in applying research to practical problems and has focused his attention on the human factors of highway safety. In his spare time, Mark enjoys drawing, reading, exercising, and playing the piano.