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Multi-Tasking and Aging: Do Older Adults Benefit from Performing a Highly Practiced Task?

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Abstract

The present study examined the effect of training on age differences in performing a highly practiced task using the psychological refractory period (PRP) paradigm (Pashler, 1984). Earlier training studies have concentrated on tasks that are not already overlearned. The present question of interest is whether task dual-task integration will be more efficient when single-task performance is approaching asymptotic levels.

Method: Task 1 was red/green signal discrimination (green = “go” and red = “wait”; analogous to pedestrian signals) and Task 2 was tone discrimination (white noise vs. a horn “honk”; analogous to traffic sound). The stimulus onset asynchrony (SOA) between Task 1 and Task 2 was varied (50 ms, 150 ms, 600 ms, and 1000 ms). All individuals participated in eight sessions spread over eight weeks (one session per week). Participants completed a dual-task pre-test (Week 1), followed by 6 weeks of single-task testing (Weeks 2-7), followed by a dual-task post-test (Week 8).

Conclusion: Although older adults showed larger overall dual-task costs (i.e., PRP effects), they were able to reduce the costs with practice as much as younger adults. However, even when training on Task 1 results in asymptotic performance, this still did not lead to an appreciable reduction in dual-task costs. Also, older adults, but not younger adults, responded more rapidly to green stimuli than to red stimuli in the Task 1 training latency data. We confirmed this green/go bias using diffusion modeling, which takes into account response time and error rates at the same time. This green/go bias is potentially dangerous at crosswalks, especially when combined with large dual-task interference, and might contribute to the high rate of crosswalk accidents in the elderly.

Multi-Tasking and Aging: Do Older Adults Benefit from Performing a Highly Practiced Task?

Juggling multiple tasks at once is very common in our daily life nowadays – for instance, watching and responding to the pedestrian signal while conversing with friends. Laboratory studies have repeatedly shown costs in time and/or accuracy when people attempt to perform multiple tasks simultaneously. Such interference has been commonly attributed to a structural processing limitation (e.g., a central bottleneck; Pashler, 1994). We suspect that many older adults would experience difficulties in performing multiple tasks simultaneously. However, because of todays' emphasis on using technologies in a learning environment, one possibility is that younger adults are capable of considerable multitasking due to extensive experience from using technologies (e.g., video games, texting, and social networking). Following the same argument, therefore, it is possible that additional practice on highly familiar, frequently encountered tasks would somehow enhance older adults' ability to juggle multiple tasks and bypass the central bottleneck limitation.

The present study examined this issue using the red/green signal discrimination task (green for "go" vs. red for "wait"; analogous to pedestrian signals) and the noise/horn honk discrimination task (analogous to traffic noise). We varied the stimulus onset asynchrony between these two tasks in the psychological refractory period (PRP) paradigm. We had two goals in mind. Our primary goal was to determine whether practicing the highly familiar task (the red/green signal discrimination) would enhance older adults' ability in multitasking. Some previous dual-task studies have shown that older adults do not benefit from practice as much as younger adults do (Gothe, Oberaurer & Kliegl, 2007; Maquestiuax, Hartley & Bertsch, 2004; Maquestiuax, Lague-Beauvais, Ruthruff, Hartley & Bherer, 2010), while others have shown they benefit equally (Allen, Ruthruff, Elicker & Lien, 2009; Bherer et al., 2005, 2006; Kramer, Larish & Strayer, 1995). These studies typically used arbitrary tasks, which did not accurately reflect the practice effect on familiarized tasks.

Our secondary goal was to examine decision making across age group on the present red/green signal task using diffusion modeling (e.g., Ratcliff, 1978; Ratcliff & Tuerlinckx, 2002; Ratcliff, Van Zandt, & McKoon, 1999; Spaniol, Madden, & Voss, 2007; Voss, Rotherman & Voss, 2004; Voss & Voss, 2007). In particular, we wished to determine if older adults show that information is accumulated toward a given response boundary (i.e., drift rate; Voss & Voss, 2007) is biased toward green/go relative to younger adults. There is evidence that older adults tend to be more liberal in response bias for certain tasks (Allen, 1990; Allen et al., 2004). It could be that older adults attempt to compensate for age-related slowing by adopting a more liberal response bias, and this could result in more accidents (pedestrian and/or driving). The advantage of diffusion modeling is that it models both latency and accuracy data simultaneously, which is important in aging research because of the increased potential for speed/accuracy tradeoffs, whereas traditional signal detection theory methods analyze just accuracy data.

The PRP Paradigm

The theoretical framework for the present study is based on the central bottleneck model proposed to account for dual-task performance in the PRP paradigm (Pashler, 1984, 1994; Ruthruff, Johnston & Van Selst, 2001). The PRP paradigm is a method in which the stimulus onset asynchrony (SOA) between the stimuli for Task 1 and Task 2 is varied. When individuals are instructed to give priority to Task 1, the typical empirical finding is that reaction time (RT) to Task 2 (RT2) increases as the SOA decreases, whereas the RT to Task 1 (RT1) is essentially unaffected. The increase in RT2 as SOA decreases is referred to as the PRP effect (Telford, 1931). According to the central bottleneck model (Pashler, 1994; Welford, 1952), the PRP effect occurs because of the inability to perform central operations for Task 2 in parallel with that of Task 1 at short SOAs (see Figure 1). The key assumption of the central bottleneck model is that central operations for Task 2 cannot begin until central operations for Task 1 are completed (Pashler, 1994). While some researchers have concluded that the central bottleneck is strategic (e.g., Meyer & Kieras, 1997), many other studies have found stronger empirical evidence in favor of a structural bottleneck (e.g., Pashler, 1994; Ruthruff, Pashler & Klaassen, 2001; Ruthruff, Johnston, & Remington, 2009; Tombu & Jolicœur, 2000).

Practice and Dual Task Performance

Ruthruff, Van Selst, Johnston, and Remington (2006) examined three possible accounts of how practice reduces dual task interference: integration, automatization, and stage-shortening. Integration might reduce dual-task interference by allowing individuals to reorganize two tasks into a single super-ordinate task, thereby allowing a reduction in resource competition. Automatization reduces dual-task interference by allowing the tasks to become so automatic that they require no central resources. Stage-shortening, on the other hand, reduces dual-task interference by speeding up completion of Task-1 central stages, so that it releases attentional resources sooner.

Ruthruff et al. (2006) found that dual-task training for younger adults did not reduce PRP effects any more than did single task training (Experiments 1 and 2), suggesting that dual-task interference was not reduced via task integration. They failed to find evidence of automatization in Experiment 1, but did find evidence in Experiment 2 when the task order was reversed (visual-manual followed by auditory-vocal). Specifically, 4 out of 18 participants bypassed the bottleneck in Experiment 2 (compared to 0 out of 18 in Experiment 1). Maquestiaux et al.

(2008) found an even larger percentage of “bottleneck bypassers” (17 out of 20) among younger adults who received training on Task 2 only, with slightly easier tasks (also see Maquestiaux et al., 2010). Thus, there may be evidence that automatization of Task 2 can occur (although see below for concerns with this assumption). Finally, Ruthruff et al. (2006) also found evidence in Experiment 1 that training shortened the duration of Task 1 stages, and that this correspondingly reduced the PRP effect. To the best of our knowledge, no study has found evidence that the PRP effect was eliminated (i.e., automatization) for older adults using behavioral indices. Our emphasis in the present study was to use a proven technique for Task 1 stage-shortening: Task 1 training (Ruthruff et al., 2006, Experiment 1).

Age Differences in Training Effects in Dual-Task Performance

The literature on age differences in dual-task training effects is mixed. Maquestiaux et al. (2004), as well as Gothe et al. (2008) found evidence that older adults did not show as much dual-task training benefit as did younger adults (see also Maquestiaux et al., 2010). On the other hand, Kramer, Larish, and Strayer (1995), Kramer, Larish, Weber, and Bardell (1999), Bherer et al. (2005, 2006), and Allen et al. (2009) all found that older adults benefitted as much from dual-task training as did younger adults. We will emphasize the Maquestiaux et al. (2004) and Allen et al. (2009) studies because both used the PRP paradigm similar to that employed in the present study.

In Maquestiaux et al.’s (2004) study, Task 1 was a 2-choice tone discrimination and Task 2 was an alphanumeric discrimination (the letters A, B, C, and D, as well as the digits 1, 2, 3, and 4 were mapped onto four different response keys). Five SOAs of 50 ms to 1000 ms were randomly intermixed within blocks. Six younger and six older adults completed four days of training (320 trials on Day 1 and 640 trials each on Days 2-4). For both age groups, the PRP effect was attenuated with practice, but the attenuation was greater for younger adults than older adults. Allen et al.’s (2009) study also involved a 2-choice tone discrimination Task 1. However, Task 2 was a letter-matching task (same/different discrimination on two simultaneously presented letters) with four SOAs from 50 ms to 800 ms. With a relatively large sample size (18 younger and 18 older), Allen et al. found equivalent PRP attenuation across age groups after four days of training (320 trials per day). Allen et al. speculated that the underperformance of older adults in Maquestiaux et al. resulted from a small sample size and considerably lower levels of education for older adults than for younger adults.

An alternative explanation for the empirical discrepancy is that Maquestiaux et al.'s (2004) participants were closer to asymptotic performance than Allen et al.'s (2009) participants. Indeed, Gothe et al. (2008) measured asymptotic performance and found that older adults did not benefit as much from dual-task training as younger adults did. The present study, with six weeks of training, was designed to ensure that both younger and older adults would be at asymptotic performance on Task 1. Also, note that in training studies in which evidence is observed for by-passing of the central bottleneck (e.g., Maquestiaux et al., 2010), Task 1 typically has more than two response alternatives (4 response alternatives in the Maquestiaux study—this increases response selection load in the central bottleneck relative to two response alternatives, and the likelihood of observing response reversals because it makes Task 2 easier with practice, but slows Task 1). Also, Maquestiaux et al. did not include a baseline measure of dual-task performance before six weeks of Task 2 training, so this study was not technically a study of single-task training on the effect of dual-task performance. Finally, Maquestiaux et al. showed PRP effects in all of their participants’ data, but their response-reversal results were confounded by significant response grouping effects for RT1. The present study was designed to overcome these potential concerns by using baseline and after-training measures of dual-task performance, using a highly familiar Task 1 (red/green light signal discrimination), and by training participants on Task 1 (while Task 1 training should reduce the central bottleneck, it is unclear how Task 2 training would do so, see Pashler, 1994; Ruthruff et al., 2006).

Whereas the studies discussed above have found age-related decrements in dual-task ability with novel tasks, other studies have found the opposite pattern with familiar tasks. In studies of lexical access, for example, Allen et al. (2002) and Lien et al. (2006) observed more absorption into slack for Task 2 word frequency effects for older adults than for younger adults. That is, the Task-2 word frequency effect was smaller at the shortest SOA than at the longest SOA (even with a two-response Task 1), especially for older adults, suggesting that some Task-2 lexical processes proceeded in parallel with Task 1 response selection. These results suggest that, for some highly over-learned processing stages (such as lexical access), older adults are capable of more efficient parallel processing than younger adults. At the same time, older adults did not eliminate dual-task interference; indeed, older adults still showed larger PRP effects than did younger adults. The most likely explanation is that older adults still struggled with the central processing stages following lexical access, such as the selection of an arbitrary keypress response to the stimulus category (word vs. non-word). So the improved parallel processing in older adults was limited to the processing stages for which they had greater amounts of cumulative practice (i.e., lexical processing). In the present study, we wished to examine whether evidence of stage-specific, parallel processing could be obtained outside of the lexical domain.

The present Task 1 (a red/green signal task: green for go or red for wait) and Task 2 (2-choice tone discrimination) involved familiar stimuli, similar to those encountered by pedestrians. In previous research we found that even when older adults show larger slack effects than younger adults for the "special" lexical domain (i.e., more efficient parallel processing at pre-bottleneck stages; Allen et al., 2002; Lien et al., 2006), they still do not bypass the central bottleneck. In fact, they still produce larger dual-tasks costs than younger adults, presumably due to longer response selection stages. Nevertheless, it remains possible that prior familiarity with the stimuli and tasks, combined with training, might help to reduce age differences in dual-task performance.

The Present Study

Our primary goal in the present study was to determine whether training on Task 1 (Ruthruff et al., 2006) would reduce dual-task interference on a familiar green/red (go/wait) pedestrian signal task for older adults at least as much as for younger adults. That is, could we reduce the PRP effect on Task 2 tone discrimination from Week 1 (baseline) to Week 8 (after six weeks of Task 1 red/green discrimination training) by shortening Task 1 for older adults as much as for younger adults? We limited training to just Task 1 in an attempt to lessen dual-task interference, because according to the central bottleneck model, it is Task-1 training that reduces dual-task interference.

Our present Task 1 consists of a green/red signal task (green light = "go," red light = "wait"). Task 2, consisting of tone discrimination (white noise vs. a horn honk), was designed so that the stimulus would either be neutral ("white noise") or inhibitory ("honk") toward Task 1 ("go") trials. We used SOAs of 50 ms, 150 ms, 600 ms, and 1000 ms, intermixed within blocks. We designed an eight-week framework in which Weeks 1 and 8 involved dual-task performance, but Weeks 2-7 involved Task 1 training. Task 1 (green/red signal discrimination: green/go or red/wait) should have already been a highly familiar task, and six weeks of training should result in asymptotic performance. The effects of SOA on Task 2 (i.e., the PRP effect) should decrease with this Task 1 training because Task 1 central stage shortening can reduce the size of the PRP bottleneck.

In the present study, 12 younger adults and 12 older adults participated in two days of dual-task testing separated by six weeks of single-task training on Task 1 (Weeks 2-7). It is important to note that the present Task 1 (i.e., green for go vs. red for wait) was intended to be highly familiar, even before practice. For many new tasks (and most, if not all tasks used in previous PRP studies that have examined age differences) there is a large initial improvement in task performance associated with learning the task. However, this sort of task learning is not likely to translate to decreased accidents in more real-world settings because real-world performance involves highly familiar tasks (e.g., green light for go vs. red light for wait discrimination) and this type of performance is likely closer to asymptotic performance.

Our key dependent variable is RT (because error rates are hypothesized to be low given the overlearned nature of Task 1). We used diffusion modeling (Ratcliff, 1978; Voss & Voss, 2007) to examine “overall” decision bias effects (diffusion modeling allows us to consider both RT and accuracy effects simultaneously on decision bias across age groups). Furthermore, diffusion modeling has not been used, heretofore, in examining task practice effects. By examining age differences in drift rate (in the present application, the rate that information is accumulated toward a red or green response), we can assess whether older adults are relatively more biased to respond “go” (green) than “wait” (red)—a situation that would likely make them more prone to accidents compared to younger adults.

Method

In the present training phase (practice on Task 1 only for six sessions), we used random coefficients ANOVAs for mixed models to analyze the RT data (Littell, Miliken, Stroup, & Wolfinger, 1996). That is, both intercepts and slopes of individuals' training/practice effects (the effect of Week) were random effects. Littell et al. provided Monte Carlo simulation evidence that such models offer greater precision than do fixed effects models. For the accuracy data, we used mixed model, logistic regression methods (SAS Glimmix macro) because mixed models use trial-level data, and accuracy data are categorical (i.e., 1 = correct, 0 = incorrect). Mixed models were used for the RT training data so that individual differences could be considered as well as the effects of independent variables. This consisted of a 2 (age: younger vs. older adults) x 2 (signal color: red vs. green light) x 6 (week: 1-6) design. Age group was a between-subjects variable, but the remaining independent variables were measured within subjects.

The pre- and post-training data for single- and dual-task conditions were analyzed using a traditional fixed effects ANOVA approach (because there were just two time points). This resulted in a 2 (age group: young vs. older) x 2 (Week: Week 1 vs. Week 8) x 4 (SOA: 50 ms, 150 ms, 600 ms, and 1000 ms) x 2 (Task 1 signal color: red or green) x 2 (Task 2 tone: horn honk or white noise) design for both RT and accuracy data. As before, age group was a between-subjects independent variable, but all other independent variables were within-subjects variables.

Participants

There were 12 younger-adult participants (mean age = 21.67 years, range: 18-24 years) and 12 older-adult participants (mean age = 71.75 years, range: 64-80 years) in the study. Younger adults were University of Akron students, and older adults were community-dwelling individuals from the Akron, Ohio area. All participants were paid $20 per week for eight weeks (a total of $160).

All participants were tested on the Wechsler Adult Intelligence Scale-Revised (WAIS-R, Wechsler, 1981) Digit Symbol Substitution Task subscale and the Mill Hill Vocabulary test (Raven, Raven, & Court, 1997). For the WAIS-R Digit Symbol test, younger adults (mean = 73) showed significantly higher scores than older adults (mean = 47), $F(1, 22) = 64.93$, $p < .001$. Alternatively, older adults (mean = 22.9) showed significantly higher vocabulary scores than younger adults (mean = 18.7), $F(1, 22) = 6.18$, $p < .05$. There were no group differences in years of education (younger = 15.75 years, older = 15.67 years) ($p = .88$).

Apparatus, Stimuli, and Procedure

Participants were tested individually using a microcomputer and a 19-inch monitor. Stimuli were presented and data were collected using the E-prime software package (Schneider, Eschman, & Zuccolatto, 2002).

All participants (12 younger and 12 older adults) participated once a week in the present study for eight consecutive weeks. For Weeks 1 and 8, participants completed dual-task blocks (Task 1 and Task 2) followed by single-task blocks (Task 1 only). There were 512 trials in both Week 1 and Week 8). Weeks 2-7 involved Task 1 training (512 single-task trials per week). We were particularly interested in determining the effect of Task 1 training on dual-task performance because, according to the central bottleneck model, stage shortening on Task 1 should reduce dual-task interference on Task 2 (whereas, perhaps counterintuitively, Task 2 training could actually increase it).

Task 1 was a green/red discrimination task (green/go vs. red/wait). A single instance of round, small (17 mm in width) or large (27 mm in width) red or green signal lights were used in the present study as Task 1 stimuli. The circular signal stimulus was presented in the center of the screen. Size was manipulated to vary Task 1 difficulty. Task 2 was a tone discrimination task (horn honk vs. white noise). Both auditory samples used for Task 2 were 100 ms in duration. For dual-task blocks, the SOA between Task 1 and Task 2 was varied (50 ms, 150 ms, 600 ms, and 1000 ms). For both single-task and dual-task conditions, there was also a variable "week" (weeks 2-7 involved single task training and weeks 1 and 8 involved the dual-task test). For both single-task and dual-task blocks, there were equal numbers of trials in each condition.

For the single-task blocks, each trial began with a spacebar press followed by a 500 ms presentation of a fixation cross. One hundred ms after the fixation cross was offset from the screen, a green or red light was presented and remained on the screen until the participant responded. Participants responded using the "z" and "x" keys located in the lower right corner of the keyboard. All participants were told to think of themselves being at a crosswalk—with the green stimulus representing the "go" condition, and the red stimulus representing the "wait" condition. For half of the participants, the "z" key was used to respond "green" and the "x" key used to respond "red." For the other half of the participants, the key assignments were reversed. ("z" and "x" keys were used as responses, and the stimulus-response assignments were counterbalanced across participants). For weeks 2-7, each participant received 512 trials per week. Both response time and accuracy were recorded.

For the dual-task blocks (weeks 1 and 8), trials were initiated by the participant pressing the spacebar. After 500 ms, a fixation cross appeared in the middle of the screen for 100 ms, followed by the presentation of Task 1. Participants responded to Task 1 using the "z" and "x" keys in the lower left-hand corner of the keyboard (using their left hand). For Task 2, the "." and "/" keys were used to respond to "horn honk" and "white noise" stimuli with their right hand (and these tones were presented to participants using headphones). As for the single-task conditions, key assignments were counterbalanced across participants. go/wait discrimination:

green for "walk" and red for "wait") for 100 ms. The Task 2 stimulus (a 100 ms sound sample of either a horn honk or white noise) was then presented after one of four randomly selected SOAs (with the requirement that each SOA occurred equally often in each block).

Results

We first present results for single-task performance during the training sessions (Weeks 2-7), followed by results for dual-task performance (Weeks 1 and 8).

Single-Task Performance during Training

Single-task training data were analyzed as a function of age (younger vs. older), Task 1 color (red vs. green), and week (2-7). Table 1 shows the mean RT and percentage of error (PEs) for each condition. Table 2 summarizes the statistical results for RT and PE.

RT data. Figure 2 shows overall mean RT across weeks for younger and older adults. For the six weeks of Task 1 training (Weeks 2-7 of the overall study), there were main effects for age, color, and week. Younger adults (467 ms) responded more rapidly than older adults (594 ms). Individuals responded faster to green stimuli (526 ms) than to red stimuli (535 ms). In addition, RT for the single Task 1 decreased with practice (Week: 1 = 546, 2 = 521, 3 = 535, 4 = 527, 5 = 523, and 6 = 530 ms). There were also significant interactions of Age x Color (young: green = 469 ms, red = 466 ms; older: green = 583 ms, red = 605 ms), and Age x Week (Young: Week 2 = 490, Week 3 = 464, Week 4 = 462, Week 5 = 463, Week 6 = 462, Week 7 = 462; Old: Week 2 = 602, Week 3 = 578, Week 4 = 609, Week 5 = 592, Week 6 = 584, Week 7 = 598 ms). Additionally, the Age x Color x Week was significant (whereas younger adults showed no red/green effect, the advantage of green over red for older adults was 13, 17, 28, 36, 19, and 23 ms for Weeks 2-7, respectively). We examined simple effects of Week separately by age, and both groups showed effects for Week (p's < .0001); although younger adults showed a significant quadratic trend (a drop from Week 2 to Week 3, but stable thereafter—one inflection point), older adults showed a significant quartic trend (three inflection points). It appeared that younger adults showed more consistent improvement after Week 2 than did older adults.

Accuracy data. There was a main effect for age group (mean PE: younger adults = 2.59%, older adults = 0.80%). There was also an Age x Week interaction (Younger: PEs were 2.550%, 2.50%, 2.60%, 3.80%, 2.80%, and 3.30% for Weeks 2-7, respectively; Older: 1.90%, 1.40%, 3.00%, .2.20%, 1.60%, and 2.20% for Weeks 2-7, respectively).

Diffusion Modeling. In keeping with Schmiedek, Lovden, and Lindenberger (2009), we used diffusion modeling to describe the present multi-session data. Diffusion modeling allows us to analyze the drift rate (i.e., the rate at which information is accumulated toward a response boundary) for green versus red responses (e.g., Ratcliff, 1978; Ratcliff & Tuerlinckx, 2002; Ratcliff, Van Zandt, & McKoon, 1999; Spaniol, Madden, & Voss, 2007; Voss, Rotherman & Voss, 2004; Voss & Voss, 2007). In particular, if older adults have a green/go bias, then the drift rate should be greater for green than for red responses. Traditionally, researchers have used signal detection methods (based upon accuracy) to examine response bias effects, but the present bias effects were reflected in RT rather than in accuracy. The key virtue of diffusion modeling is that it allows one to simultaneously model response biases in RT and accuracy data. We used the Fast-dm (Voss & Voss, 2007) procedure (which uses the Kolmogorov-Smirnov test, T, to optimize model fitting) to fit the present diffusion model.

The diffusion model assumes that information is accumulated continuously during a decision process, and that this decision process terminates as soon as the accumulation process reaches an upper or lower threshold. The complete model comprises seven parameters, which are (1) mean speed (and direction) of information accumulation (drift rate, v), mapping (e.g., perceptual processes), (2) threshold separation (a), reflecting whether the decision style is liberal vs. conservative, (3) starting point of the process (z), representing a decisional bias whenever it deviates from $a/2$, (4) the duration of non-decisional processes (t_0; e.g., response execution), and three so-called inter-trial variability parameters, representing trial-to-trial variability in starting point, drift rate and non-decisional components (s_v, s_z, and s_{t0}, respectively).

In our model, the upper and lower boundaries represented "green" and "red" responses, respectively. Consequently, positive drift rates for green stimuli and negative drift rates for red stimuli are expected. A decisional bias in favor of a "green" response (i.e., green responses are based on less information than red responses) would lead to a starting point closer to the upper threshold ($z/a > 0.5$). We estimated separate models for each participant and session, where drift rates were allowed to differ between target colors. That is, each model had 10 parameters and was based on 512 trials.

We estimated separate models for each participant and session, where drift rates were allowed to differ between target colors and target sizes using fast-dm with precision of the calculation set to 4.0 (high precision). Each model had 10 parameters (a, z, $\mathrm{v}_{\mathrm{green/large}}$, $\mathrm{v}_{\mathrm{green/small}}$, $\mathrm{v}_{\mathrm{red/large}}$, $\mathrm{v}_{\mathrm{red/small}}$, t_0, s_z, s_v, s_{t0}) and was based on 512 trials. For analyses, drift values were collapsed across target sizes (as was done in the dual-task analyses in order to reduce the number of independent variables).

The data for 11 younger adults and 10 older adults showed good fit indices ($p>.05$); we eliminated the data for three participants that had multiple fit violations. This resulted in 21 x 6 submodels for a total of 126. We analyzed six parameters using a fixed effects, mixed 2 (age group: a between-subjects variable) x 6 (week: a within-subjects variable) design. However, for drift rate, we had a 2 (age group) x 2 (color: green vs. red) x 6 (week) mixed design that was analyzed using a random intercepts, mixed model design (so slopes and intercepts could vary across independent variables).

For the threshold (*a*) and starting point (z/a) parameters, age was not significant, F(1, 19) = 3.84, p = .06, F(1, 19) = 2.61, p = .12, respectively (although older adults showed a trend toward being more conservative in their threshold: older = 1.65, younger = 1.31). The starting point parameter (z/a) had a mean value of .484, which did not differ significantly from .5 (p > .05), indicating no overall bias. For *t0*, older adults did show slower nondecisional processing speed (376 ms) than younger adults (294 ms), F(1, 19) = 15.55, p = .0009. For the variability indices, none reached statistical significance, s_z (starting point variability): F(1, 19) = 3.00, p = 10, s_v (drift rate variability): F(1, 19) = .42, p =.52, s_t (nondecisional variability): F(1, 19) = 3.35, p = .08 (older = .133, younger = .069).

The key diffusion analysis, though, was for drift rate (i.e., the absolute value of the positive drift for green and the negative drift of red reflects the rate at which evidence is accumulated toward a response boundary). A “go bias” would be supported if the net green minus red drift rate was positive, and a “wait bias” would be supported if the net green minus red drift was negative. As noted by Spaniol et al. (2008), the drift rate parameter *v* reflects the systematic influence that drives the decision process from starting point *z* toward one of two response boundaries (in this case, either green or red). The mixed model analysis for these data did not show a main effect for age group, F(1, 870) = 1.89, p = .17, although there was a significant Age x Color interaction, F(1, 870) = 7.10, p < .008. This interaction occurred because older adults showed a larger bias toward green (go) stimuli (4.26) than younger adults (3.82), although there was no appreciable difference in red bias (younger = -3.82, older = -3.94).

Dual Task Performance as a Function of Training

Fixed effects analyses of the dual-task data are reported because the critical time variable has just two levels (Week 1 vs. Week 8—the six intervening weeks consisted of single-task training). Trials with latencies less than 200 ms or greater than 3000 ms on either task were excluded (this resulted in less than 2% of trials being excluded for younger adults and less than 4% for older adults). The analysis was a 2 (age group) × 2 (Task1 color: green vs. red) × 2 (Task 2 tone) × 4 (SOA) × 2 (week 1 vs. week 8) mixed design. Age group was a between-subjects variable, but the remaining variables were within-subjects variables. Tables 3-6 summarize the statistical results for RT and PE for Task 1 and Task 2. Figure 3 shows the mean RT1 and RT2 as a function of SOA and week (1 vs. 8) for younger and older adults.

Task 1 RT. There were main effects for age (younger = 828 ms, older = 1074 ms), SOA (RTs = 859 ms, 878 ms, 976 ms, and 1092 ms at the 50-, 150-, 600-, and 1000-ms SOAs, respectively, suggesting response grouping), and Task-2 tone (white noise = 943 ms, honk = 959 ms). Also, there was a main effect of week (Week 1 = 1006 ms, Week 8 = 896 ms) indicating that practice reduced dual-task Task 1 latencies.

Task 1 errors. There were main effects for SOA (PEs were 1.7%, 1.8%, 1.2%, and 1.4% at the 50-, 150-, 600-, and 1000-ms SOAs, respectively), and color (red = 0.8%, green = 2.1%),. There was also a Color x Tone Type x SOA interaction, indicating there was an increase in errors for the 150 ms SOA, green, horn condition that did not occur for the green, noise condition, or either red conditions (green horn PE: 50 ms = 2.6%, 150 ms = 3.2%, 600 ms = 1.2%, 1000 ms = 1.9%; green noise PE: 50 ms = 2.4%, 150 ms = 2.1%, 600 ms = 2.3%, 1000 ms = 2.0%; red, horn PE: 50 ms = 1.0%, 150 ms = .9%, 600 ms = 1.2%, 1000 ms = 0.9%; red noise PE: 50 ms = 0.8%, 150 ms = 0.9%, 600 ms = 0.3%, 1000 ms = 0.7%).

Task-2 RT. There were main effects for age (younger = 784 ms, older = 1120 ms), SOA

(1162, 1092, 833, and 720 ms at the 50-, 150-, 600-, and 1000-ms SOAs, respectively), tone (white noise = 963 ms, horn = 943 ms), and week (Week 1 = 1000 ms, Week 8 = 892 ms). The interaction of SOA × Age was significant; the PRP effect was 386 ms for younger adults but was 498 ms for older adults (see Figure 3). The overall PRP effect decreased from Week 1 (474 ms) to Week 8 (410 ms), reflected in the Week × SOA interaction (Week 1: SOA = 50 = 1185 ms, SOA = 150 = 1167 ms, SOA = 600 = 885 ms, SOA = 1000 = 761 ms; Week 8: SOA = 50 = 1090 ms, SOA = 150 = 1018 ms, SOA = 600 = 780 ms, SOA = 1000 = 680 ms). This Week × SOA interaction was qualified by a Week × SOA × Color interaction; the drop in the PRP effect across weeks was 47 ms for green stimuli and 73 ms for red stimuli. There was also Week × Tone × Age interaction; RT2 was generally faster to the horn than the white noise, but this effect was attenuated for older adults after practice (Young: Week 1: White Noise = 847 ms, Horn = 823 ms, Week 8: White Noise = 749 ms, Horn = 714 ms; Older: Week 1: White Noise = 1209 ms, Horn = 1168 ms, Week 8: White Noise = 1047 ms, Horn = 1058 ms).

Task 2 errors. There was a main effect for SOA (50 ms = 1.8%, 150 ms = 1.5%, 600 ms = 1.2%, 1000 ms = 1.6%). Also, there was a Color x SOA interaction that occurred because error rates tended to increase across SOA for red stimuli, but tended to remain fairly consistent across SOA for green stimuli (mean PE: green: 50 ms = 1.8%, 150 ms = 2.0%, 600 ms = 0.5%, 1000 ms = 1.7%; red: 50 ms = 2.1%, 150 ms = 1.4%, 600 ms = 2.2%, 1000 ms = 2.8%). Finally, there was a Week x Color x Tone Type interaction, $F(1, 22) = 4.99$, $p < .05$ (Week 1: green/horn = 1.8%, green/noise = 2.0%, red/horn = .8%, red/noise = 1.7%; Week 8: green/horn = 2.1%, green/noise = 1.4%, red/horn = 1.8%, red/noise = 2.8%). When we ran simple effects analyses by Week, the Color x Tone Type simple effect was not significant for Week 1, $F(1, 22) = 0.00$, $p = .9728$. However, the Color x Tone Type simple effect for Week 8 was significant, $F(1, 22) =$

5.59, p < .05. These results suggested that errors were relatively constant across all four conditions for Week 1, but that errors were higher for the horn honk with green Task 1stimuli, and for the white noise with the red Task 1 stimuli at Week 8. That is, after practice (but not before; i.e., in Week 8, but not in Week 1) both age groups inhibited the Task 2 “white noise” response when Task 1 involved a red stimulus, and both age groups inhibited the Task 2 “horn honk” response when the Task 1 involved a green stimulus.

Cost of Concurrence. We analyzed the cost of concurrence by comparing Task 1 performance (“green/go” vs. “red/wait” responses) for single task and dual-task for Week 1 and Week 8 across age group. This resulted in a 2 (age group) × 2 (Week of Testing: Week 1 vs. Week 8) × 2 (Task Type: Single Task vs. Dual Task) mixed design (age group was between subjects and the other two variables were measured within subjects). There were significant main effects of age group, F(1, 22) = 10.23, p < .01 (mean RT: younger adults = 694 ms, older adults = 868 ms), and task type, F(1, 22) = 113.85, p < .001 (single task = 555 ms, dual task = 952 ms). Thus, there was a 397 ms cost of concurrence on Task 1. That is, it took approximately 397 ms longer to perform Task 1 in dual-task conditions, than just Task 1 in isolation. There was an effect for week, F(1, 22) = 4.52, p < .05 (week 1 = 781 ms, week 8 = 726 ms), and the Task Type x Week interaction was also significant, F(1, 22) = 6.72, p < .05 (week 1: single task = 555 ms, dual-task = 1006 ms; week 8: single task = 555 ms, dual-task = 895 ms). However, the Age Group × Task Type × Week interaction, F(1, 22) = 0.07, p = .79, was not significant. Younger adults showed a cost of concurrence of 388 ms at Week 1 and 291 ms at Week 8, whereas older adults showed costs of concurrence of 514 ms and 394 ms, respectively.

Discussion

In the present dual-task study, we examined the stage-shortening aspects of initiating a red/green signal decision for Task 1, an improvised version of a highly familiar pedestrian signal task, after training relative to baseline before training. We believe the present study is important for a more thorough understanding of the effect of training on dual-task processing because previous training research claiming to find evidence of automaticity (Maquestiaux et al., 2010) is controversial for several reasons. First, Maquestiaux et al. observed a significant PRP effect (indicating the presence of a central bottleneck for response selection). Also, their Task 1 included four response alternatives (instead of the present two) resulting in more slack time to complete at least some stages of Task 2 before Task 1 response selection was complete, thereby increasing the odds of observing response reversals. Additionally, their observation of response reversals in some younger and older adults was confounded by their observation of significant main effects for SOA for both younger and older adults (suggesting that response grouping occurred). Finally, this earlier study did not measure baseline dual task performance (just after training), thus, we do not know how training affected dual task performance. While Allen et al. (2009) did examine dual-task performance across four sessions, their tasks were not familiar at baseline, and all sessions included both tasks (so we could not examine Task 1 training effects on dual-task performance).

The present design with a highly familiar Task 1 (red/green color discrimination with round stimuli that resembled traffic lights) allowed us to determine whether six weeks of intensive practice would allow participants to attenuate the central bottleneck (in this case, to shorten Task 1 via training, so that Task 2 central operations can proceed immediately after completing Task 1 central operations). For dual-task performance, we were particularly interested in whether older adults exhibit more dual-task interference than younger adults (as measured by the magnitude of the PRP effect), and whether both groups would benefit from 3000 trials of Task 1 practice (inserted between the dual-task tests on Weeks 1 and 8). To examine potential response bias differences across age group in greater detail for the single-task training trials, we included diffusion modeling of the drift rate (Ratcliff, 1978; Voss et al., 2004), which simultaneously analyzes both RT and accuracy data, to more precisely determine whether there were any age differences in decision bias with regard to “go” versus “wait.” This potential “green bias” for older adults was of particular interest because past research has shown that older adults have more liberal response biases than younger adults (e.g., Allen, 1990, Allen et al., 2004). Because participants were told that the green stimulus was the “go” stimulus and the red stimulus was the “stop” stimulus, we hypothesized that older adults would move more rapidly toward the green decision boundary than the red in an attempt to compensate for slower walking speed (participants were told to imagine that they were at a crosswalk and that the red/green stimulus told them whether to go or wait).

Dual Task Results

For the dual-task data (Weeks 1 and 8), we observed a substantial PRP effect on Task 2 RT and this effect was significantly more pronounced for older adults (502 ms) than younger adults (386 ms). This difference in PRP effects probably underestimates the actual difference in interference; the reason is that the long SOA is probably not free of interference for older adults, because their mean RT1 is so long. This sort of age effect is typically observed in PRP research in aging (e.g., Allen et al., 2009; Lien et al., 2006; Maquestiaux et al., 2004, 2010; although see Allen, Smith, Vires-Collins & Sperry, 1998). However, one might hope that dual-task training would help reduce dual-task interference in older adults, perhaps even closing the gap on younger adults. This did not happen. While older adults did reduce their PRP effect slightly with practice (by 78 ms), this reduction was modest and not appreciably greater than the reduction for younger adults (51 ms) (the Age x SOA x Week interaction was not significant, p = .8326). This is notable since older adults, having a higher initial PRP effect, had much more room to reduce their PRP effect with training. We had reasoned that use of a familiar task context (green = go, red = wait) might benefit older adults, but this was not the case. The final PRP effect in older adults (459 ms) after extensive training was still 48 ms greater than that of younger adults before training (411).

Training Results

For the training data, we observed a ”go” bias for older adults’ response latencies (older adults showed faster responses to green stimuli than to red, but younger adults showed no effect). While there is no evidence that this green bias for older adults in the training sessions transferred to dual-task performance, there was a Color x Tone Type x Week interaction for the dual-task data. This dual-task 3-way interaction was not the result of practice transfer, though. In Week 8 (after practice), but not in Week 1 (before practice), both age groups inhibited the Task 2 “horn honk” response when Task 1 involved a green stimulus, and inhibited the Task 2 “white noise” response when Task 1 involved a red stimulus. Thus, it appears that training was related to both younger and older adults becoming overly biased by the Task 1 condition in their responding to Task 2. This suggests that training on one task in isolation may have unintended consequences. That is, the goal of Task 1 training was to improve Task 1 performance—not to bias individuals to be biased toward Task 2 responses.

Diffusion Modeling

Diffusion modeling allows one to isolate sensitivity changes from bias changes using RT and PE data at the same time (thus dealing effectively with speed-accuracy tradeoffs). This approach is particularly useful for assessing age effects, since older adults are sometimes more accurate than younger adults. It is also useful for more precise tests of differential processing of green ("go") vs. red ("wait") stimuli. We found an age difference in drift rate, replicating the results of Spaniol et al. (2008; episodic but not semantic memory) and Thapar, Ratcliff, and McKoon (2003; letter matching). However, not all studies have reported such differences (see, e.g., Ratcliff, Thapar, Gomez, & McKoon, 2004, studying lexical decisions and Ratcliff, Thapar, & McKoon, 2004, studying recognition memory). The presently observed age difference in drift rate suggests that age differences in RT distributions in the present study were associated with an age-related decline in the quality of the information recovered during the decision process. Applied to the present red/green signal discrimination task, this means that older adults were biased to respond “go” (i.e., they reached the green response boundary faster than the red response boundary) relative to younger adults.

These results are particularly important because they show that the Age × Color interaction for single task training (over six weeks) held even when accuracy data were considered. This suggests that older adults are more likely to make a “go” decision than younger adults – a situation that could be potentially dangerous if these results were translated to a stoplight or crosswalk situation. Thus, the present single-task results are consistent with past research that suggests that older adults tend to have a more liberal response bias on single-task performance compared to younger adults (e.g., Allen, 1990; Allen et al., 2004). However, these single-task training results are inconsistent with research on aging and crosswalk dual-task performance. For example, Neider, Gaspar, McCarley, Crowell, Kaczmarski, and Kramer (2011) found that older adults tended to be more cautious in crosswalk planning, although the present diffusion modeling examines the net effect of speed and accuracy. Also, as noted earlier, we observed that participants in the present dual-task Week 8 condition showed no evidence of a green bias. Instead, they showed evidence (i.e., the Task 1 Color x Task 2 Tone Type x Week interaction for Task 2 errors) that Task 1 condition "primed" individuals to respond to the congruous Task 2 condition ("white noise" for green Task 1, and "horn honk" for red Task 1). Thus, it appears that the Task 1 training had an unintended consequence of framing congruent Task 2 expectancies—a strategy that could be dangerous in real-world performance (e.g., one cannot assume that no cars will run a red light even if a pedestrian has a walk signal). It should be noted, though, that a major difference between the Neider et al. study and the present study is that the Neider et al. study simulated a real-world crosswalk situation (walking and headphone listening), whereas the present study examined the early attentional aspects of perceiving go/wait signals in the presence of additional information (Task 2: a horn honk or white noise). In the Neider et al. study, older adults were slower to begin their movement across the crosswalk, whereas in the present study, older adults responded relatively more rapidly to green than to red stimuli in the single-task training condition, but showed no go/wait bias in the dual-task sessions—indeed, both younger and older adults were biased by the Task 1 stimulus. Thus, the present dual-task result was more perceptual in nature, whereas the Neider et al. seemingly inconsistent results had an actual motoric, walking component that was not present in the present study. One final difference between the two studies is that the present diffusion modeling examines the net effect of speed and accuracy, whereas these were separate measures in the Neider et al. study. Consequently, future research needs to be conducted in order to more carefully examine the effect of processing stage (response selection vs. response execution related to walking initiation) on response bias. It does appear that Task 1 training may have unintended consequences on dual-task performance, though, and this is a potentially important observation from the present investigation.

Why so Small of Training Effects on Single and Dual Tasks?

The present study observed surprisingly small training effects for Task 1, and for dual-task processing (i.e., the reduction of the PRP effect from baseline relative to after training). We suspect that this occurred because our Task 1 was already highly familiar. Indeed, Strobach, Liepelt, Pashler, Frensch, and Schubert (in press) observed a similar finding for a visual Task 1 using a PRP task transfer methodology. They failed to observe transfer facilitation effects for highly familiar visual stimuli and suggested that baseline differences in task expertise might be responsible for this result. The results from Strobach et al. and the present study, then, suggest that highly familiar tasks may not show much performance improvement with additional training.

Conclusions

The present study provides evidence that while training can improve dual-task performance somewhat on a highly practiced task (both younger and older adults show a significant reduction in the duration of the central bottleneck in a PRP task), this attenuation is surprisingly small (72 ms for older adults and 51 ms for younger adults). That is, while older adults benefitted as much from dual-task training as did younger adults (Allen et al., 2009; Bherer et al., 2005, 2006; Kramer et al., 1995), neither group improved by a very large percentage (e.g., compared to Maquestiaux et al., 2010, although this was not a highly familiar task at baseline as in the present study). Thus, older adults produced larger PRP effects after training than younger adults did before practice. In other words, training cannot necessarily remedy an age-difference in dual-task performance in the present context. The residual PRP effect after training is consistent with the structural bottleneck view (e.g., Pashler, 1984. 1994).

Consequently, the present results show that even over 3000 trials of training do not appreciably affect age differences in dual-task interference. While there is evidence that younger adults can, in some cases bypass the central bottleneck (Maquestiaux et al., 2008; Ruthruff et al., 2006), there is little evidence that older adults can do so. Hartley, Maquestiaux, and Butts (2011) showed no cost of concurrence, but these investigators did not use a PRP paradigm to confirm whether they eliminated PRP effects or observed slack or general savings effects. Maquestiaux et al. (2010) did use a PRP paradigm that involved Task 2 training and claimed to observe substantial central bottleneck elimination (based upon response reversals) for many younger adults, but just one-out-of-twelve older adults showed any evidence of doing so. Furthermore, as we noted earlier, their results are inconclusive. The present results that entailed Task 1 training were even less optimistic than the Maquestiaux et al. results because no older or younger adults were able to bypass the central bottleneck (although both age groups showed general savings). However, it does appear that some stage-shortening of Task 1 did occur with training for both age groups in the present study, as well as for Maquestiaux et al. (2010). Perhaps, then, automatization is not a realistic goal for most individuals in most contexts – but that the stage-shortening first noted by Ruthruff et al. (2006) is a more realistic goal of training research.

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Table 1.

Mean Response Time (in ms) and Mean Percentage of Error (in parenthesis) for Single-Task Training on Task 1 in Weeks 2-7 as a Function of Age (Younger vs. Older), Task-1 Color (Red vs. Green), and Week (2-7).

	Week					
	2	3	4	5	6	7
Younger Adults						
Green	493 (3.2)	466 (2.9)	464 (3.0)	466 (3.4)	460 (3.2)	464 (4.2)
Red	487 (2.8)	463 (2.5)	460 (3.2)	460 (4.7)	464 (3.5)	460 (4.1)
Older Adults						
Green	596 (2.2)	570 (1.8)	595 (2.9)	574 (2.7)	575 (2.2)	587 (3.2)
Red	609 (2.4)	587 (1.9)	623 (3.5)	610 (3.3)	594 (2.7)	610 (3.5)

Table 2.

A Summary Table for the Overall ANOVAs on Response Time and Percentage of Error for Single Task-1 Training in Weeks 2-7 as a Function of Age (Younger vs. Older), Task 1 Color (Red vs. Green), and Week (2-7).

Effect	*df*	*F*	*p*
Response Time			
Age (A)	1,71000	10.83	<.001
Color (C)	1,71000	80.17	<.0001
Week (W)	5,109	31.73	<.0001
A × C	1,71000	137.86	<.0001
A × W	5,71000	<1.0	.4693
C × W	5,71000	2.27	.0449
A × C × W	5,71000	3.49	.0037
Percentage of Error			
Age (A)	1,71000	17.64	<.0001
Color (C)	1,71000	7.57	.0059
Week (W)	5,109	1.30	.2701
A × C	1,71000	1.29	.2560
A × W	5,71000	2.35	.0384
C × W	5,71000	<1.0	.5119
A × C × W	5,71000	<1.0	.6036

Table 3.

A Summary Table for the Overall ANOVAs on Task-1 Response Time in Dual-Task Performance as a Function of Age (Younger vs. Older), Task 1 Color (Red vs. Green), Task 2 Tone (White Noise vs. Horn Honk), Stimulus Onset Asynchrony (50, 150, 600, or 1000 ms), and Week (1 vs. 8).

Effect	*df*	*F*	*p*
Age (A)	1,22	9.28	.0059
Task-1 Color (C)	1,22	1.48	.2363
Task-2 Tone (T)	1,22	6.21	.0207
Stimulus Onset Asynchrony (SOA)	3,66	19.34	.0001
Week (W)	1,22	5.94	.0233
A × C	1,22	<1.0	.8403
A × T	1,22	<1.0	.6199
A × SOA	3,66	<1.0	.9994
A × W	1,22	<1.0	.8355
C × T	1,22	<1.0	.7816
C × SOA	3,66	<1.0	.6284
C × W	1,22	2.85	.1053
T × SOA	3,66	<1.0	.5028
T × W	1,22	<1.0	.4994
SOA × W	3,66	<1.0	.7577
A × C × T	1,22	2.47	.1300
A × C × SOA	3,66	<1.0	.6095
A × C × W	1,22	1.53	.2288
A × T × SOA	3,66	<1.0	.4745
A × T × W	1,22	<1.0	.4948
A × SOA × W	3,66	<1.0	.5568
C × T × SOA	3,66	<1.0	.8379
C × T × W	1,22	<1.0	.7764
C × SOA × W	3,66	2.20	.1059
T × SOA × W	3,66	2.25	.1113
A × C × T × SOA	3,66	<1.0	.4840
A × C × T × W	1,22	<1.0	.9095
A × C × SOA × W	3,66	<1.0	.9446
A × T × SOA × W	3,66	<1.0	.6919
C × T × SOA × W	3,66	1.65	.1817
A × C × T × SOA × W	3,66	1.13	.3441

Table 4.

A Summary Table for the Overall ANOVAs on Task-1 Percentage of Errors for Dual-Task Performance as a Function of Age (Younger vs. Older), Task 1 Color (Red vs. Green), Task 2 Tone (White Noise vs. Horn Honk), Stimulus Onset Asynchrony (50, 150, 600, or 1000 ms), and Week (1 vs. 8).

Effect	*df*	*F*	*p*
Age (A)	1,22	<1.0	.9774
Task-1 Color (C)	1,22	4.55	.0443
Task-2 Tone (T)	1,22	3.60	.0710
Stimulus Onset Asynchrony (SOA)	3,66	3.60	.0297
Week (W)	1,22	2.22	.1500
A × C	1,22	<1.0	.9606
A × T	1,22	<1.0	.8853
A × SOA	3,66	<1.0	.9971
A × W	1,22	<1.0	.9560
C × T	1,22	1.10	.3049
C × SOA	3,66	1.08	.3531
C × W	1,22	<1.0	.3302
T × SOA	3,66	<1.0	.5210
T × W	1,22	<1.0	.7675
SOA × W	3,66	2.62	.0935
A × C × T	1,22	<1.0	.6341
A × C × SOA	3,66	<1.0	.9804
A × C × W	1,22	<1.0	.9255
A × T × SOA	3,66	<1.0	.9994
A × T × W	1,22	<1.0	.8768
A × SOA × W	3,66	<1.0	.9900
C × T × SOA	3,66	5.11	.0340
C × T × W	1,22	2.17	.1547
C × SOA × W	3,66	<1.0	.6653
T × SOA × W	3,66	1.65	.1976
A × C × T × SOA	3,66	<1.0	.9771
A × C × T × W	1,22	<1.0	.6681
A × C × SOA × W	3,66	<1.0	.9977
A × T × SOA × W	3,66	<1.0	.9986
C × T × SOA × W	3,66	2.50	.0762
A × C × T × SOA × W	3,66	<1.0	.9764

Table 5.

A Summary Table for the Overall ANOVAs on Task-2 Response Time in Dual-Task Performance as a Function of Age (Younger vs. Older), Task 1 Color (Red vs. Green), Task 2 Tone (White Noise vs. Horn Honk), Stimulus Onset Asynchrony (50, 150, 600, or 1000 ms), and Week (1 vs. 8).

Effect	*df*	*F*	*p*
Age (A)	1,22	16.10	.0006
Task-1 Color (C)	1,22	<1.0	.8886
Task-2 Tone (T)	1,22	7.25	.0133
Stimulus Onset Asynchrony (SOA)	3,66	312.52	.0001
Week (W)	1,22	20.84	.0002
A × C	1,22	<1.0	.9411
A × T	1,22	<1.0	.3982
A × SOA	3,66	4.55	.0227
A × W	1,22	<1.0	.5522
C × T	1,22	<1.0	.8483
C × SOA	3,66	<1.0	.4146
C × W	1,22	<1.0	.3335
T × SOA	3,66	<1.0	.4308
T × W	1,22	2.17	.1550
SOA × W	3,66	6.86	.0010
A × C × T	1,22	1.32	.2627
A × C × SOA	3,66	<1.0	.6865
A × C × W	1,22	<1.0	.7226
A × T × SOA	3,66	1.70	.1872
A × T × W	1,22	5.33	.0308
A × SOA × W	3,66	<1.0	.8326
C × T × SOA	3,66	<1.0	.6793
C × T × W	1,22	<1.0	.4436
C × SOA × W	3,66	3.55	.0293
T × SOA × W	3,66	<1.0	.5210
A × C × T × SOA	3,66	<1.0	.4238
A × C × T × W	1,22	<1.0	.7267
A × C × SOA × W	3,66	<1.0	.6765
A × T × SOA × W	3,66	<1.0	.6668
C × T × SOA × W	3,66	<1.0	.6251
A × C × T × SOA × W	3,66	<1.0	.6380

Table 6.

A Summary Table for the Overall ANOVAs on Task-2 Percentage of Errors for Dual-Task Performance as a Function of Age (Younger vs. Older), Task 1 Color (Red vs. Green), Task 2 Tone (White Noise vs. Horn Honk), Stimulus Onset Asynchrony (50, 150, 600, or 1000 ms), and Week (1 vs. 8).

Effect	*df*	*F*	*p*
Age (A)	1,22	<1.0	.7967
Task-1 Color (C)	1,22	2.95	.0999
Task-2 Tone (T)	1,22	2.80	.1087
Stimulus Onset Asynchrony (SOA)	3,66	3.60	.0471
Week (W)	1,22	<1.0	.3651
A × C	1,22	<1.0	.9190
A × T	1,22	<1.0	.7940
A × SOA	3,66	<1.0	.9463
A × W	1,22	<1.0	.5012
C × T	1,22	3.01	.0968
C × SOA	3,66	6.70	.0033
C × W	1,22	22.63	.0001
T × SOA	3,66	3.36	.0449
T × W	1,22	<1.0	.6296
SOA × W	3,66	1.11	.3466
A × C × T	1,22	<1.0	.8618
A × C × SOA	3,66	<1.0	.7731
A × C × W	1,22	<1.0	.7731
A × T × SOA	3,66	<1.0	.9044
A × T × W	1,22	<1.0	.6848
A × SOA × W	3,66	<1.0	.9778
C × T × SOA	3,66	1.46	.2337
C × T × W	1,22	4.99	.0364
C × SOA × W	3,66	1.12	.3380
T × SOA × W	3,66	1.79	.1741
A × C × T × SOA	3,66	<1.0	.9795
A × C × T × W	1,22	<1.0	.8191
A × C × SOA × W	3,66	<1.0	.9208
A × T × SOA × W	3,66	<1.0	.8951
C × T × SOA × W	3,66	<1.0	.4860
A × C × T × SOA × W	3,66	<1.0	.9829

Figure Captions

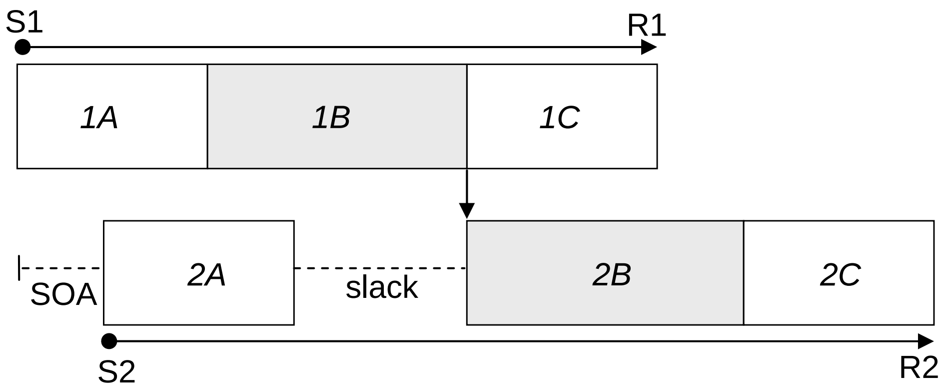
Figure 1. The temporal relations between processing stages of Task 1 and Task 2 at a short SOA (top panel) and a long SOA (bottom panel) in the psychological refractory period paradigm, as suggested by the central bottleneck model. This model assumes that perceptual and response initiation/execution stages of Task 2 can operate in parallel with any stage of Task 1, but that central stages of Task 2 cannot start until central stages of Task 1 have been completed. 1A, 1B, and 1C are the perceptual, central, and response initiation/execution stages of Task 1, respectively. 2A, 2B, and 2C are the corresponding stages for Task 2. S1: stimulus for Task 1; S2: stimulus for Task 2; R1: response for Task 1; R2: response for Task 2; SOA: stimulus onset asynchrony.

Figure 2. Mean response times for Task 1 (RT1) as a function of age group (younger versus older adults), stimulus onset asynchrony (SOA; 50, 150, 600, and 1,000 ms), and Week (2-7).

Figure 3. Mean response times for Task 1 (RT1) and Task 2 (RT2) as a function of age group (younger versus older adults), stimulus onset asynchrony (SOA; 50, 150, 600, and 1,000 ms), and Week (wk; 1 vs. 8).

Figure 1

Short SOA:



Long SOA:

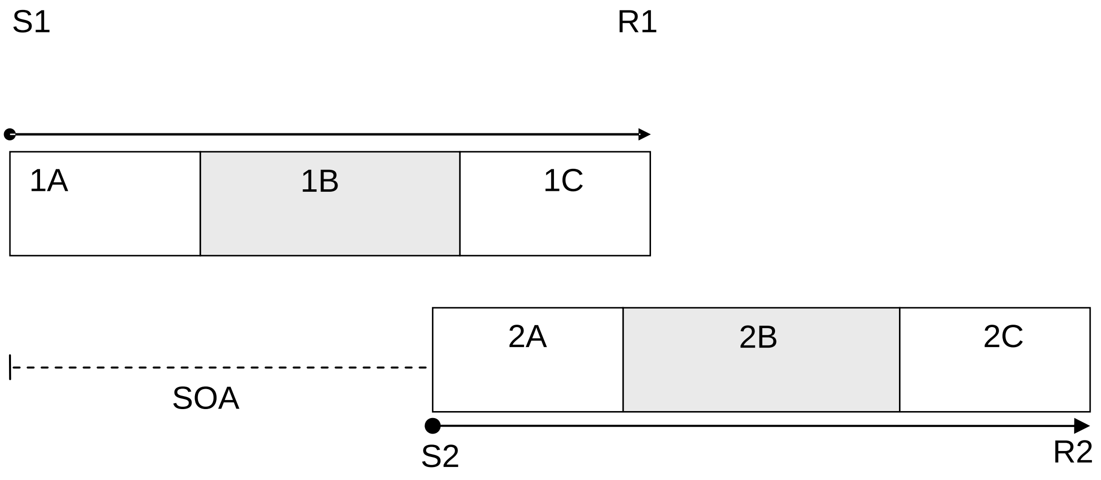


Figure 2

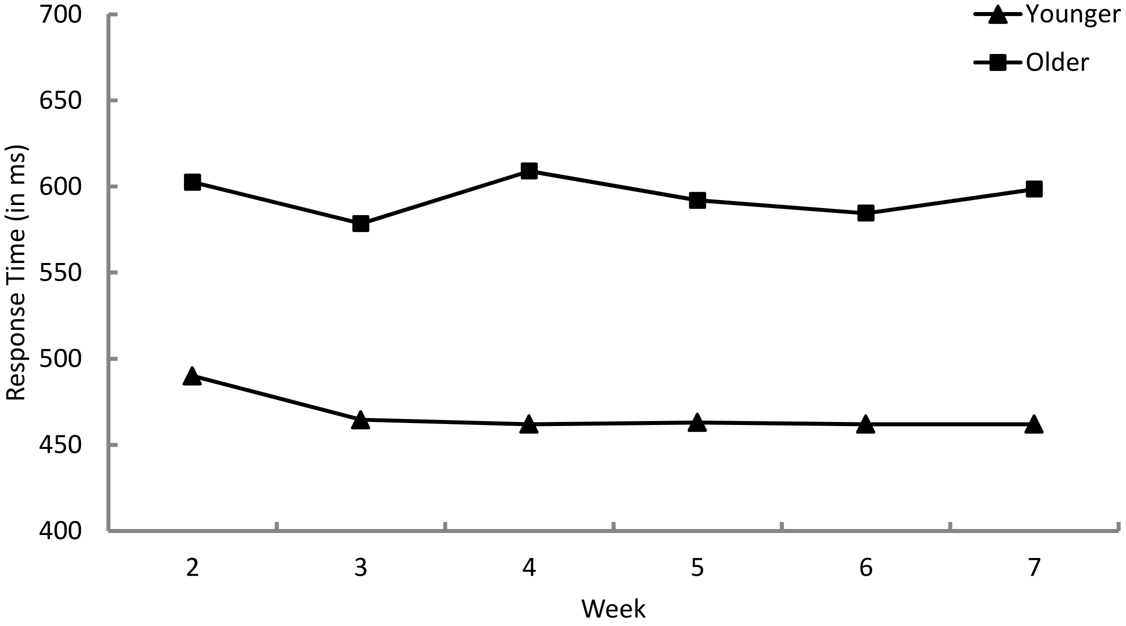
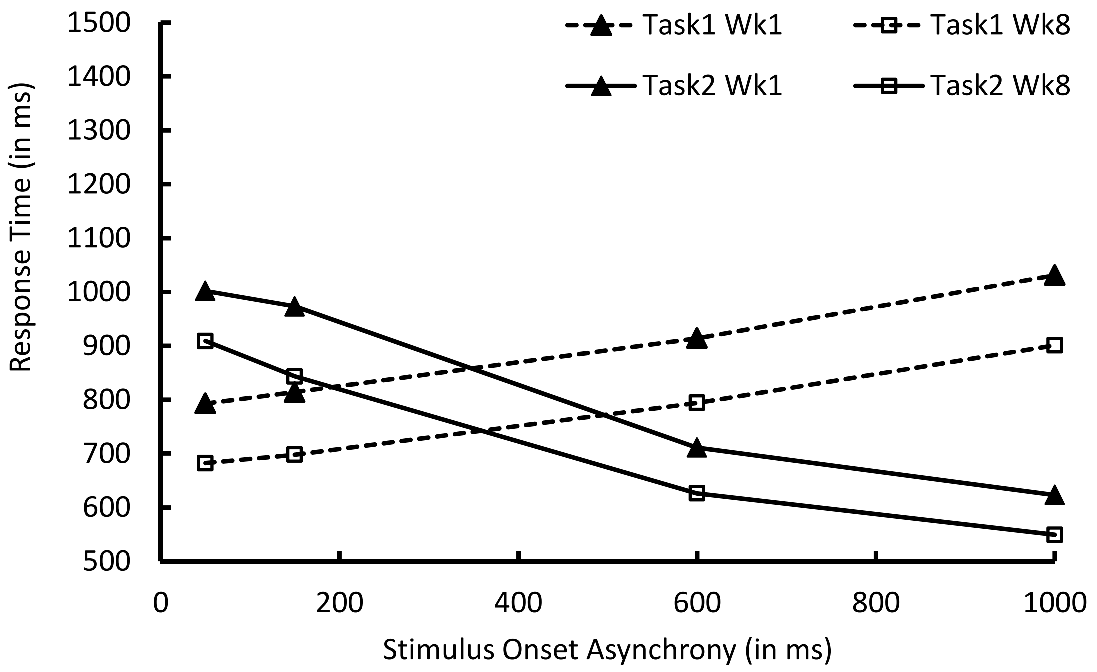

Younger
Older
700
650
600
550
500
450
400
Response Time (in ms)
2
3
4
5
6
7
Week

Figure 3

Younger



Older