Cognitive aging and task-coordination strategies for dual-task performance

Jennifer M. Glass, Travis L. Seymour, Eric H. Schumacher, Leon Gmeindl,
David E. Meyer, David E. Kieras
University of Michigan

Abstract

Age effects are ubiquitous in dual-task situations, but the source of these effects is elusive. One possibility is that older adults use different dual-task coordination strategies. The effects of different strategies on performance in two experiments using the psychological refractory period (PRP) procedure are reported. Strategies were quantified with the Executive-Process/Interactive-Control (EPIC) architecture (Meyer & Kieras, 1997), a computational framework for modeling dual-task performance. The results show that strategy differences are a major part of age effects on dual-task performance.

Aging & Dual-Task Performance

A typical finding in cognitive aging research is that older adults exhibit larger decrements in dual-task performance than do young adults. Two hypotheses about the source of this decrement are described below.

Dual-task deficit hypothesis. States that aging causes a deficit in the ability to perform multiple tasks.

Generalized slowing hypothesis. States that the larger dual-task costs seen with older adults are due to changes in the ability to perform each component task on its own (Somberg & Salthouse, 1982).

These hypotheses can be tested by calculating relative measures of dual-task cost that use single-task performance as a baseline. The generalized slowing hypothesis predicts no age effect when relative measures are used. The dual-task deficit hypothesis predicts that age effects will occur even when relative measures are used.

Several researchers have used relative measures of dual-task costs, with mixed results. Some find no age effects (Somberg & Salthouse, 1982; Salthouse, Fristoe, Lineweaver & Coon, 1995) while others continue to find age effects (Salthouse, Rogan & Prill, 1984; McDowd & Craik, 1988).

Cautious strategy hypothesis. Perhaps strategy differences between the young and older adults account for the differences in their dual-task performance. Sometimes older adults may use more cautious strategies than do young adults. In this case the relative dual-task costs would be larger for older adults. In other instances, the strategies used by young and older adults might be the same, and then the relative dual-task costs will be equal.

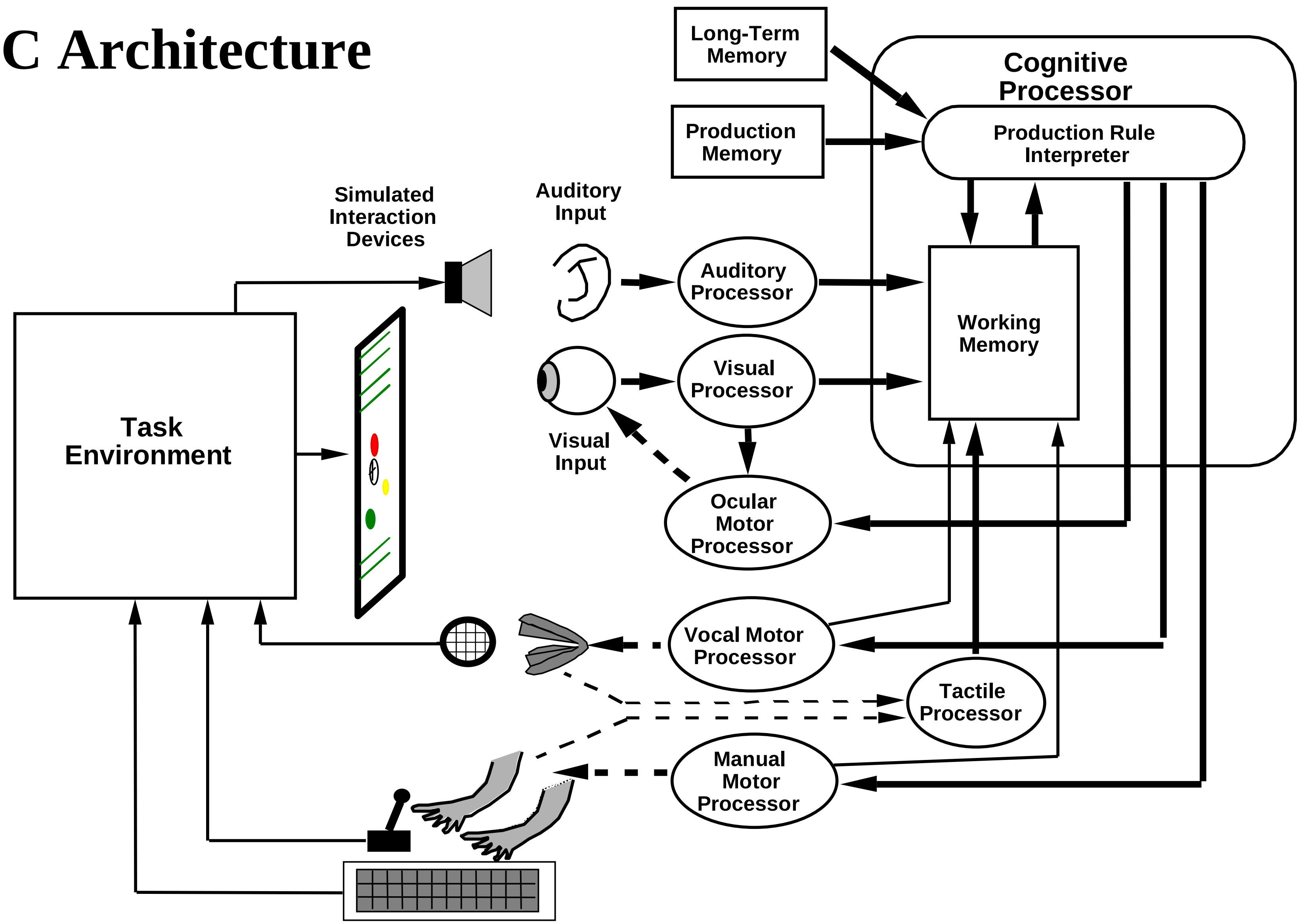
The appeal to strategy differences is useful only if there is a way to describe and quantify the possible strategies that people might use to coordinate dual-task performance. The EPIC architecture (Meyer & Kieras, 1997) provides the necessary description and quantification.

The Epic Architecture

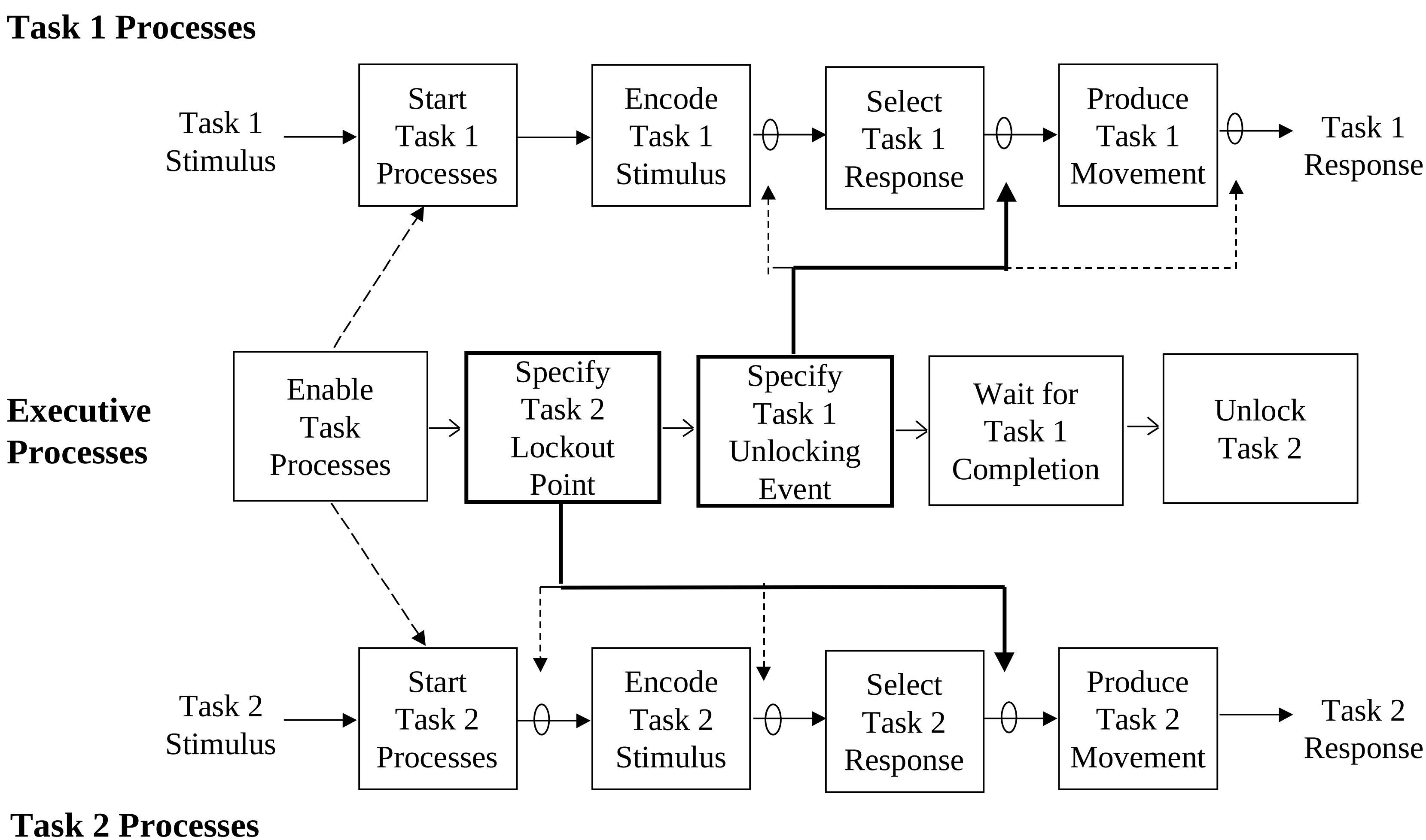
Figure 1 illustrates the EPIC architecture. EPIC has perceptual processors, motor processors, and a cognitive processor. Within the cognitive processor are working memory and a production rule interpreter.

The cognitive processor operates in cycles of a set duration. Generalized slowing can be simulated by increasing the duration of the cognitive processor cycle. EPIC **does not** have a limited pool of attentional resources or a central bottleneck limiting the number of cognitive operations that can be carried out in parallel. Instead, EPIC uses flexible executive control for dual-task performance. This executive control allows EPIC to comply with situational constraints such as instructions to give one task priority over another task.

The EPIC Architecture



Adaptive Executive-Control (AEC) Models



Adaptive Executive-Control (AEC Models)

Meyer and Kieras (1997) developed a class of Adaptive Executive-Control (AEC) models within the EPIC architecture specifically for situations where two tasks are performed simultaneously and the instructions are to give one of the tasks priority. Figure 2 shows an example of an AEC model with a daring task-coordination strategy. In this figure, the top boxes represent the processing stages for the primary task. The bottom boxes represent similar processing stages for the secondary task.

The boxes in the middle show the executive processes that control the course of the secondary task. The two executive processes most important for strategic control of task coordination are outlined in bold. The first of these specifies a lockout point in Task 2 where the processing for Task 2 is stopped. This ensures that the response for Task 1 will be produced before the response for Task 2.

The Task 2 lockout point specified in Figure 2 occurs after the response-selection stage. However, the location of the lockout point is flexible. It could occur before the response-selection stage or before the stimulus-encoding stage.
The second executive process outlined in bold specifies a Task 1 unlocking event. After this event occurs, processing can resume for Task 2. Here, the unlocking event comes after Task 1 response selection. The unlocking event is flexible and could occur after stimulus encoding or movement production.

Together the executive processes control how much overlap occurs between the two tasks. The strategy here is daring because the Task 2 lockout point is as late as possible. This allows considerable overlap in the stages of the two tasks. An early Task 2 lockout point or a late Task 1 unlocking event would result in more cautious strategies since there would be less overlap between the tasks.

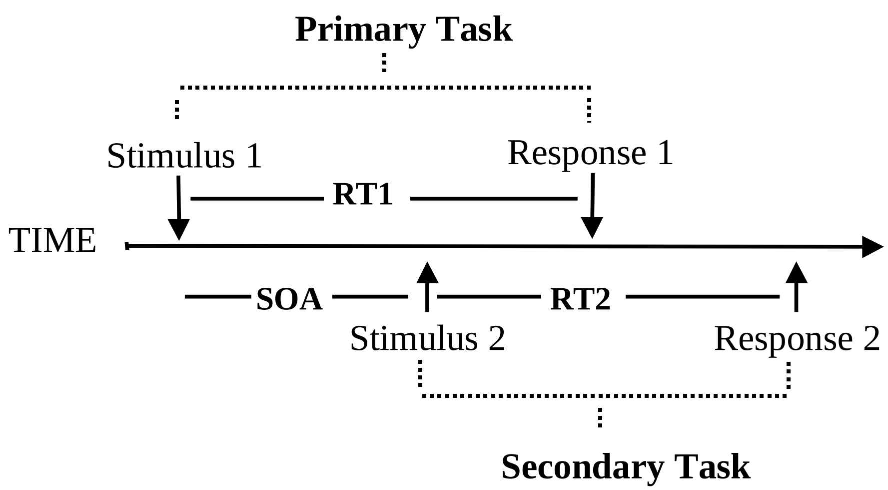
To test the hypothesis that older adults sometimes use more cautious task-coordination strategies, we conducted two experiments using the psychological refractory period (PRP) procedure.

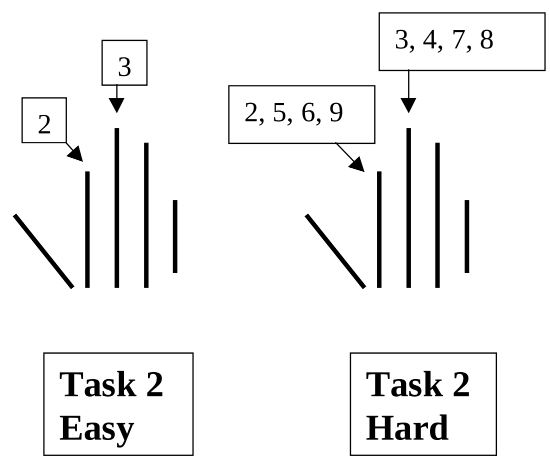
Experiment 1

- 10 young adults (mean age 20) and 10 older adults (mean age 65)
- PRP procedure outlined below
- Task 1: Tone discrimination (800hz or 1200hz); left-hand key presses
- Task 2: Digit identification; right-hand key presses; two versions:

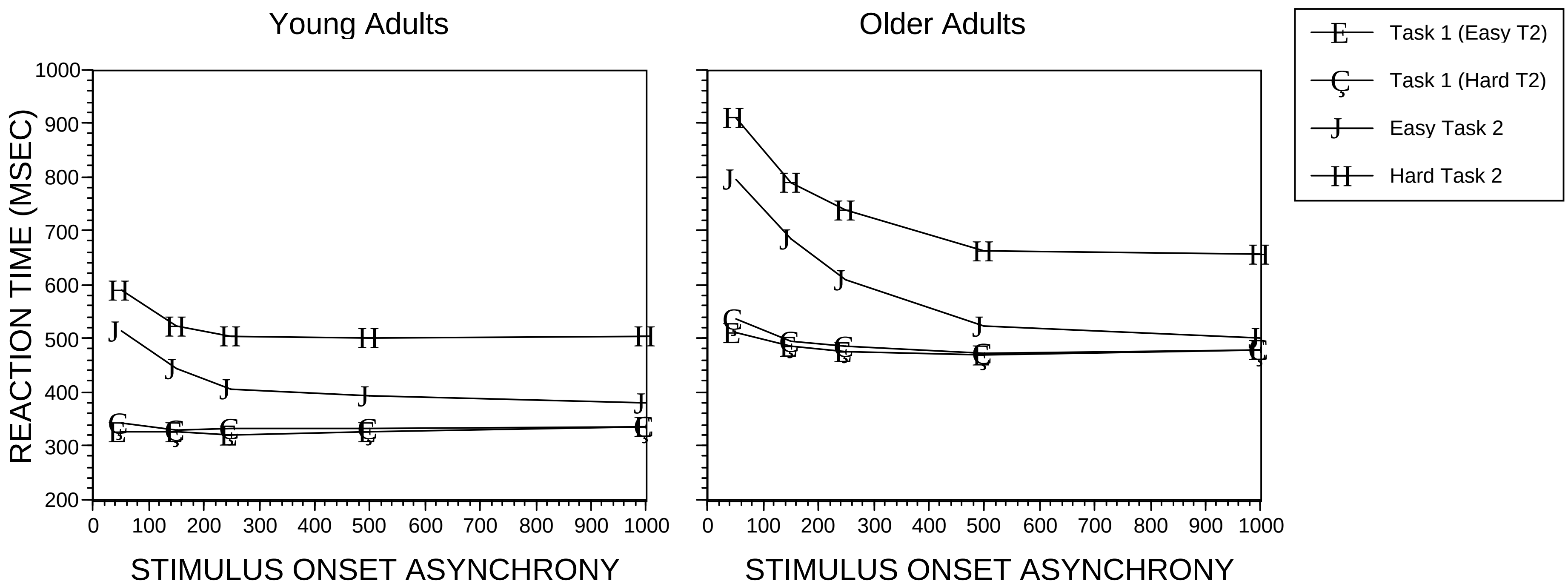
  Easy: 2 digits mapped to 2 key presses

  Hard: 8 digits mapped to 2 key presses





Experiment 1 Results



- Older adults are slower overall.
- Older adults have a larger PRP effect than young adults.
- Both age groups have an SOA by Task 2 difficulty interaction.
- Very few out-of-order responses (0.02% for young, 0.03% for older adults).

- Very few out-of-order responses (0.02% for young, 0.03% for older adults).

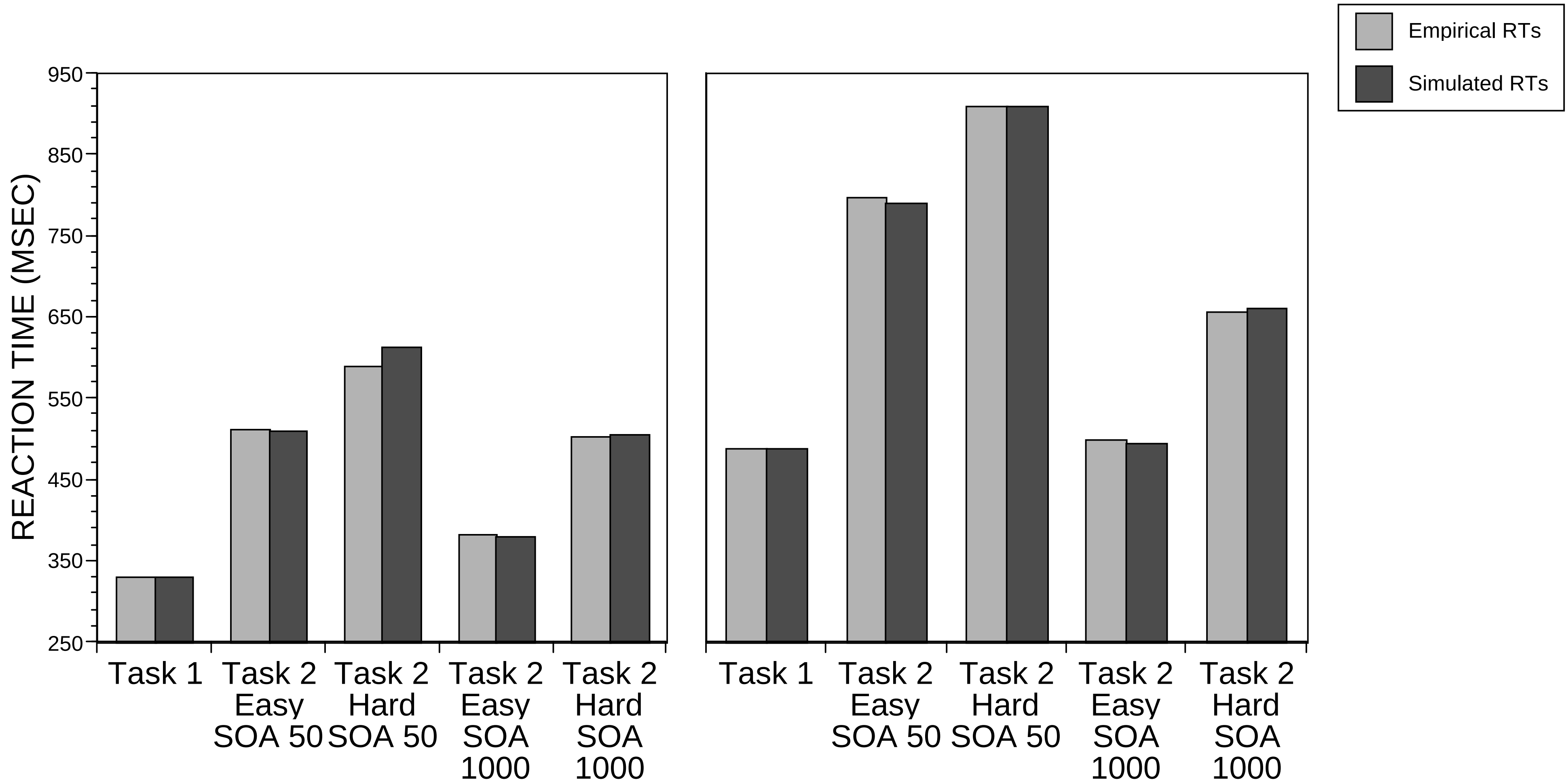
Application of AEC Models to Experiment 1

The SOA by Task 2 Difficulty interaction (diverging PRP curves) indicates overlap in the response-selection stages of Tasks 1 and 2 for both young and older adults. Thus, we used an AEC model with a late Task 2 lockout point. Generalized slowing was simulated by increasing the duration of the cognitive processor cycle from 50 msec (value for young adults) to 56 msec.

The empirical and simulated RTs from the models that give the best fit are shown in Figure 5. The model that gives the best fit for older adults is different from young adults in three ways:

- Longer cognitive processor duration.
- Longer stimulus encoding stages, especially for Task 1 (tone discrimination).
- Cautious (i.e. later) Task 1 unlocking event. Older adults waited longer before resuming Task 2 processing.

AEC Models From Experiment 1

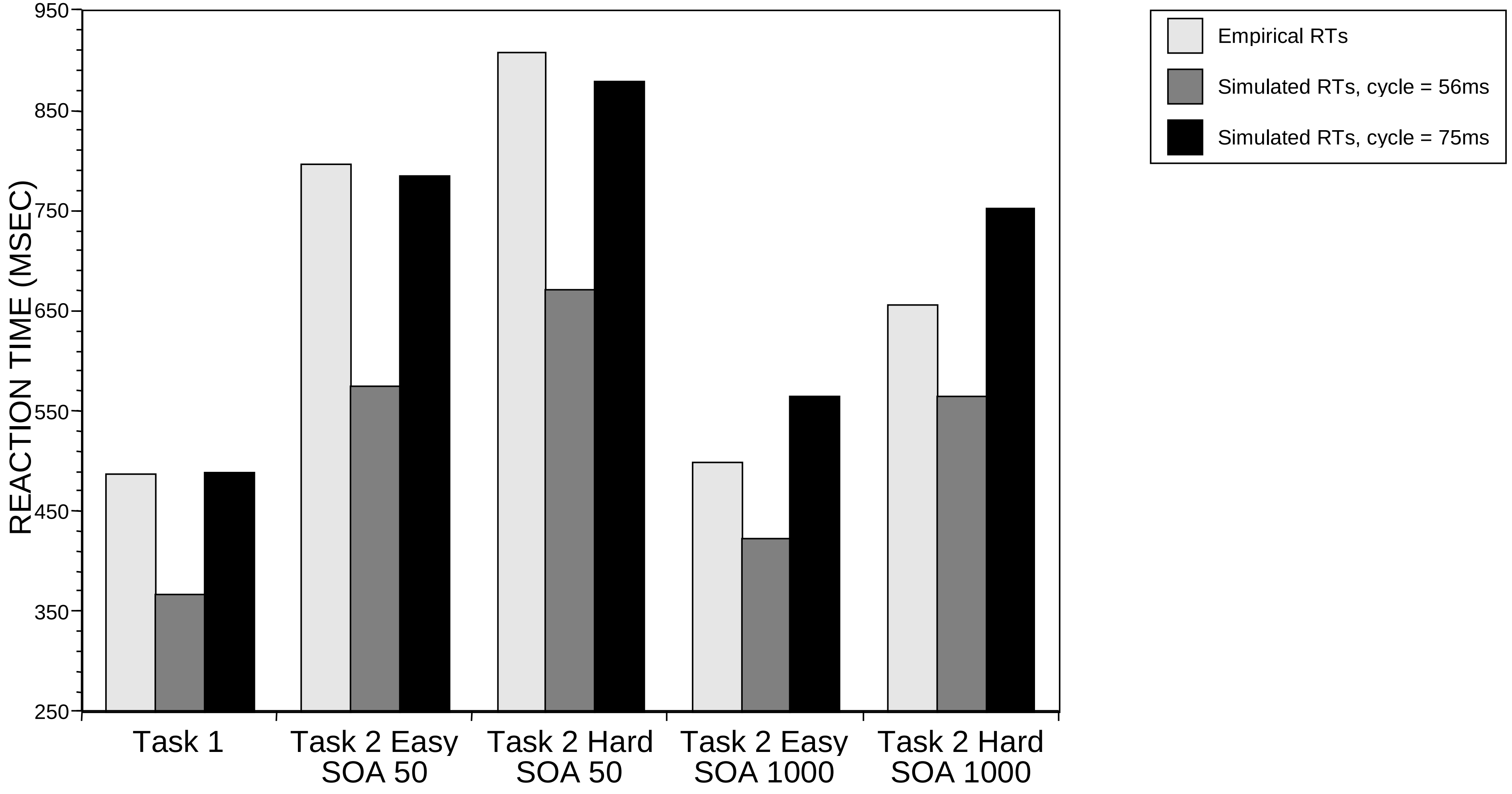


Conclusions From Experiment 1

Dual-Task Deficit. This hypothesis was not supported. Older adults were just as capable at coordinating the tasks as young adults. This is indicated by the diverging PRP curves and the absence of out-of-order responses. Older adults were able to overlap the processing stages of both tasks without violating the PRP instructions.

Generalized Slowing. Although generalized slowing is embodied the AEC model of the older adults, it is not enough to accurately capture the age effects. Figure 6 shows the results from two additional AEC models for the older adults. These models differ from the young adults model only in the cognitive processor cycle duration. In the first model the duration was 56 msec and in the second model 75 msec. Each of these two models fail to capture all of the differences between the young and older adults PRP performance.

Generalized Slowing AEC Models (Experiment 1)



Cautious Task-Coordination Strategies. These results indicate that strategy differences are an important part of the explanation of dual-task performance in older adults.

Combined sources. Instead of a unitary source for age effects on dual-task performance, we found three sources: strategy differences, generalized slowing, and specific slowing.

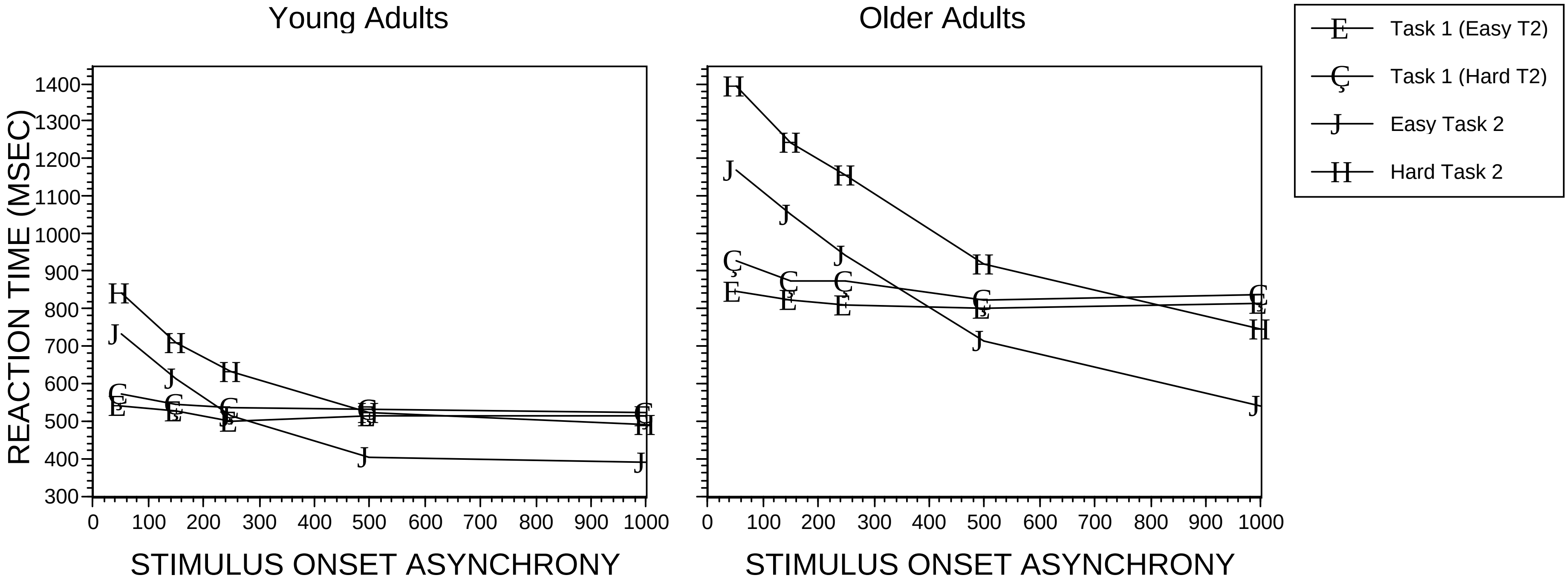
To further examine the role of task-coordination strategies in the dual-task performance of older adults, we conducted a second experiment using tasks that have produced cautious (i.e. early Task 2 lockout point) task-coordination strategy in previous studies with young adults (Meyer et al., 1995). The results of Meyer et al. showed that young adults can use different strategies in different situations. We wanted to know if older adults could be as flexible in their use of task-coordination strategies as young adults are. If not, the strategy found in Experiment 1 could be the one that older adults always use.

EXPERIMENT 2

Experiment 2 is identical to Experiment 1, except that Task 1 is a four tone discrimination task rather than a two tone discrimination task.

- 9 young adults (mean age 21) and 10 older adults (mean age 66).
- PRP procedure outlined in Figure 4.
- Task 1: Tone discrimination (333hz, 500hz, 1120hz, or 1450hz); left-hand key presses.
- Task 2: Digit identification; right-hand key presses.
  Easy: 2 digits mapped to 2 key presses.
  Hard: 8 digits mapped to 2 key presses.

Experiment 2 Results



- Older adults slower overall.
- Older adults have a larger PRP effect.
- No SOA by Task 2 difficulty interaction for both age groups.
- Very few out-of-order responses (0.65% for young, 0.46% for older adults).

Application of AEC Models to Experiment 2

The lack of an SOA by Task 2 difficulty interaction (parallel PRP curves) indicates there is no overlap in the response selection stages of Tasks 1 and 2 for both age groups. Therefore we used an AEC model with an early Task 2 lockout point.

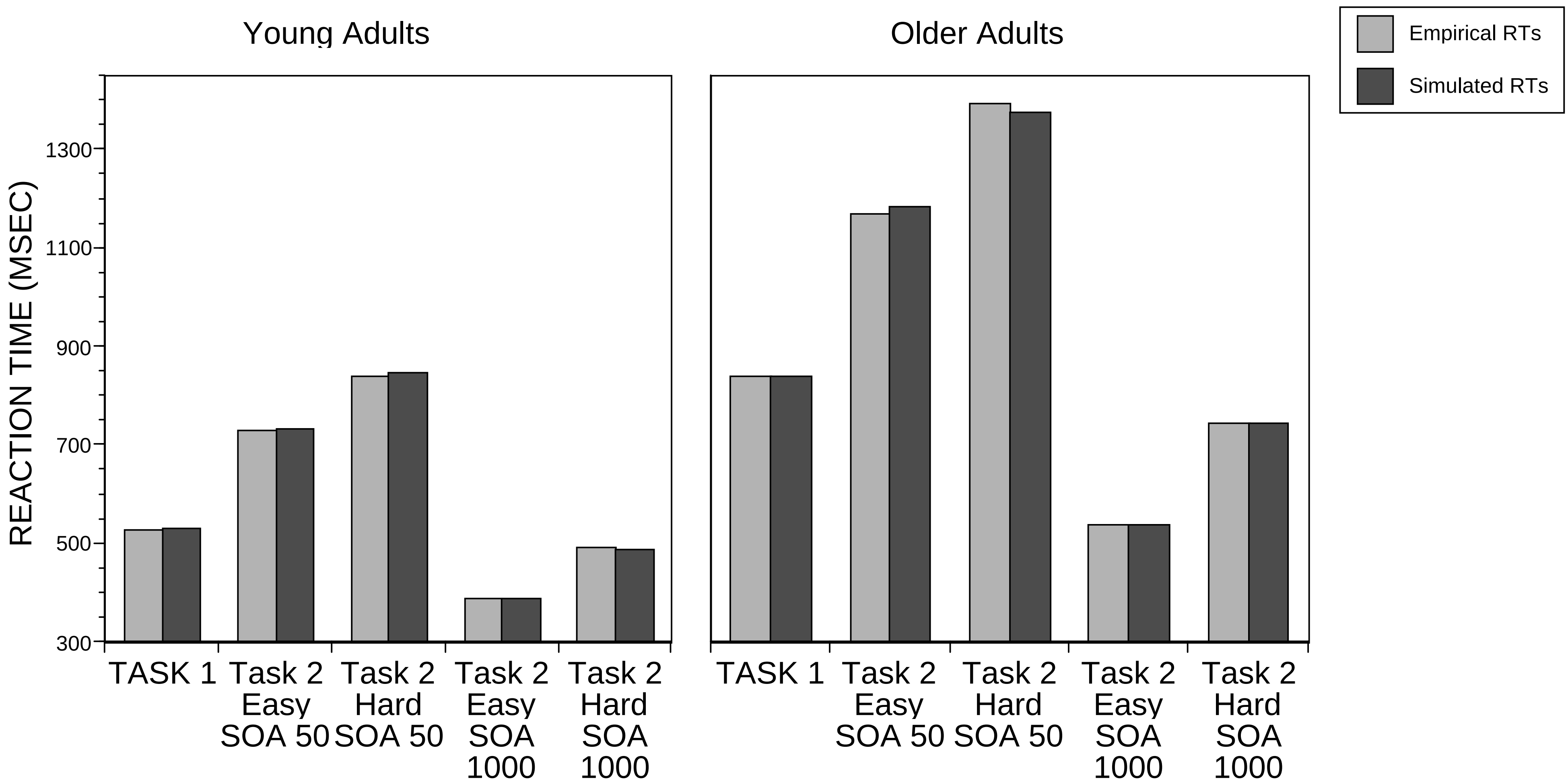
As before, we simulated generalized slowing by using 56 msec for the cognitive processor cycle duration in the older adults' AEC model.

The empirical and estimated RTs from the models that give the best fit for young and older adults are shown in Figure 8. The model for the older adults differs from the young adults in 2 ways:

- Longer cognitive processor cycle time.
- Longer task encoding times, especially Task 1.

In Experiment 2, the older adults used a strategy that was similar to the young adults in both Task 2 lockout point and Task 1 unlocking event. This contrasts with Experiment 1 where older adults used a more cautious strategy.

AEC Models From Experiment 2



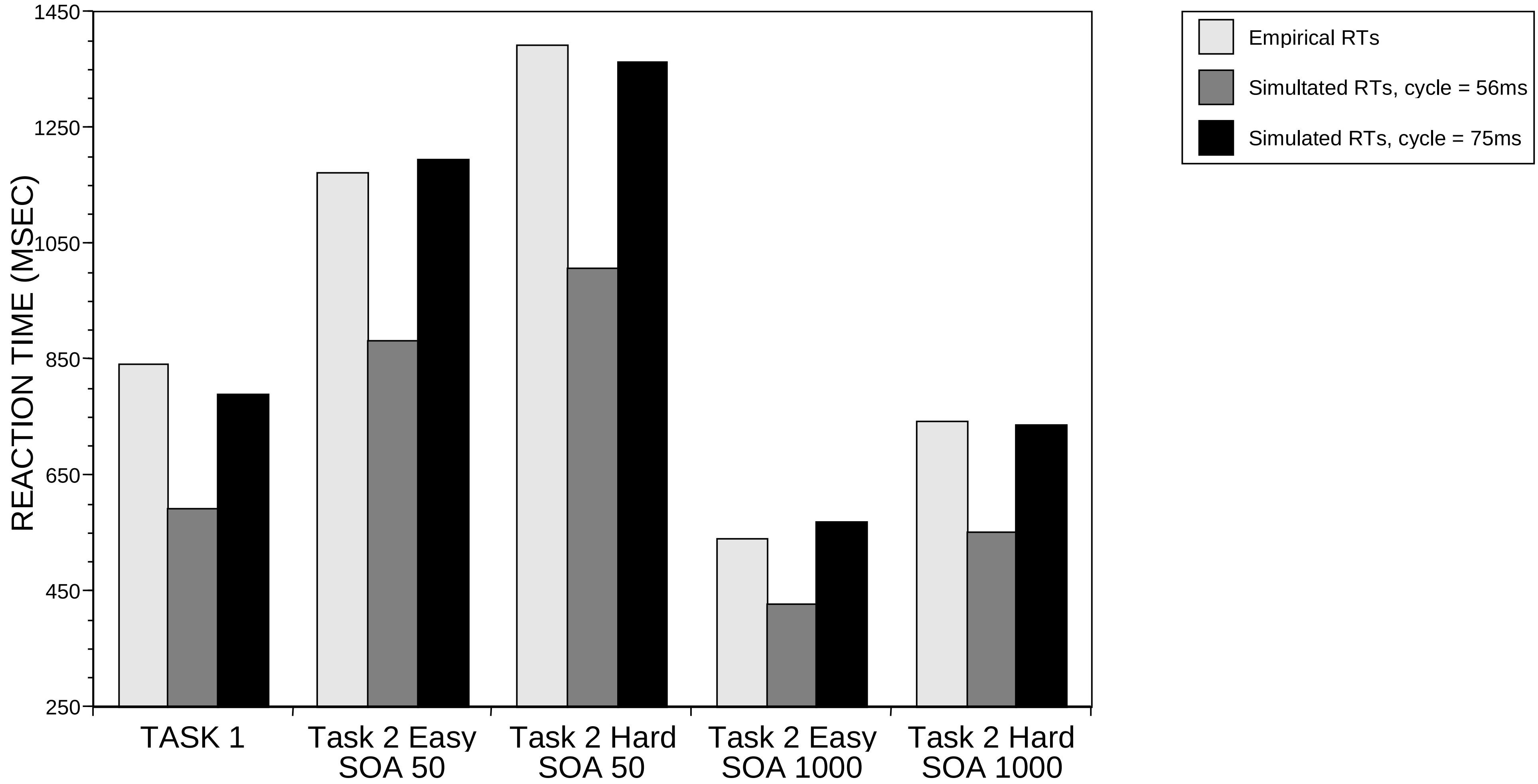
Conclusions From Experiment 2

Again, the **dual-task deficit** hypothesis was not supported. Older adults made very few out-of-order responses. Older adults in Experiment 2 were able to use a different Task 2 lockout point than the older adults in Experiment 1, indicating that they can be flexible in their use of task-coordination strategies.

As with Experiment 1, **generalized slowing** was not enough to explain the results. Figure 9 shows the results from two additional AEC models where only the cognitive processor cycle duration was varied. Again, these models do not capture all of the differences between the young and older adults PRP performance.

Unlike in Experiment 1, **strategy differences** in Experiment 2 were not an important part of the explanation of dual-task performance by older adults. This supports our claim that the reason for the inconsistent findings in the past is due to strategy differences between young and older adults.

Generalized Slowing AEC Models (Experiment 2)



Conclusions

- Source of age effects in dual-task performance is not unitary.
- We found three sources: differences in task-coordination strategies, generalized slowing, and specific slowing.
- The importance of each source for dual-task performance changes depending on task parameters.
- Older adults exhibit flexibility in their task-coordination strategies.
- Larger dual-task costs for older adults do not necessarily imply a dual-task or executive-control deficit. Cautious task-coordination strategies still require executive control.

- It is not necessary to postulate limited resources to understand the effects of aging on dual-task performance: Reaction times in the PRP procedure can be fit precisely for both young and older adults with the EPIC architecture.
- The present results provide further evidence against a diminished resource view. Task 1 in Experiment 2 was more difficult. According to diminished resources, the effects of age should be largest with Experiment 2. However, the relative size of the PRP effect for older adults was larger in Experiment 1.
- It is not necessary to postulate a central response-selection bottleneck to understand the effects of aging on dual-task performance.
- The complexity hypothesis (McDowd & Craik, 1988) states that age differences in performance increase as complexity increases. However, in the present experiment, the difference between young and older adults task-coordination strategies decreased when complexity was increased from Experiment 1 to Experiment 2.

Future Directions

Predicting task-coordination strategies. The present results show that strategies are important for understanding the effects of age on dual-task performance, but they don’t tell us when older adults will use strategies that are different from young adults. Work is currently underway examining the effects of task parameters and response modality on task-coordination strategies.

Training for daring task-coordination strategies. Meyer et al. (1995) successfully trained young adults to use daring task-coordination strategies (i.e. with a late Task 2 lockout point) in a dual-task situation where subjects typically use cautious task-coordination strategies. Work is currently underway applying the training regimen of Meyer et al. to older adults.

Details of Models

PARAMETERS

- Cognitive-processor cycle time (t_c).
- Working-memory gating time (t_g).
- Mean perceptual-identification time (t_i).
- Mean response-selection duration (t_s).
- Motor execution duration (t_m).
- Response transduction time (t_r).
- Unlocking onset latency (t_u).
- Minimum unlocking duration (t_v).
- Suspension waiting time (t_w).

REACTION TIME EQUATIONS FOR THE SRD MODELS

- Task 1 RT or Task 2 RT (SOA 1000) = $(t_i) + (t_g) + (t_s) + (t_m) + (t_r)$
- Task 2 RT (SOA 50) =

  If $(t_{i1}) + (t_{s1}) + (t_u) - (t_{i2}) - (t_{s2}) >= SOA$, Then:

  $RT = (t_{i1}) + (t_g) + (t_{s1}) + (t_u) + (t_v) + (t_w) + (t_{m2}) + (t_r) – SOA$,

  Else:

  $RT = (t_{i2}) + (t_g) + (t_{s2}) + (t_v) + (t_w) + (t_{m2}) + (t_r)$

REACTION TIME EQUATIONS FOR THE RSL MODELS

- Task 1 RT or Task 2 RT (SOA 1000) = (ti) + (tg) + (ts) + (tm) + (tr)
- Task 2 RT (SOA 50) = $(t_{i1}) + (t_g) + (t_{s1}) + (t_u) + (t_v) + (t_w) + (t_{s2}) + (t_{m2}) + (t_r)$