

# Age-Related Differences in Response Preparation: The Role of Time Uncertainty

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**This study explored the ability of younger and older participants to use a variable preparatory interval (PI) to enhance reaction time (RT) performance. In Experiment 1, 30 seniors and 15 young adults completed simple and choice RT tasks with short and long variable PIs. RT decreased with increasing PI duration in both younger and older adults, but the PI effect was larger in elderly individuals. The results of Experiment 2 (20 seniors and 20 young adults) showed an equivalent preparatory effect in older and younger adults when the probability of the shortest PI was increased. These findings suggest that older adults do not prepare as well as younger adults for unlikely events and that time uncertainty affects age-related differences in response preparation.**

IN recent years, there has been a growing interest in age-related differences in attention (see Hartley, 1992, and McDowd & Shaw, 2000, for reviews). Deficits of attention are likely to have a tremendous impact on daily activities given the ubiquitous aspect of attention in cognitive functioning. However, attention encompasses a large number of cognitive processes, and, despite a growing effort, understanding how attentional components are modified with age deserves further investigation (McDowd & Shaw, 2000). Preparation is an attentional component involved in the execution and control of voluntary action, and empirical data suggest that it may become impaired in the process of normal aging (Hillman, Weiss, Hagberg, & Hatfield, 2002; Salthouse, 1985a). However, the pattern of age-related differences in preparatory behaviors and the source of these differences remain to be clarified.

Preparatory processes have been referred to as a voluntary or attention-demanding set of strategic behaviors that sustain the development and maintaining of an optimal processing state prior to the execution of movement (Stuss, Shallice, Alexander, & Picton, 1995). Typically, preparation has been studied with reaction time (RT) tasks under the rationale that response latency is modulated not only by stimulus processing and response execution but also by the preparatory processes that take place prior to stimulus occurrence (Henderson & Dittrich, 1998). In RT tasks, preparatory processes take place during the preparatory interval (PI), which separates the warning signal from the imperative or response signal. The PI has a strong predictive value on signal occurrence and thus considerably affects response latency, as will be described in the paragraphs that follow. Two important distinctions should be made regarding preparation in RT tasks. First, preparation can be specific or nonspecific. Specific preparation refers to preparation of a predetermined response to a specific stimulus. For example, when stopped at a red light, the driver prepares to press the gas pedal as soon as the light turns green. Studies using simple RT tasks in which the action is known measure specific preparation. Nonspecific preparation, often called temporal preparation (Holender, 1980), refers to the synchronization of an action in time. For instance, most drivers will not prepare to start when they

have just stopped at the red light; rather, they tend to delay their preparation until a certain amount of time has passed, when they anticipate the light must soon turn green. This example highlights how temporal information is a critical aspect of preparatory behaviors. When a forecoming response is unknown (e.g., in choice RT), only temporal preparation improves response latency (Bertelson, 1967; Boons & Bertelson, 1961). Preparatory processes have greater impact when both temporal preparation and specific preparation are combined, as in a simple RT task. A second procedural distinction in preparation studies relates to the use of a fixed-PI or a variable-PI design. In a fixed-PI design the same PI is used repeatedly over several trials, whereas in a variable-PI design the PI varies randomly from trial to trial within a block of trials.

It has been observed that older adults are impaired in preparatory processes and that temporal parameters may affect the age-related increase in RT (Gottsdanker, 1982; Wilkinson & Allison, 1989; see Welford, 1977, for a review). More recently, Hillman and colleagues (2002; see also Loveless & Sanford, 1974) reported a larger amplitude in event-related potential indexes of preparation in older adults (i.e., stimulus preceding negativity and contingent negative variation), which suggests that neural processing is less efficient in older adults when they anticipate an upcoming event. On the basis of the existing yet scant data in the literature, Salthouse (1985a) proposed two forms of inefficient preparation in normal aging: an incapacity to develop an optimal prepared state rapidly, or an inability to maintain preparation over a certain period of time. According to the first account, older adults need more time to achieve an optimal preparation state before the imperative stimulus occurs. In contrast, a maintenance deficiency account predicts that older adults have impairment in sustaining an optimal preparation state over long delays. An additional hypothesis proposed by Lahtela, Niemi, and Kuusela (1985) suggested that aged persons fail to prepare for events that have a low subjective probability. Empirical support for each of these accounts has been reported in the literature.

When one is concerned with age-related differences in temporal preparation, one must distinguish studies using

a fixed-PI design from those using a variable-PI design. When the PI is fixed, response latency normally increases as a function of the interval duration, at least within a range of relatively short PI values (e.g., 1–4 s). This has been attributed to less accuracy in temporal estimation processing with longer delays (Luce, 1986; Niemi & Näätänen, 1981). Results from aging studies suggest that, within a short temporal frame (approximately 250–300 ms), older persons can attain preparation as fast as young persons (Nebes & Brady, 1993; Rabbitt, 1984). However, they show impairment with longer PI durations (4–6 s; Botwinick, 1965; Botwinick, Brinley, & Robbin, 1959; Gottsdanker, 1982; Strauss, Wagman, & Quaid, 1983). This observation has led to the conclusion that older participants have difficulty maintaining preparation over long delays.

Although results with a fixed-PI design have provided some valuable information regarding preparation in aged persons, a variable-PI design is perhaps a better way in which to explore one's ability to modulate preparation. Typically, each PI value is presented the same number of times in a given block of trials. In this case, RT is longer with short PIs and tends to decrease for longer ones (Näätänen & Merisalo, 1977; Polzella, Ramsey, & Bower, 1989; Requin & Granjon, 1969; Requin, Granjon, Durup, & Reynard, 1973; Stilitz, 1972). The classical interpretation of this effect (Stilitz, 1972, but see Los & Van Den Neudel, 2001) is that participants increase their level of preparation because signal likelihood increases with time (conditional probability). For example, consider the use of three PIs of 1, 2, and 3 s, each occurring randomly but equally often in a block of trials. In a given trial the probability that the response signal will occur after 1 s is .33 and increases to .50 at 2 s. If no signal occurs after 2 s, the probability that it will occur at 3 s is 1. Variable designs appear to reflect real-life demands more accurately than fixed designs because the events that one encounters in typical daily situations rarely occur at fixed intervals. For instance, when stopped at an intersection, a driver rarely knows precisely when the red light will turn green. However, as time elapses, the probability that the green light will replace the red light increases.

With a variable-PI design, Lahtela and colleagues (1985) observed that RTs of older adults decrease as a function of PI duration, even when they are extended up to 6 s (2, 4, and 6 s). This suggests that preparation is still possible up to this length of delay. However, these authors found an important age effect with the shortest delay in older adults (see Ferraro & Moody, 1996, for similar results with PIs of 1, 2, and 3 s). Results reported previously with a fixed-PI design indicate that older adults can prepare as fast as younger adults, even with very short delays, and thus slowing to prepare a response cannot account for the age-related difference in a variable-PI design. Lahtela and colleagues (1985) explained the larger age effect that they observed at the shortest PI as reflecting poor preparation for uncertain events in older adults. In parallel, studies with long variable PIs support the maintenance deficit hypothesis. Strauss and associates (1983) reported that, in a group of aged women, RTs decreased as a function of the PIs of 1, 3, and 6 s. However, RT was slower with a long PI (7, 9, and 13 s) and did not improve within the time window. Unfortunately, this study did not include a control group of young participants. Thus, the question remains as to whether this pattern of preparation with long delays is specific to aged

participants or could be due to the experimental conditions of this study.

In summary, few empirical studies have directly measured the effect of normal aging on temporal preparation, and those that have done so obtained divergent results (for a review, see Salthouse, 1985a). Therefore, it is unclear at this point whether normal aging has a genuine impact on preparation. Inconsistencies in previous findings may be due in part to the use of different tasks (simple vs. choice RT paradigm), different designs, or different PI duration. These aspects of the task greatly affect preparation and may favor or harm response preparation.

The goal of the present study is to evaluate the impact of age on temporal preparation and to test the three hypotheses of temporal preparation deficits in normal aged persons. In a first experiment, we examined participants' ability to use randomly varied PIs within a block of trials in older and younger adults. To contrast the maintenance and fast-developing hypotheses, we used two duration windows in different blocks: a relatively short one (1–5 s) and a relatively long one (5–9 s). If aged persons have difficulty developing preparation rapidly, they should show impairments on the shortest PI of the short-duration window. If, in contrast, aged persons have difficulty maintaining preparation, they should not take advantage of longer PIs. If this is the case, the RT of older adults will not vary as a function of PI in the long-duration window. Finally, if aged persons have a low level of preparation for uncertain events, they will have slow response latencies at the shortest interval of the distribution independent of the absolute interval duration. Thus, the effect will be found with both short- and long-duration windows.

We measured temporal preparation with initiation time as a measure of response latency. This approach has been used in movement-restructuring studies with older adults (see Amrhein, 1996) and studies of motor preparation in Parkinson's disease (Bherer, Belleville, & Gilbert, 2003; Jahanshahi, Brown, & Marsden, 1992). It is hypothesized that this approach better dissociates the cognitive and motor portions of the global RT. Because preparation is a cognitive process that precedes action, and, consistent with previous studies, the execution time should be less sensitive to experimental conditions intended to measure temporal preparation. Age-related differences in preparation pattern should rather affect initiation time.

## Experiment 1

### METHODS

#### *Participants*

Participants in the experiment were 45 right-handed volunteers, 30 older and 15 younger adults, living in Montréal, Canada. A questionnaire was used to ensure that they were all in good health and none of them had undergone surgery or suffered from psychiatric disorders in the few years prior to testing. They had no history of neurological disease and were not taking any medications known to affect cognition. As a way to exclude persons with early dementia, older participants completed the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). No one was excluded on the basis of this test, as all participants scored 27 and above ( $M = 29$ ,  $SD = 1.3$ ; the cutoff score was 24). Elderly participants were 19 women and 11 men with an average age

of 70.5 years ( $SD = 2.8$ , range = 65–78). The young group was composed of 8 women and 7 men with a mean age of 21.5 years ( $SD = 2$ , range = 20–26). The level of education was 14.2 years ( $SD = 3.2$ ) for the older participants and 14.3 years for the young participants ( $SD = 1.5$ ). Participants also completed a general verbal performance test (Mill Hill) to assess general mental abilities, in which they had to select the synonyms of given words among six choices. The elderly and young participants scored 36.8 and 36.4, respectively, on this test.

### Materials

The experiment was under the control of PsyScope 1.0.1 (Cohen, MacWhinney, Flatt, & Provost, 1993), running on a Macintosh Quadra 800. The preparatory signal was a sine wave tone of 1000 Hz presented at 80 to 85 dB for 250 ms. The visual stimuli were 4-cm circles, either black (the imperative signal) or white, presented in the center of a 14-in. (35.56-cm) computer screen. The visual stimuli remained on the screen until participants responded. Participants started the trials and gave their response on a three-button response box (PsyScope ButtonBox). The three buttons of different colors (left to right: red, yellow, and green) were arranged linearly on a 17 cm  $\times$  13 cm panel separated by 3 cm. Response time was measured at the nearest millisecond.

### Procedures

All participants completed both simple and choice RT tasks in a single experimental session. In both tasks, the letters "O.K." appeared in the center of the computer screen before each trial to indicate to the participant that he or she could start the trial. To do so, the participant pressed the central yellow button. At this moment, the letters disappeared and the auditory preparatory signal occurred. Participants were required to hold down the central button until the occurrence of the imperative signal (the black circle). In the simple RT condition, the black circle appeared in the center of the computer screen and the participant reacted by quitting the home key and pressing the response key to the right of the home key as quickly as possible. In the choice RT task, the imperative signal was the same black circle appearing to the right or left of a white circle. The correct response in this condition consisted of pushing the button (right or left) that corresponded to the position of the black circle. After 1,000 ms of interstimulus interval, the "O.K." signal appeared again, indicating to participants that they could start a new trial.

In both the simple and choice RT tasks, two PI duration windows were used in separate blocks. PIs were 1, 3, or 5 s in the short-duration condition and 5, 7, or 9 s in the long-duration condition. Within each experimental condition, the PI varied randomly and the proportion of the three PI values was equal in each block of trials. First, participants completed 5 practice trials of simple RT and 5 practice trials of choice RT in the short-duration condition. Then, they completed two blocks of trials for one of the duration conditions (short vs. long): simple RT in the first block and choice RT in the second block. In the simple RT task, 15 trials were completed at each PI value in each duration window. There were 30 trials per PI value in the choice RT task. The target occurred 15 times on the left and 15 times on the right. After a short rest of approximately 15 min, participants again completed 45 trials of simple RT and 90 trials

of choice RT in the other duration condition. The order of presentation of the duration conditions (short vs. long) was counterbalanced across participants.

### RESULTS

Response times were included in the analyses for correct answers only. Response initiation time (IT) was measured from the occurrence of the imperative stimulus to the moment when participants removed their fingers from the home key. Response times shorter than 100 ms or longer than 3,000 ms were not included in the analysis. The execution time (ET) was the remaining portion of the global RT, that is, the time to move from the home key to the response key. When Mauchly's test of sphericity reached a significant level for repeated measures, an effect is reported significant according to the adjusted alpha level (Greenhouse–Geisser).

The results reported here focused on IT only. This choice of measure is based on previous studies that separated IT and ET portions of global RTs in normal older adults, such as those by Amrhein (1996) and Bherer and Belleville (in press), and studies of motor preparation in Parkinson's disease, such as those by Bherer and colleagues (2003) and Jahanshahi and colleagues (1992), which have shown that experimental conditions that affect preparation only have a moderate effect on ET. Moreover, there is no strong evidence of an age-related difference in the pattern of ET variation induced by experimental conditions known to affect preparation. In the present study we observed that ET was longer in older than younger adults, and that it increased with task complexity and from the first to the second PI within a specific time window. Experiment 1 showed a Group  $\times$  Task (i.e., simple vs. choice) interaction,  $F(1, 43) = 7.3$ ,  $p < .01$ ,  $\eta^2 = .14$ , caused by a larger task effect in the aged group than in the young group. In Experiment 2, an increase in ET from the first to the second PI was larger in older than younger adults,  $F(2, 72) = 3.4$ ,  $p < .05$ ,  $\eta^2 = .09$ . However, in both experiments, age-related differences appeared to be the mere product of general slowing because the effects were no longer significant when general slowing was controlled for, using Madden's approach (Madden, 2001). This suggests that there is no substantial evidence of an age-related difference in the pattern of ET variation induced by experimental conditions that affect preparation.

### Initiation Time

We performed three sets of preliminary analyses to assess the counterbalancing effect of the duration windows, the effect of responding to the right or left in the choice RT task, and the effect of gender. None of these factors had any effect on the analyses.

Figure 1 shows the IT for the two groups of participants in the simple (upper portion) and choice (lower portion) RT conditions. An inspection of the data reveals that RT decreased with PI in all experimental conditions, with both long and short temporal windows and in choice and simple tasks, although the effect appears to be larger in the simple task in the short time window. This general pattern was found in both groups. However, in all conditions, the effect of PI appears to be larger in older than younger adults.

We performed a repeated-measures analysis of variance (ANOVA) on IT with age group as a between-subject factor

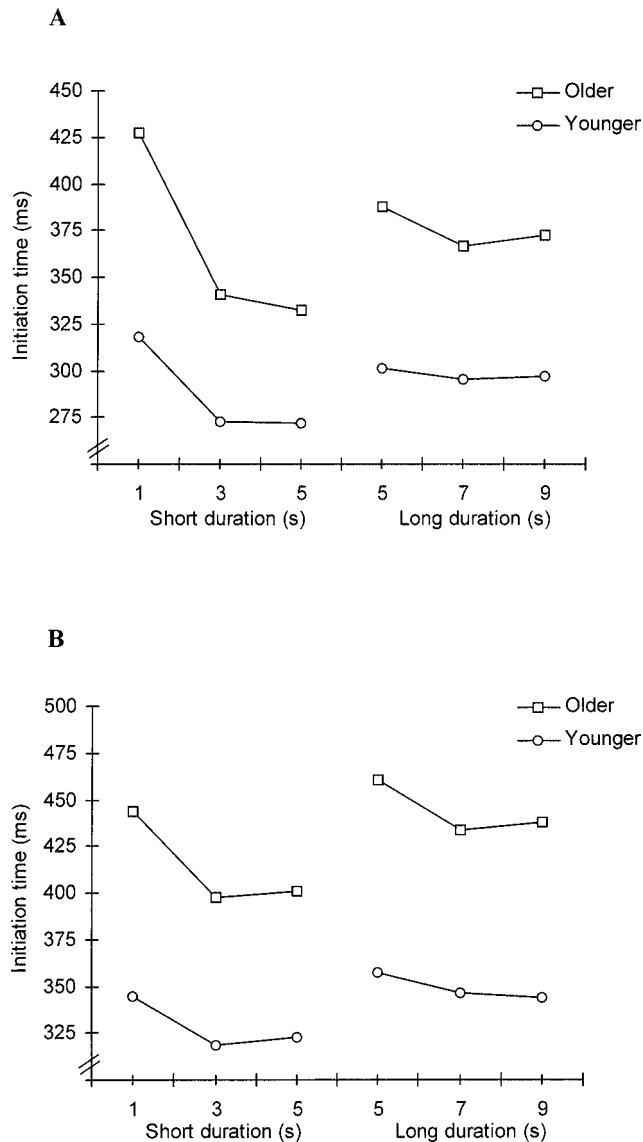


Figure 1. Mean initiation time in Experiment 1 as a function of preparatory intervals and duration condition for older and younger participants in the (A) simple and (B) choice reaction time tasks.

and task (simple vs. choice), duration condition (short vs. long), and PI as within-subject factors. This analysis revealed a main effect of group,  $F(1, 43) = 14.7, p < .001, \eta^2 = .26$ . Main effects of task,  $F(1, 43) = 79.7, p < .001, \eta^2 = .65$ , and duration,  $F(1, 43) = 22.9, p < .001, \eta^2 = .35$ , reached a significant level. The PI effect was also significant,  $F(2, 86) = 75.6, p < .001, \eta^2 = .64$ , as a result of a significant decrease from the first to the second PI. Moreover, the following two-way interactions were significant: Group  $\times$  PI,  $F(2, 86) = 8.8, p < .001, \eta^2 = .17$ ; Task  $\times$  Duration,  $F(1, 43) = 7.3, p < .01, \eta^2 = .15$ ; Task  $\times$  PI,  $F(2, 86) = 4.9, p < .01, \eta^2 = .10$ ; and Duration  $\times$  PI,  $F(2, 86) = 27.4, p < .001, \eta^2 = .39$ . Finally, the Task  $\times$  Duration  $\times$  PI interaction also reached significance,  $F(2, 86) = 16.2, p < .001, \eta^2 = .27$ . It is important that, for our hypotheses, the duration factor did not interact with group or with group and PI.

The Group  $\times$  PI interaction is of major importance with regard to aged-related differences in preparation. Table 1 presents the mean ITs relevant to this interaction. We performed simple effects analyses to clarify how the pattern of group performance differed as a function of PI. These analyses revealed that IT significantly decreased with PI in both older ( $p < .001, \eta^2 = .70$ ) and younger ( $p < .001, \eta^2 = .22$ ) adults, and that the difference among groups was significant at each of the three PI values ( $p < .001$ ). The Group  $\times$  PI interaction seems to be due to a larger PI effect in the elderly groups. We confirmed this by conducting repeated contrasts, which compare across groups the reduction in IT between two consecutive PI values (SPSS, 1997). These contrasts indicated that the decrease of IT from the first to the second PI was significantly different across groups,  $F(1, 43) = 11.6, p < .001, \eta^2 = .21$ , being larger for the older group (45 ms) than for younger participants (22 ms). Differences in IT between the second and third PIs were equivalent among groups.

The significant three-way interaction among task, duration condition, and PI suggests that the magnitude of the PI effect was different in the simple and choice RT and among duration conditions. To understand this interaction, we performed further analyses contrasting simple and choice RT tasks in the short- and long-duration conditions separately. The results indicated that the Task  $\times$  PI interaction was significant in the short-duration condition,  $F(2, 86) = 16.1, p < .001, \eta^2 = .27$ . In this condition, the PI effect was significantly larger in the simple RT task than the choice RT task. However, this was only the case from the 1-s PI to the 3-s PI,  $p < .001, \eta^2 = .24$ , as indicated by the repeated contrasts. It is worth noting, however, that IT significantly decreased from 1 to 3 s in both the simple,  $p < .001, \eta^2 = .57$ , and the choice,  $p < .001, \eta^2 = .51$ , RT tasks. In the long temporal duration (5 to 9 s), the Task  $\times$  PI interaction was not significant,  $F(2, 86) = 1.1$ , which indicates that the PI effect was equivalent in both the simple and choice RT tasks. In both tasks, IT decreased significantly from 5 s to 7 s,  $p < .001, \eta^2 = .23$ .

The major finding of this experiment is the Group  $\times$  PI interaction. It suggests that older adults are at a disadvantage when a PI has a low probability, and that this is independent of the duration of the PIs and the time window. Another way to disentangle the effect of probability and absolute duration is to compare performance at the 5-s PI with a high probability and the 5-s PI with a low probability. This could be accomplished because the 5-s PI in the short-duration condition was the longest interval of the window and thus has the highest probability of occurrence. In the long window, the 5-s PI was the shortest interval of the temporal window, which corresponds to the lowest probability. In both groups of participants, the fastest IT was observed with the 5-s PI of the short window and IT increased at the 5-s PI of the long window. Importantly, this effect appears to be larger in elderly persons. An ANOVA performed on the IT at the 5-s PI of the two temporal window conditions confirmed that the increase was larger in older adults, as the Group  $\times$  Duration condition reached significance,  $F(1, 43) = 8.8, p < .01, \eta^2 = .17$ . Again, this indicated that the probability of occurrence has a larger impact on older adults.

Interpreting an interaction in the presence of a main group effect is an important methodological concern discussed by many authors (Belleville, Rouleau, & Caza, 1998; Loftus,

Table 1. Mean Initiation Time as a Function of PI

Groups	Experiment 2								
	Experiment 1			Equal			Skewed		
	PI 1	PI 2	PI 3	PI 1	PI 2	PI 3	PI 1	PI 2	PI 3
Older	430 (93)	385 (90)	386 (89)	433 (75)	337 (66)	336 (64)	375 (67)	339 (68)	337 (68)
Young	330 (40)	308 (41)	309 (41)	303 (38)	272 (29)	272 (25)	283 (23)	248 (26)	257 (31)
Young-trans.	415 (61)	384 (64)	385 (62)	418 (68)	362 (52)	362 (44)	381 (42)	319 (46)	335 (55)

Notes: Time is given in milliseconds; it is a function of preparatory interval (PI) in both age groups in Experiments 1 and 2 (standard deviations are shown in parentheses). Younger adults' transformed data are also provided (Young-trans.). For Experiment 1, data are pooled over task and duration conditions.

1978; Salthouse, 1985b). In the present study, the PI effect in aged participants might be more pronounced because they benefited more from PIs as slower responders. General slowing has often been put forward as a general account of age-related cognitive impairments (Salthouse, 1996). One of the strongest empirical arguments in favor of the general-slowing account is the nearly perfect linear relation between the RTs of older and younger adults (Brinley, 1965; but see Fisk & Fisher, 1994, for the limits of this approach). To control for general slowing, Madden, Pierce, and Allen (1992) proposed to transform younger adults' RT performance based on this linear relation. The technique consists in transforming younger adults RTs by using the equation from a regression analysis performed between the RTs of older adults and younger adults. This eliminates the main group difference, as well as any difference spuriously observed because of a difference in the general level of performance (Madden, 2001). If a group difference persists, it likely comes from a genuine task-dependent age-related difference.

We applied the transformation suggested by Madden and colleagues (1992) to our data, first by performing a regression analysis on the IT of older and younger adults. The results indicated that a large proportion of the older adults' performance can be explained by the performance of younger participants (Older = Young  $\times$  1.4 - 42,  $r^2 = .95$ ), which suggests that general slowing can account for a large proportion of the IT difference between older and younger adults in our tasks. We then transformed the data of the young participants by using the equation of the regression analysis. The transformed data of younger adults are shown in Table 1. It can be observed that the preparatory effect remains larger in older than younger adults even after the transformation. An ANOVA performed on the transformed data for younger adults and untransformed data of older adults indicated that although the main group difference was no longer significant after the regression-based transformations,  $F(1, 43) = .00$ , the Group  $\times$  PI interaction remained significant,  $F(2, 86) = 3.02$ ,  $p = .05$ ,  $\eta^2 = .07$ , as a result of a significantly larger IT reduction from the first to the second PI in the older group,  $F(1, 43) = 4.1$ ,  $p < .05$ ,  $\eta^2 = .09$ . This suggests that the age-related difference in the PI effect is independent of a general-slowing factor.

It is well known that RT performance is affected by practice. Moreover, in studies using a variable PI paradigm, repetition of the same PI value in two consecutive trials greatly affects RT performance. It has also been observed that participants expect repetition and thus react faster to the short PI if the preceding trial contained a short PI rather than a long PI (Niemi & Näätänen, 1981). To assess the potential contribution of

practice and repetition effects in Experiment 1, we performed an ANOVA by contrasting the mean IT for the first and the second half of the trials within a block (first vs. last 22 trials in simple RT and first vs. last 44 trials in choice RT). We also performed an ANOVA to assess the potential effect of repetition on the preparatory patterns observed in our results. These analyses indicated that neither practice nor repetition had a significant impact on the pattern of age-related differences in temporal preparation.

#### Error Rate

In general, participants made very few anticipation errors, and many of them made no incorrect responses. In the simple RT task, the mean number of anticipation errors was, respectively for the short and long temporal windows, 1.83 and .87 in older adults and .67 and .20 in younger adults. The respective scores in the choice RT task were .83 and 1.40 in older adults and .40 and .33 in younger adults. Nonparametric tests on error scores (Mann-Whitney) revealed age-group differences in mean anticipation scores for the long temporal window only (5-7 s) in the simple ( $p < .01$ ) and choice RT ( $p < .05$ ) tasks. Although older adults produced more anticipation errors in the short temporal window in the simple RT task, there was no significant group difference in anticipation errors for the short temporal window (1-5 s) on either task. The mean number of incorrect responses in the choice RT task was equivalent in older and younger responders (respectively for the short and long temporal windows, .10 and .20 in older adults and .13 and .20 in younger participants).

Given the group difference in anticipation errors in the long window, we performed correlation analyses on anticipation means and IT to assess the speed accuracy trade-off in older adults. A speed accuracy trade-off would have led to a significant negative correlation between anticipation means and latencies. The results indicated weak and nonsignificant correlations between anticipation rate and IT in the simple RT task,  $r = .22$ , and in the choice RT task with short PIs,  $r = -.10$ , as well as a positive correlation in the simple RT task with long PIs,  $r = .41$ ,  $p < .05$ . However, the correlation was negative and significant in the long window in the choice RT task,  $r = -.37$ ,  $p < .05$ . Further observations indicated that this was due to two participants who made more than 5 and 9 anticipations in this condition, which is much greater than the mean number of anticipations by other seniors. When these respondents were excluded, the correlation was substantially reduced and no longer reached significance,  $r = -.14$ ,  $p = .47$ . It is also worth noting that the two participants performed within the normal range with regard to accuracy in the short temporal window and

in the simple RT task. Moreover, when these two participants were excluded from an ANOVA, the exact same pattern of results was obtained as in the previous analysis with reaction time. Specifically, a significant Group  $\times$  PI interaction was observed,  $F(2, 82) = 8.11, p < .001, \eta^2 = .17$ , with no other interactions involving the group factor.

## DISCUSSION

Experiment 1 explored age-related differences in preparatory capacities by using RT tasks embedded in a variable-PI design. The results indicated that RT generally decreased with an increasing PI in both older and younger adults. These results suggest that older adults can prepare for intervals longer than 5–6 s, contrary to conclusions drawn in previous studies that used a fixed-PI design. These results contrast with the study by Strauss and colleagues (1983) of a group of aged women, in which RT did not decrease with PIs in a long temporal window (7, 9, and 13 s). It is unlikely that this reflects gender difference in preparation, as our results did not show any difference between men and women. It may be the case that the larger temporal window or longer PI duration used by Strauss and colleagues (1983) did not favor temporal preparation (Niemi & Näätänen, 1981); however, in the absence of a control group of young participants in Strauss's study, this interpretation remains speculative.

A major finding of the first experiment is that the pattern of RT variation with PI varied among groups of older and younger adults. A larger age difference was observed at the shortest PI than at the longest PI, and this effect was irrespective of the temporal window. As discussed earlier, when all PIs have an equivalent probability of occurrence in a variable PI design, the probability of signal occurrence increases with time in a given trial, the subjective impression being that the shortest interval has the lowest probability. Consequently, one interpretation of the larger age-related difference in RT at the shortest PI is that older adults tend to direct their preparation toward the moment of high probability. This suggests a different response preparation strategy in older adults according to which they tend to ignore uncertain events. The hypothesis of an age-related difference in preparatory strategy with regard to uncertain events better accounts for the pattern of age-related differences in the present results than the alternative hypotheses of a slowness to prepare or a difficulty in maintaining preparation. However, PI duration may be a confounding variable in our results, because the longest intervals are always associated with the highest probability and the shortest with the lowest probability. Further evidence in favor of the uncertainty hypothesis would be obtained if older adults can prepare as much as younger adults if the probability of the shortest PI is increased. In the past, studies with young adults have shown that increasing the probability of the shortest PI in a variable-PI condition leads to a faster RT compared to a standard condition of equal probability (Baumeister & Joubert, 1969).

## Experiment 2

### METHODS

The goal of the second experiment was to directly test the hypothesis that older adults prepare to a lesser extent for the shortest PIs because of their lowest probability of occurrence.

We conducted this experiment by comparing the PI effect in two conditions: one in which the relative probability of the shortest PI is increased and one in which it is equal to that of other PIs. According to the uncertainty hypothesis, it is expected that increasing the probability of the shortest PI should reduce the age-related difference at the shortest PI.

### Participants

Participants in the experiment were 40 right-handed volunteers, 20 older adults and 20 younger adults. The selection criteria were similar to those used in the first experiment. Older participants completed a short mental examination (MMSE;  $M = 29, SD = .8$ ). Elderly participants were 16 women and 4 men with an average age of 72.3 years ( $SD = 3.8$ ). The young group was composed of 16 women and 4 men with a mean age of 21.7 years ( $SD = 1.9$ ). The level of education was 15.3 years ( $SD = 2.8$ ) for the older participants and 15.4 years for the young participants ( $SD = 1.5$ ). In the general verbal performance test (Mill Hill), the elderly and young participants scored 38 and 35 respectively,  $t(38) = 3.1, p < .05$ .

### Materials and Procedure

The experimental materials were the same as used in the first experiment. All participants completed a simple RT task in a short temporal window only. The PIs were 1, 3, or 5 s long. This condition was preferred, as this was the condition in which the largest preparatory effect was found in both age groups in Experiment 1. As in Experiment 1, the PI varied randomly but the number of PI presentations differed here among experimental conditions. In the equal probability condition, the proportion of the three PI values was equal in the block of trials. Each PI was presented 30 times for a total of 90 trials. In the skewed condition, the number of presentations for each PI was modified to increase the probability of the shortest PI. In this condition, the 1-s PI occurred on 50% of trials, the 3-s PI occurred on 30% and the 5-s PI on 20% of trials. The number of trials for each PI value was thus 45, 27, and 18 respectively for the 1-, 3-, and 5-s PIs. The participants were assigned randomly to one of the two conditions. The subgroups of older adults assigned to the equal condition were comparable with the one assigned to the skewed conditions on age (equal,  $M = 73$ ; skewed,  $M = 71$ ), education (equal,  $M = 16$ ; skewed,  $M = 15$ ), and performance on the MMSE (equal,  $M = 29$ ; skewed,  $M = 29$ ) and the Mill Hill (equal,  $M = 38$ ; skewed,  $M = 38$ ). The experimental session involved 5 practice trials in the standard condition to become familiar with the apparatus. Participants then completed one block of 90 trials in the equal or the skewed probability condition.

## RESULTS

### Initiation Time

Table 1 presents the response times for the two groups of participants in both experimental conditions. The performance of both the old and young groups of participants improved on the short PI in the skewed probability condition. It is important that, as we hypothesized, the PI effect observed in older adults assigned to the skewed condition was close to the one observed in young adults. This contrasts with the equal condition, in which the PI effect appeared to be larger in older than younger adults.

We performed a repeated-measures ANOVA on IT with age group and condition (equal vs. skewed) as between-subject factors and PI as a repeated-measures factor. This analysis revealed a main effect of group,  $F(1, 36) = 30.4, p < .001, \eta^2 = .46$ . The main effect of PI also reached significance,  $F(2, 72) = 83, p < .001, \eta^2 = .70$ , because of a significant decrease from the first to the second PI. The Group  $\times$  PI interaction,  $F(2, 72) = 11.8, p < .001, \eta^2 = .25$ , and the Condition  $\times$  PI interaction,  $F(2, 72) = 8.2, p < .001, \eta^2 = .19$ , also reached significance. What is more important is that the Group  $\times$  Condition  $\times$  PI effect was significant,  $F(2, 72) = 7.8, p < .001, \eta^2 = .18$ , confirming the observation that the pattern of PI effect among age groups differed according to the experimental condition. In the first experiment, we observed that when each PI had the same probability in a variable-PI condition, the pattern of group differences differed from the first to the second PI only. This result was replicated here. When the two age groups were compared in the equal condition, the Group  $\times$  PI interaction was significant,  $F(2, 36) = 20.5, p < .001, \eta^2 = .53$ , as a result of a larger PI effect in older adults between the first and the second PIs,  $F(1, 18) = 30.8, p < .001, \eta^2 = .63$ , a pattern that was not observed from the second to the third PI. In the skewed condition, although RT decreased significantly from the first to the second PI,  $F(2, 36) = 18.5, p < .001, \eta^2 = .51$ , the PI effect was equivalent in both groups: Group  $\times$  PI,  $F(2, 36) < 1$ .

We also applied the transformation suggested by Madden and colleagues (1992) to the data of Experiment 2. As observed in Experiment 1, the results from the regression analysis indicated that a large proportion of the older adults' performance could be explained by the performance of younger participants (Older = Young  $\times 1.8 - 128, r^2 = .78$ ). We then compared the transformed data of the younger adults with the untransformed data of older participants (see Table 1). Transforming the data did not modify any of the interactions previously reported. The PI effect observed in the equal condition remained larger in older than younger adults, as indicated by the Group  $\times$  PI  $\times$  Condition interaction,  $F(2, 72) = 3.7, p = .05, \eta^2 = .09$ . The interaction was due to a larger PI effect in the older adults compared with younger adults in the equal probability condition from the first to the second PI,  $F(1, 18) = 4.9, p < .05, \eta^2 = .21$ , which was not observed in the skewed probability condition,  $F(1, 18) < 1$ .

### Error Rate

Participants made very few anticipation errors. The mean number of anticipation errors was, respectively for the equal and skewed conditions, 1.47 and 1.17 in older adults and .47 and .67 in younger adults. Nonparametric analyses performed on error scores at each PI between the four subgroups (Kruskal–Wallis) revealed no significant group difference.

### DISCUSSION

The results of Experiment 2 revealed that, in a variable-PI condition, the performance of both the older and younger adults improved at the short PI when the likelihood of this PI was increased substantially. It is important that, in the skewed condition, the RT–PI function observed in older adults was equivalent to that of the young adults, which suggests that the improvement observed at the shortest PI from the skewed to the equal condition was larger in the older group. This finding

strongly supports the hypothesis by Lathela and colleagues (1985) that, in a variable-PI design with an equal probability of each PI, larger age effects are observed at the shortest PI because older adults do not prepare for uncertain events. Indeed, increasing the probability of the shortest PI helped older adults to prepare for this PI, leading to an equivalent RT–PI function in older and younger adults.

### GENERAL DISCUSSION

The first experiment reported in this study explored age-related differences in preparatory capacities by using simple and choice RT tasks in which the PI varied randomly between trials. The experiment reproduced preparation effects that were expected according to both temporal and specific preparation. First, response latencies (IT) decreased with an increasing PI duration from the first to the second PI. There was only a minor effect or no effect between the second and the third PI. This replicated the effect typically observed in a variable-PI design with this range of delays (Näätänen & Merisalo, 1977). Second, the effect was larger in simple than choice RT tasks, when PIs were relatively short (varying from 1 to 5 s). Again, this is in line with previous findings that temporal preparation effects are larger when combined with specific preparation, as in the simple RT task, and that they are of greatest amplitude with moderate PI duration (Niemi & Näätänen, 1981). The most important findings relevant to the study of preparation in normal aged persons is that the pattern of RT variation with PI varied among groups of older and younger adults, with a larger PI effect in older participants. It is important to note here that, using Madden's approach to control for general slowing, we observed that the age-related difference in the pattern of temporal preparation cannot be accounted for by a general-slowing factor. Moreover, the effect was found to be independent of the task (choice or simple) and the temporal window, a finding that is of major importance with regard to previous accounts of age-related differences in preparation.

The larger PI effect in older as compared with younger adults was replicated in Experiment 2 in the equal probability condition. However, when the probability of the shortest PI was increased in Experiment 2, RT decreased and the preparatory pattern observed in older adults was similar to that observed in younger adults. These results suggest that the specific deficit of older adults at the shortest PI in a variable-PI condition could be overcome by increasing the probability of the shortest PI.

The results reported here confirm with a somewhat different design results that have been previously reported in studies that used either simple (Ferraro & Moody, 1996) or choice (Lahtela et al., 1985) RT tasks. As in previous studies, in spite of spared preparation by increasing the likelihood of signal occurrence, the typical PI effect, older participants were particularly slow at the shortest PIs. An important finding of the present study is that the effect appeared irrespective of the temporal window, which suggests that the impairment that older persons exhibit with the shortest PIs in a variable-PI design is not due to temporal constraints. If this were the case, aged persons would not have been slower relative to younger adults on the first PI of the long temporal window. These results call into question the validity of the hypothesis according to which older participants take longer than younger adults to prepare a response. Results from Experiment 2 bring further support to this view by

showing that preparation can be enhanced in older adults even with a rather short PI (1 s). The present results are also incompatible with the hypothesis that older participants are unable to maintain preparation over long delays. Indeed, the IT of aged people continued to decrease with PI with intervals longer than 4–6 s (5 s in the short condition and 7 and 9 s in the long condition).

Instead, our finding favors the hypothesis that older adults experience greater difficulties preparing for uncertain events. In the paradigm used in our study, the PI varied from trial to trial and the shortest PI was associated with the lowest probability of occurrence. Impaired preparation for the first PI, in both the long and short temporal windows in Experiment 1, is thus compatible with an explanation by which aged persons do not prepare as well as do younger adults for less probable events. The results of Experiment 2 bring further support to this hypothesis, because the pattern of age-related impairment in preparation was overcome by increasing the probability of the shortest PI.

It could be argued that the tendency for older adults to reduce preparation for the least likely events may represent a compensatory strategy. Because paying attention to the entire set of PIs may be too demanding, a strategic preparation consists of paying maximal attention when there is a greater chance that a response will be required. However, our findings do not support this interpretation. When the condition yielded greater preparation for the shortest PI (Experiment 2), older participants were faster at the shortest PI relative to an equal probability and they were quite effective at responding to the longest PIs. Thus, better preparation for the shortest PI did not incur additional costs, which suggests that the preparatory effect observed in Experiment 1 reflects a preparatory strategy. We have reported findings congruent with this interpretation in a training study performed with a different set of older and younger participants. In that study, it was found that, after training in a skewed condition, both older and younger participants showed a comparable PI effect once reverted to a condition in which each PI had an equal probability (Bherer & Belleville, in press). Although the training study used a within-subject design, contrary to the study reported here, results from both studies support the hypothesis of an age-related difference in preparatory strategy that is based on flexible endogenous processes.

The results reported in the present study are consistent with recent proposals of age-related differences in attentional control, or in the control exerted on attentional behaviors (McDowd & Shaw, 2000). Preparation is a voluntary or attention-demanding strategic behavior, which relies on the ability to develop and maintain an optimal processing state prior to the execution of movement (Stuss et al., 1995). Thus, the age-related difference in temporal preparation supports the contention that age comes with impairment in the control of attention. Also consistent with the findings of the present study, a greater RT cost has been observed in older adults in a condition in which a target has a low probability of occurrence (see Experiment 1 in Hoyer & Familant, 1987). Moreover, it has been found recently that age-related impairments are related to task uncertainty in task-switching paradigms (Kray, Li, & Lindenberger, 2002).

In sum, an important feature of this study is the finding that

the magnitude of the RT slowness in older adults may fluctuate according to the responder's state, and that it is larger when preparation is minimal. Thus, as suggested by Salthouse (1985a), difficulties in response preparation may modulate the slowness of older participants on RT tasks. Rabbitt (1996) recently suggested that a slowing of RT in aged adults might be due to impairments in control and monitoring processes. Temporal or nonspecific preparation may be a useful way to further explore monitoring processes involved in RT tasks, in which very simple motor responses are required in highly controlled temporal settings (Henderson & Dittrich, 1998). Although such tasks are often considered extremely simple in terms of cognitive processing requirements, studies of preparation effects, specifically with clinical populations (Bherer et al., 2003; Gauntlett-Gilbert & Brown, 1998; Jahanshahi & Frith, 1998; Stuss et al., 1995), have shown that this approach may be misleading and that attentional control processes may play a major role even in very simple experimental situations.

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