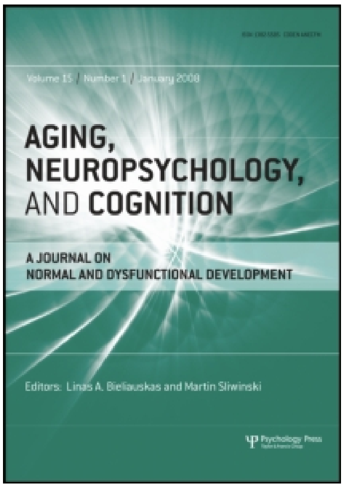

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The Effect of Training on Preparatory Attention in Older Adults: Evidence for the Role of Uncertainty in Age-Related Preparatory Deficits

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ABSTRACT

Thirty-two older adults and 20 younger adults completed a simple visual detection task in which the preparatory interval (PI; 1, 3, and 5 s) that separates the warning signal from the target varied randomly on each trial. Participants were divided into two groups. In a control condition, participants completed four blocks of trials with the three PIs occurring equally often within a block. In the experimental condition, participants completed an equal probability block (Block 1) followed by two blocks (Blocks 2 and 3) in which the shortest PI (1 s) occurred on 2/3 of the trials, followed again by an equal probability block (Block 4). In Block 1, the results indicated a larger PI effect in older than younger participants, independent of general slowing. Increasing the likelihood of the shortest PI (Blocks 2 and 3 in the experimental condition) improved RT in older and younger adults and led to an equivalent PI effect in both age groups. This was not observed in the control condition, in which the age-related difference persisted during the four blocks of trials. Importantly, the improvement observed in the experimental group was maintained in the fourth block, where the PIs were reverted to an equal probability distribution. This supports the hypothesis that elderly participants prepare for events that have the greatest probability of occurrence and that this is a flexible process that can be modulated with brief training.

Everyday situations often necessitate the execution of simple or complex actions that need to be implemented at a given moment in time. Temporal cues are sometimes useful to ensure the synchronization of a critical action in a complex situation. For instance, a yellow traffic light is intended to forewarn the driver that he or she will be required to stop shortly. This temporal information allows the driver to prepare to stop at the red light. Preparing an action is a voluntary or attention-demanding strategic behavior (Stuss, Shallice, Alexander, & Picton, 1995), which relies on basic cognitive mechanisms, namely the ability to activate and maintain a specific action schema prior to stimulus occurrence. Preparatory processes have been a major concern in research on action control impairments (Henderson & Dittrich, 1998; Jahanshahi & Frith, 1998) and their neurological basis (Brunia, 1999; Brunia & van Boxtel, 2001; Jahanshahi & Frith; Jeannerod, 1997).

In experimental settings, the participants' ability to synchronize their actions in time can be assessed with a reaction time (RT) paradigm, in

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which the participants are asked to respond as quickly as they can to a specific stimulus. It has long been known that in such tasks, RT is not only modulated by the cognitive processes involved in the task, but also by preparatory processes that allow the participant to optimize the forthcoming response (Henderson & Dittrich, 1998). The temporal parameters of the task provide cues that allow a faster response at the moment when the target is most likely to occur, a behavior which is sometimes referred to as temporal preparation. In a typical RT task, the preparatory interval, which separates a warning signal from the response signal, is the most salient time parameter and thus manipulating this interval allows for an assessment of participants' ability to use time information to optimize their performance (Bertelson, 1967; Boons & Bertelson, 1961).

It has been reported previously that older adults show preparatory deficits in RT tasks (Botwinick, Brinley, & Robbin, 1959; Gottsdanker, 1982; Loveless & Sanford, 1974; Strauss, Wagman, & Quaid, 1983), suggesting that preparatory processes may become impaired with age. More recently, Hillman, Weiss, Hagberg, and Hatfield (2002) 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 the presence of increased neural resources devoted to preparation for an imperative signal. The authors suggested that neural processing is less efficient in seniors when they anticipate an upcoming event. Salthouse (1985) originally proposed that the preparatory deficit in older adults could be explained either by a slowing in the development of an optimal processing state, or an inability to maintain preparation over long delays. However, empirical results in support of these hypotheses do not abound, and comparing results from different studies is somewhat difficult, due in part to the use of divergent temporal parameters (Bherer & Belleville, in revision). Of great importance to the study of temporal preparation is the duration of preparatory intervals used in the RT tasks, as well as the way preparatory intervals vary within a block of trials.

The effect of the preparatory interval (PI) on RT has been well documented in young adults (e.g., Niemi & Näätänen, 1981). Typically, different PI values are used in a given experiment either in a fixed PI design, in which the PI is constant within a block of trials, or in a variable PI design, in which PIs of different lengths vary randomly within a block of trials. Results with fixed PI designs have brought partial support to the hypothesis that older adults may have difficulty maintaining preparation over long delays. Indeed, in a fixed PI design, RT is known to increase with PI value (e.g., 4–6 s) and this effect seems to be greater in older adults (Botwinick, 1965; Botwinick et al., 1959; Gottsdanker, 1982; Strauss et al., 1983). However, results with a variable PI design do not support the maintaining hypothesis and lead to a different hypothesis in regard to preparatory deficit in older adults.

In a typical variable PI design, each PI occurs the same number of times in a given block of trials (rectangular distribution). RT is usually longer with the shortest PI value and tends to decrease for longer ones (Näätänen & Merisalo, 1977; Polzella, Ramsey, & Bower, 1989; Requin & Granjon, 1969; Requin, Granjon, Durup, & Reynard, 1973; Stilitz, 1972). This has been suggested to reflect signal expectancy (Stilitz). RT decreases with time because stimulus likelihood increases. For instance, if PIs of 1, 2 and 3 s occur randomly in a block of trials, the probability that the signal will occur after one second is 1/3, then it increases to 1/2 at 2 s and it is perfect at 3 s. Participants use this probability of occurrence to modulate and increase preparation over time. This classic effect has been found in elderly persons. Lahtela, Niemi, and Kuusela (1985) reported a decrease in the RT of older adults in a variable PI design, even when the PIs were extended up to 6 s (PI = 2, 4, 6 s). This suggests that preparation is still possible up to this length of delay, and thus older adults do not show difficulty in maintaining preparation. However, they found an important age effect, with the shortest delay resulting in a different RT-PI function. Lahtela et al. (1985) interpreted their data as reflecting a poor preparation for uncertain events in older adults, since the shortest PI has the lowest probability. However, slowness to prepare a response, as suggested by Salthouse (1985), could also account for this pattern of results.

Further support for the uncertainty hypothesis that older adults may not prepare their response for uncertain events (Lahtela et al., 1985) has been observed recently (Bherer & Belleville, 2002, Exp. 1; Bherer, Belleville, & Gilbert, 1998). A reduced preparation at the shortest PI was reported in older adults, yielding a Group by PI interaction in simple and choice RT tasks with short (1, 3 and 5 s) and long (5, 7 and 9 s) temporal windows. The design was otherwise typical, with the three PI values equally distributed in a block of trials. Importantly, this was not simply related to slowness in developing preparation, since it was observed in both the long and the short time windows. Moreover, the effect remained after controlling for the main level of RT slowing in older adults (Bherer & Belleville, in revision), using the technique proposed by Madden, Pierce, and Allen (1992), which suggests that the age-related differences were task specific and cannot be accounted for entirely by a general slowing factor (Salthouse, 1996). A difficulty in developing rapid preparation could not account for this pattern of results, nor could they be explained by the maintaining hypothesis, since preparation occurs up to 5 s. Thus, these results strongly support the uncertainty hypothesis. These findings suggest that in a variable design with a rectangular distribution of PIs, larger age effects are observed at the shortest intervals because the likelihood of stimulus occurrence is weak.

The uncertainty hypothesis also leads to two predictions with regard to RT performance in a variable PI design. First, it can be predicted that increasing the probability of the shortest PI interval would lead older adults to react faster at this PI, producing a flat RT-PI function (see Niemi & Näätänen, 1981, for results with younger adults) and that this should reduce the age-related difference in the RT-PI function. A second prediction comes from the interpretation of the preparatory effect. The uncertainty hypothesis suggests that preparation relies on attentional controlled processes (Stuss et al., 1995) and thus the larger PI effect observed in older adults reflects an attentional strategy (endogenous factor) that is not necessarily or entirely related to the PI distribution (exogenous factor). A strategic interpretation would predict that once older adults are trained to adopt a different strategy, by increasing the likelihood of the shortest PI (skewed probability condition), the learned strategy would generalize to a typical variable PI design in which each PI has equal likelihood.

The present study investigated whether training older adults in a skewed probability condition would lead them to adopt a less conservative preparatory strategy and whether this would reduce the age-related deficit in temporal preparation observed in previous studies (Bherer et al., 1998; Lahtela et al., 1985). A control group of older and younger adults allowed for an assessment of the effect of training on the RT-PI function. Although there was only a small amount of training/practice in the present experiment, the experimental condition is referred to as the training condition to emphasize that changing PI likelihood is intended to induce a different strategy that should not be observed in the control group, who simply practiced the task repeatedly in an equal probability condition.

The use of a home key allowed for the disentangling of initiation time and execution time from the global response latency. Having applied this technique to a simple and a choice visual detection task, both with normal older adults (Bherer & Belleville, 2002; in revision) and Parkinson's Disease patients (Bherer, Belleville, & Gilbert, in press), we observed that temporal preparation had a large impact on initiation time with almost no effect on execution time. It was thus expected that the training procedure would mainly improve initiation time, rather than the execution time portion of the response latency.

METHOD

Participants

Participants were 32 right-handed older adults and 20 right-handed young adults living in the community, in Montréal, Canada. Senior volunteers ranged in age from 63 to 82 years and young adults ranged from 19 to 26 years of age. A short health questionnaire was used to exclude any major disease that could impact on cognitive performance. Thus, none of the participants had suffered from psychiatric disorders, had a history of neurological disease or took medications known to affect cognitive functions. Moreover, questionnaires on past and present auditory and vision abilities were used

Table 1. Characteristics of Participants (Standard Deviation Are Shown in Parenthesis).

Groups	N	Age	Education (years)	Mill Hill	DSST	MMSE
Control						
Older	16	70.2 (5.1)	13.8 (3.5)	36 (5.8)	12 (1.9)	29.1 (0.9)
Younger	10	22.7 (2)	16 (1.2)	36.9 (2.9)	13 (2.3)	–
Experimental						
Older	16	70.5 (5.2)	15.8 (3.7)	35.4 (5.4)	12 (2.1)	28.9 (0.7)
Younger	10	22.3 (1.8)	15.9 (1.1)	36.8 (2.6)	13 (2.8)	–

to screen any participants who suffered from major perceptual impairments. To exclude persons with early dementia or developmental cognitive deficiency, senior participants completed a short mental examination (Mini-Mental State Examination, Folstein, Folstein, & McHugh, 1975) and all participants completed a vocabulary test (Mill Hill) and a psychomotor speed test (Digit symbol coding test of the WAIS–R). Participants were randomly assigned to the control or the experimental condition (see description below). Sixteen older participants, 4 males and 12 females, completed the control condition and 16 older adults, 5 males and 11 females, were trained in the experimental condition. In younger adults, 10 participants, 3 males and 7 females, completed the control condition and 10 others, 3 males and 7 females, were assigned to the experimental condition. Table 1 shows the mean chronological age, level of school education and performance on the screening tests for the four groups. With the exception of age, $p < .001$, there was no statistical difference between the four subgroups on these characteristics ($F = 1.8$, for education level and $F < 1$, for the other measures).

Materials

The experiment was under the control of *Psyscope 1.0.1* (Cohen, MacWhinney, Flatt, & Provost, 1993) running on a MacIntosh PowerPC. The preparatory signal was a tone of 1000 Hz presented at 80–85 db for 250 ms. The target signal was a black circle of 4 cm presented on a white background and in the centre of a 14-in. computer screen. In each trial, 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 by 13 cm panel separated by 3 cm. This device allowed for the measurement of response time to the nearest ms.

Procedure

Participants completed a simple visual detection task. In this task, the letters "O.K." appeared in the center of the computer screen prior to 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 "O.K." disappeared and the auditory preparatory signal occurred. The auditory signal served to indicate that pushing the central button properly started the trial and thus it also indicated the exact trial onset occurrence. The preparatory interval (PI) separated the preparatory signal and the target occurrence, during which a black cross appeared in the middle of the computer screen as a fixation point. PI values of 1, 3 and 5 s were used. These PIs were presented randomly within a block of trials. Participants were required to push the central button until the occurrence of the imperative signal (the black circle). The PI ended with the black circle appearing in the center of the computer screen. The participant reacted by quitting the home key and pushing the response key to the right of the home key as quickly as possible. After a 250 ms interstimulus interval, the "O.K." signal appeared again, indicating to the participant that he or she could start a new trial. First, participants completed five practice trials to ensure that the procedure was properly understood. Participants then completed four blocks of 90 trials. Two consecutive blocks were separated by a rest period of 5–10 min, during which participants completed the clinical test and questionnaires described above.

The experiment consisted of four blocks of trials (Blocks 1–4). There were two conditions which differed according to the number of times each PI was presented within the second and third blocks of trials. In the control condition, each PI occurred the same number of times in the four blocks of trials: for each block the three PIs occurred 30 times, for a total of 90 trials within a block. In the experimental condition, each PI also occurred 30 times in the first block. However, in Blocks 2 and 3, the shortest PI was presented on 2/3 of the trials. In these two blocks, there were 60, 20 and 10 trials for the 1, 3 and 5 s PI respectively. In Block 4, the number of trials with each PI value was equal, meaning that each PI was presented 30 times.

RESULTS

Response initiation (IT) was measured as the time elapsing from the occurrence of the imperative stimulus to the moment when participants removed their finger from the home key. The execution time (ET) was the remaining portion of the global reaction time (i.e., the time taken to move from the home key to the response key). Anticipate responses (i.e., leaving the home key before the imperative signal) were not included in the analyses (mean numbers of anticipation are presented below). Furthermore, trials were rejected if the IT was shorter than 100 ms or if the global response time was longer than 3000 ms, which resulted in the exclusion of 0.20% of the trials in older adults and 0.04% in the younger adults.

Figure 1 shows the IT in the four blocks of trials for both older and younger adults in the control and the experimental condition. An inspection of the data reveals that the effect of PI differed across blocks as a function of the experimental conditions. In fact, in the second and third blocks, IT improved considerably at the first PI in participants trained in the experimental condition relative to participants in the control condition, and this was true for older and younger adults. Moreover, older and younger adults showed a parallel IT-PI function in the third and the fourth block, despite the fact that in the last block each PI was presented the same number of times. In the control condition, IT never improved at 1 s in older adults as it did in the experimental condition, and the PI effect appeared to be larger in older than younger adults in all four blocks of trials.

Age-Related Difference in PI Effect

Analysis of participants' performance in the first block allowed us to replicate, with a group of new participants, the age-related differences previously observed in this task (Bherer et al., 1998). An ANOVA performed on mean initiation time (IT), with Age group and Condition (Experimental vs. Control) as between subject factors and PI as a within subject factor, showed that older adults took more time to initiate their response than younger adults, $F(1, 48) = 26$, $p < .001$, $\eta^2 = 0.35$. Mean IT was 360 ms for older adults and 289 ms for young adults. IT also decreased with increasing PI duration in both groups (the classical PI effect), $F(2, 96) = 71.8$, $p < .001$, $\eta^2 = 0.60$. A significant Age by PI interaction also indicated that the PI effect was larger in older adults, $F(2, 96) = 10.8$, $p < .001$, $\eta^2 = 0.18$. The mean IT was, for the 1, 3 and 5 s PI's respectively, 432, 327, 321 ms in older adults and 321, 276, 271 ms in younger participants. Simple effects analyses revealed that IT significantly decreased with PI in both older, $p < .001$, $\eta^2 = 0.65$, and younger adults, $p < .001$, $\eta^2 = 0.18$, and that the difference among groups was significant at each of the three PI values ($p < .001$ for the 1st, the 2nd and the 3rd). It is important to emphasize that the pattern of age-related differences was equivalent among experimental groups, as indicated by the absence of an Age × Condition × PI interaction, $F(2, 96) < 1$, $\eta^2 = 0.002$.

The Age by PI interaction appeared to be due to a larger PI effect in the elderly groups (see effect sizes of the simple effects reported above). This was confirmed by conducting repeated-contrasts, which compare the reduction in IT between two consecutive PI values across age groups (SPSS, 1997). These contrasts indicated that the decrease of IT from the first to the second PI was significantly different across the age groups, $F(1, 48) = 11.5$, $p < .001$, $\eta^2 = 0.19$, being larger for the older group (105 ms) than for younger participants (45 ms). Differences in IT between the second and third PIs were equivalent among Age groups, $F(1, 48) < 1$, *ns*, $\eta^2 = 0.00$. Unexpectedly, and despite random assignment of the participants to the experimental condition, the groups assigned to the experimental condition (older and younger) showed a slower IT than the control group, $F(1, 48) = 4.9$, $p < .05$, $\eta^2 = 0.09$. The mean IT was 309 ms in the control group and 340 ms in the experimental group. Importantly, this difference did not interact with age, $F(1, 48) < 1$, *ns*, $\eta^2 = 0.01$, which also indicates that the age-related slowing was roughly the same in the control (79 ms) and experimental group (63 ms).

Cognitive aging theoreticians have often suggested that when a main group difference exists in RT, an interaction with age and the

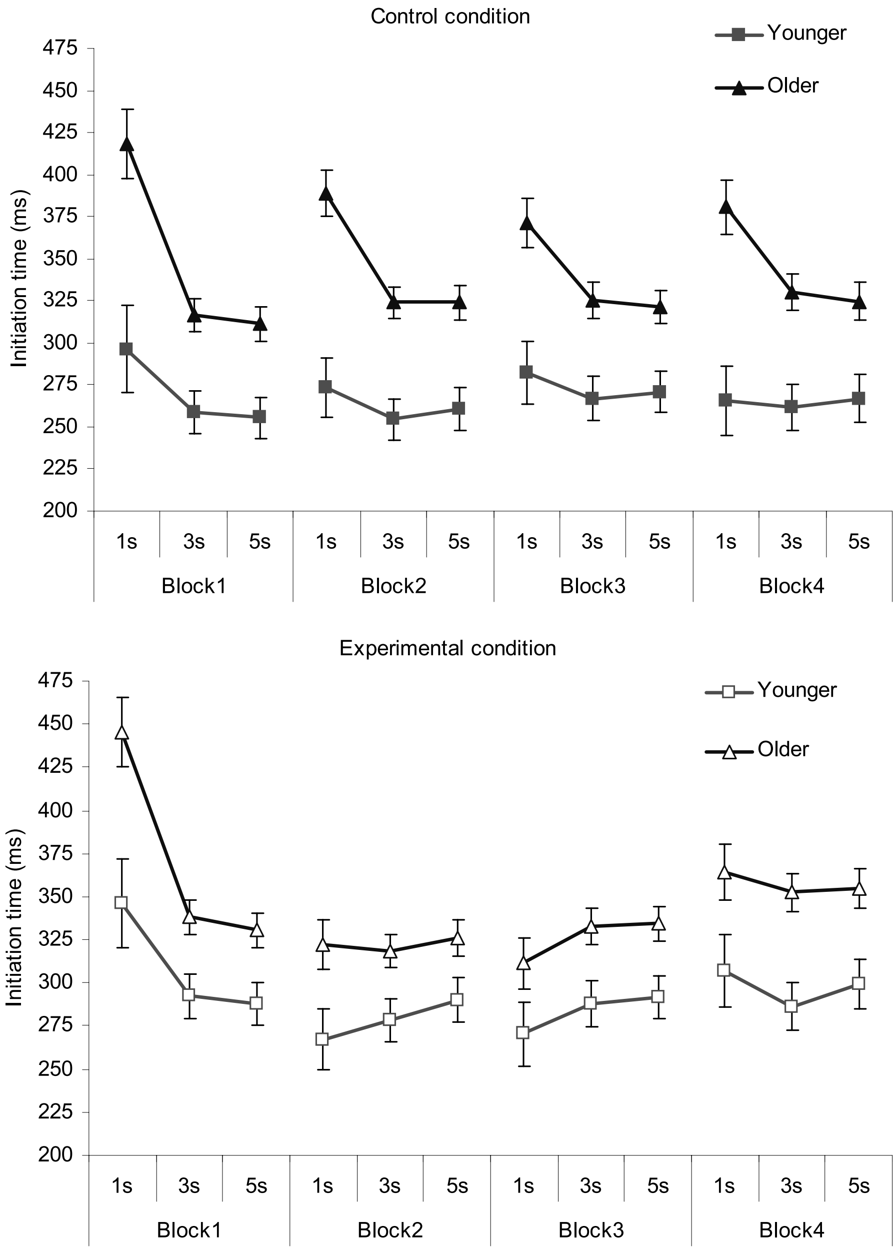

Fig. 1. Mean initiation time (ms) as a function of preparatory intervals in the four blocks of training for the control groups (upper portion) and the experimental groups (bottom portion) of older and younger participants.

independent variable should be interpreted cautiously (Belleville, Rouleau, & Caza, 1998; Loftus, 1978; Salthouse, 1996). It could be argued that the Group by PI interaction reported here is a mere effect of general slowing, with the larger PI effect in older adults being proportional to RT slowing. Different approaches have been proposed to control for spurious age effects due to a difference in the general level of performance (see Madden, 2001). One method consists of eliminating the main group difference by transforming the data of the younger adults, based on the regression equation between older and younger adults RTs (Madden et al., 1992). This transformation method has the advantage of correcting for the age difference in baseline RTs (see Madden) and thus controls for general slowing observed in the task of interest. Madden et al. argued that if an interaction remains after transforming the RT of younger adults with this method, it is likely that the interaction is due to an age-related difference that is independent of general slowing. We applied the transformation suggested by Madden et al. to our data. A regression analysis on the IT of older and younger adults indicated that a large proportion of the older adults' performance can be explained by the performance of younger participants (Older = Young $*$ 1.5–85, $r^2 = .77$), which suggests that general slowing can account for a substantial amount of the IT difference between older and younger adults in our task. We then transformed the data of the young participants according to the equation of the regression analysis. An ANOVA performed on the transformed data for younger adults and untransformed data for older adults indicated that although the main age-related difference in IT was no longer significant after the regression-based transformations, $F(1, 48) < 1$, $\eta^2 = 0.01$, the Age by PI effect remained significant, $F(2, 96) = 3.5$, $p < .05$, $\eta^2 = 0.07$, due to a larger PI effect in older participants between the first and the second PI, $F(1, 48) = 3.9$, $p = .05$, $\eta^2 = 0.08$. This suggests that a general slowing factor alone cannot account for the age-related difference in the pattern of PI effect observed in Block 1.

The Effect of Increasing the Likelihood of the Shortest PI

As shown in Figure 1, increasing the likelihood of the shortest PI in the Experimental condition (bottom panel) lead to fastest RT at this PI in Blocks 2 and 3, which results in a flatter IT-PI function. In Block 2, a slight PI effect seems to remain in the aged group, but not in the young participants. In the Control groups (upper panel) a typical IT-PI function was still observed in Blocks 2 and 3, although practice lead to a slight reduction in IT at the first PI. Results of an ANOVA confirm these observations. In Block 2, the analyses showed a significant age effect, $F(1, 48) = 28.5$, $p < .001$, $\eta^2 = 0.37$. The mean IT was 334 ms in older and 271 ms in younger adults. The age-related difference was equivalent in the experimental and control conditions as indicated by the absence of an Age by Condition interaction, $F(1, 48) = 2.7$, *ns*, $\eta^2 = 0.05$. A general PI effect, $F(2, 96) = 8.1$, $p < .001$, $\eta^2 = 0.14$, was observed. The Age by PI interaction was also significant, $F(2, 96) = 8$, $p < .001$, $\eta^2 = 0.14$. Repeated-contrasts indicated a larger PI effect in older adults than in young participants from the first to the second PI, $F(1, 48) = 9.1$, $p < .01$, $\eta^2 = 0.16$. The mean IT was, at 1, 3, and 5 s respectively, 356, 321 and 325 ms in older adults and 270, 266 and 275 ms in younger adults. A Condition by PI interaction was also observed, $F(2, 96) = 17.4$, $p < .001$, $\eta^2 = 0.27$, due to a larger PI effect between the first two PIs, $F(1, 48) = 20.3$, $p < .001$, $\eta^2 = 0.30$, in the control condition as compared to the experimental condition. The mean IT was, at 1, 3, and 5 s respectively, 331, 289 and 292 ms in the control group and 295, 298 and 308 ms in the experimental group. The three-way interaction did not reach significance; Age × Condition × PI interaction, $F(2, 96) = 1.8$, *ns*, $\eta^2 = 0.04$, which suggests that the experimental manipulation lead to a major improvement at the shortest PI in both older and younger adults, despite the apparent larger improvement in younger participants. Indeed, comparing older and younger adults only in the experimental condition confirmed the absence of a Age by PI interaction, $F(2, 48) = 1.7$, *ns*, $\eta^2 = 0.07$. To control for age-related general slowing, additional analyses were conducted after transforming the RT scores of younger adults according to the regression equation between the initial RT performance of older and younger adults (using the equation from Block 1). Analyses with the regression-based transformed data revealed that the Group by PI effect remained significant, $F(2, 96) = 7.7$, $p < .001$, $\eta^2 = 0.14$, even in the absence of an age-related difference, $F(1, 48) < 1$, $\eta^2 = 0.02$. The Condition by PI interaction also remained significant with the transformed data, $F(2, 96) = 22$, $p < .001$, $\eta^2 = 0.31$.

Although only the young participants showed a flat IT-PI function as early as in Block 2, it appeared that older adults benefited from the second to the third block. Only in the third block did older adults show an IT-PI function parallel to the young adults' function. In the control groups, the PI effect remained despite practice. The analyses confirmed this pattern. As in the previous blocks, a general age-related difference was observed, $F(1, 48) = 21$, $p < .001$, $\eta^2 = 0.30$. The mean IT was 333 ms in older adults and 278 ms in younger adults. Again, the age-related slowing was equivalent in the experimental and control conditions, Age by Condition, $F(1, 48) < 1$, *ns*, $\eta^2 = 0.02$. A significant Condition by PI interaction, $F(2, 96) = 14.7$, $p < .001$, $\eta^2 = 0.23$, confirmed that the PI effect differed among Condition groups between the first two PIs, $F(1, 48) = 16.7$, $p < .001$, $\eta^2 = 0.26$. In the control group, the mean IT was 327, 296 and 296 ms, respectively, for the 1, 3 and 5 s PIs. The corresponding means in the experimental group were 291, 310 and 313 ms. Although the PI effect was larger in the control group of older adults as compared to younger controls, the three way interaction failed to reach significance, $F(2, 96) = 2$, *ns*, $\eta^2 = 0.04$. Here again, the pattern of results remained unchanged with the regression-based transformed data, which allows for the control of the effects of age-related general slowing. Analyses with the transformed data showed a significant Condition by PI interaction, $F(2, 96) = 17$, $p < .001$, $\eta^2 = 0.26$, in the absence of a general age-related difference, $F(1, 48) = 2$, *ns*, $\eta^2 = 0.00$.

Transfer to an Equal Probability Condition

We hypothesized that learning to prepare for the shortest PI in Blocks 2 and 3 would allow older adults to prepare better for the shortest PI and that this would generalize to a condition in which PIs had an equivalent likelihood. As a result, older adults' preparatory deficit in an equal probability condition should no longer be observed. This seems to be the case, as results from the fourth block, in which PIs had an equal probability in the experimental condition, revealed a parallel IT-PI function in older and younger adults. In contrast, in the control group, the PI effect still appeared to be larger in older compared to younger adults. The ANOVA indicated that older participants were slower than younger participants, $F(1, 48) = 28.7$, $p < .001$, $\eta^2 = 0.37$. The mean IT was 351 ms in older adults and 281 ms in younger adults. As observed in the previous blocks, the age-related difference was of the same magnitude among Condition groups, Age by Condition interaction, $F(1, 48) < 1$. As observed in the first block, the experimental groups responded slower overall than the control groups. The mean ITs were 305 and 327 ms for the control and the experimental groups respectively, although this effect failed to reach significance in Block 4, $F(1, 48) = 3$, *ns*, $\eta^2 = 0.06$. Also, as observed previously, IT significantly decreased with PI, $F(2, 96) = 6.9$, $p < .01$, $\eta^2 = 0.13$.

More importantly, the analyses revealed a significant Age × Condition × PI interaction, $F(2, 96) = 3.3$, $p < .05$, $\eta^2 = 0.06$, and thus confirmed that the PI effect varied as a function of Age groups and experimental conditions, which contrasts with the results observed with the same experimental conditions in Block 1. ANOVAs comparing older and younger adults separately in each condition showed a significant PI effect, $F(2, 96) = 4.2$, $p < .05$, $\eta^2 = 0.13$, along with the typical Group by PI interaction in the control condition, $F(2, 48) = 3.9$, $p < .05$, $\eta^2 = 0.14$, despite four practice blocks. This contrasts with the experimental condition in which a PI effect was observed, $F(2, 48) = 3.6$, $p < .05$, $\eta^2 = 0.13$, however, this effect was equivalent for older and younger adults, Group by PI, $F(2, 48) < 1$, $\eta^2 = 0.02$. Here again, the pattern of age-related differences remained unchanged using the regression-based transformed data to control for age-related general slowing. The analysis with the transformed data revealed a significant three-way interaction, $F(2, 96) = 3.6$, $p < .05$, $\eta^2 = 0.07$, as well as a significant Group by PI interaction in the control condition, $F(2, 48) = 3.6$, $p < .05$, $\eta^2 = 0.13$, despite the correction for age-related slowing, $F(1, 48) < 1$, $\eta^2 = 0.02$.

The results in Figure 1 suggest that the experimental condition produced a modified response bias in older adults, leading to an overall cost in RT in the fourth block. However, there are several reasons why this is unlikely, or at least that this is not related to age. First, the Experimental

Table 2. Mean Execution Time (ms) as a Function of Block and PI. Standard Errors Are Shown in Parenthesis.

Groups	Block 1			Block 2			Block 3			Block 4		
	1 s	3 s	5 s	1 s	3 s	5 s	1 s	3 s	5 s	1 s	3 s	5 s
Control												
Older	131 (12)	153 (13)	157 (13)	141 (13)	166 (13)	164 (14)	157 (13)	166 (14)	176 (16)	142 (11)	165 (14)	167 (15)
Younger	95 (16)	102 (16)	98 (17)	81 (16)	93 (17)	89 (18)	82 (16)	90 (17)	87 (20)	90 (14)	93 (18)	93 (18)
Experimental												
Older	160 (12)	187 (13)	184 (13)	148 (13)	177 (13)	188 (14)	148 (13)	167 (14)	169 (16)	142 (11)	168 (14)	163 (15)
Younger	104 (16)	109 (16)	106 (17)	99 (16)	104 (17)	98 (18)	102 (16)	106 (17)	98 (20)	103 (14)	107 (18)	103 (18)

condition seemed to produce greater improvement overall from the first to the fourth block (340–327 ms) compared to the Control condition (309–305 ms). Thus, if anything, the difference between the Experimental and the Control groups decreased in the course of training. Second, and most importantly, the absence of an Age by Condition interaction in Block 4 shows that the magnitude of the age effect is equivalent in the control and experimental conditions, which suggests that the experimental condition did not produce an extra cost in older adults' overall performance. Third, the age-related difference in IT in the fourth block of the control (81 ms) and experimental (57 ms) conditions was roughly equivalent to the difference observed in the first block (79 and 63 ms for the control and experimental conditions, respectively). Taken together, these observations suggest that if the experimental condition modified the response bias and produced a cost in overall RT in Block 4, it did not affect the pattern of age-related differences in performance.

Execution Time

The pattern of Execution time (ET), shown in Table 2, was quite similar through all four blocks of trials. Specifically, ET was generally slower for older than younger adults and tended to increase slightly from the first to the second PI. This replicated the pattern of results observed previously with this paradigm. ANOVAs performed on Execution time (ET) showed that ET was significantly slower in older than younger participants in Block 1, $F(1, 48) = 18$, $p < .001$, $\eta^2 = 0.28$, Block 2, $F(1, 48) = 23.4$, $p < .001$, $\eta^2 = 0.33$, Block 3, $F(1, 48) = 21$, $p < .001$, $\eta^2 = 0.30$, and Block 4, $F(1, 48) = 16$, $p < .001$, $\eta^2 = 0.25$. ET increased significantly with PI in Block 1, $F(2, 96) = 13$, $p < .001$, $\eta^2 = 0.21$, Block 2, $F(2, 96) = 9.7$, $p < .001$, $\eta^2 = 0.17$, Block 3, $F(2, 96) = 3.8$, $p < .05$, $\eta^2 = 0.07$, and Block 4, $F(2, 96) = 10$, $p < .001$, $\eta^2 = 0.17$. In general, the ET increment was larger in older than younger adults, as indicated by a Group by PI interaction that reached significance only in Block 1, $F(2, 96) = 6.2$, $p < .01$, $\eta^2 = 0.11$, Block 2, $F(2, 96) = 4.5$, $p < .05$, $\eta^2 = 0.09$, and Block 4, $F(2, 96) = 6.6$, $p < .01$, $\eta^2 = 0.12$. Importantly, neither the age-related difference $F(1, 48) < 1$ for all blocks, nor the Group × PI interaction, $F(2, 96) < 1$ for all blocks, interacted with the experimental condition. It is also important to note that the Group × PI interaction was no longer significant when the analyses were performed with the younger adults' transformed data based on the regression equation between older and younger ET in Block 1 (Old = Young ∗ 3.7–214, $r^2 = 91$). The transformed data showed no interaction between Group and PI in Blocks 1 and 2, $F(2, 96) \leq 1$, and in Blocks 3 and 4, $F(2, 96) \leq 2$, once age-related slowing was controlled for; age group difference in Blocks 1 and 4, $F(1, 48) < 1$, and in Blocks 2 and 3, $F(1, 48) = 2$. These results suggest that the interaction is likely an artifact of general slowing.

Anticipation Rate

In general, participants made few anticipation errors. In older adults, the mean number of anticipations was, respectively, for the control and the experimental groups: 0.7 and 0.9 at 1 s, 1.1 and 1.1 at 3 s, and 1.2 and 0.6 at 5 s. In younger adults, the corresponding mean number of anticipations was: 0.1 and 0.3 at 1 s, 0.2 and 0.3 at 3 s, and 0.4 and 0.4 at 5 s. Due to the small number of errors and the frequent repetition of 0 or 1 total scores, non-parametric tests were used to assess group differences on anticipations at each PI. The analyses (Kruskal–Wallis) showed a group difference at the first, $p < .05$, and second PI, $p < .05$, but not the third PI. Group comparisons (Mann–Whitney) revealed that in both experimental conditions, older adults tended to produce more anticipations than younger adults at 1 s, $p < .05$, and 3 s, $p < .05$, but not at 5 s. There was no difference between the control and the experimental condition in older and younger adults.

DISCUSSION

Three main findings emerged from the present study. First, increasing the probability of the shortest interval (experimental condition) in a variable PI design reduced the RT for this particular interval. Older adults seemed to benefit more from this manipulation, as both age groups showed a parallel RT-PI function (see Block 3) despite the initial larger PI effect observed in older adults. Second, improving RT at the shortest PI occurs with no major cost for the longest PIs. Third, following this manipulation, older and younger participants had parallel RT-PI functions even when exposed to an equal probability condition. Each of these findings will be discussed, along with their possible impact on the interpretation of preparation deficits in older adults.

Before providing an interpretation to the aforementioned findings, it is important to note that performance on Block 1 replicates previous results observed with a variable PI condition. Specifically, older adults show a larger PI effect compared to younger adults, due to a disproportional slowing at the shortest PI. This has been observed in different experimental conditions, with choice RT (Bherer & Belleville, in revision; Bherer et al., 1998; Lahtela et al., 1985) and simple RT tasks (Bherer & Belleville, in revision), and with long and short PI durations (Bherer et al., 1998). Moreover, and as observed in the present study, this effect cannot be fully explained by a general slowing account (Bherer & Belleville, in revision).

The present study suggests that there are differences in the preparatory patterns of older and younger adults (see also Hillman et al., 2002). When older adults are asked to provide a fast response in a given time window, they tend not to prepare when the stimulus likelihood is low. This contrasts with recent reports that no age-related preparatory deficit exists in task switching (Meiran, Gotler, & Perlman, 2001). Meiran et al. (2001) found that older participants used a cue-target interval as effectively as younger adults to better switch among tasks. As noted by the authors, this type of preparation likely relies on the ability to activate in advance a specific task-set (Meiran et al., 2001, p. 98). To prepare for a new task-set in a task-switching paradigm, the participants need to activate all possible stimulus-response combinations involved in the forthcoming task. In a typical task-switching paradigm, the identity of the forthcoming stimulus, and related answer, is not known in advance, and thus specific preparation cannot occur. It might be argued that preparation of a specific motor response to a simple stimulus, as required in the paradigm used in the present study, allows for optimally speeded performance and that age-related differences with regard to preparation emerge only in this condition. Moreover, a fundamental aspect of our paradigm is that temporal and probabilistic information must be used to prepare an optimal response. The results reported here indicate that in spite of intact abilities to prepare a response when provided with a cue, age impairs the ability for temporal preparation, or the ability to synchronize a specific action in a temporal window and as a function of temporal probability. It is worth noting that the large age-related difference in conditions of high uncertainty (i.e., at the shortest PI) is consistent with recent findings with the task-switching paradigm, which indicated that age-related impairments in the task-switching component are related to task uncertainty (Kray, Li, & Lindenberger, 2002). Thus, the necessity to use probabilistic information to prepare a forthcoming response in the present study could explain the difference between our results and the observations of Meiran et al. (2001).

An important finding of the present study is that preparation can be modulated in younger and older adults by manipulating the conditional probability of events. In a condition that shifted the conditional probability towards the earliest PI, performance was dramatically improved for this PI. Moreover, after sufficient practice, senior participants benefited from this condition to a greater extent than younger participants. This result is congruent with the uncertainty hypothesis, which suggests that older individuals modulate their level of preparation to the disadvantage of the least probable events (Lahtela et al., 1985). In conditions where all PIs occurs the same number of times in a block of trials (rectangular distribution as in Block 1), aged persons show reduced preparation for the shortest interval relative to that of young persons. It was proposed that older adults favor preparation for the most probable events to the detriment of the least probable ones, supporting the uncertainty hypothesis. The rationale for this interpretation is that stimulus likelihood increases with time in a variable PI design, with the probability of occurrence being maximal for the longest PI. Additional support for this interpretation comes from our finding that increasing the probability of the shortest PI in Blocks 2 and 3 yields to parallel RT-PI functions in older and younger adults. Thus, older adults can prepare as much as younger adults for the shortest PI in a variable PI design as much as the likelihood of this PI is significantly increased.

It could be argued that reducing preparation for the least probable events in older persons results from a compensatory strategy. Paying attention to the entire set of PIs may be too demanding for older adults. Thus, reducing preparation for the least likely events may represent a form of adaptive strategy used by the older participants to optimize their performance throughout the task. This strategy would represent the best cost-benefit solution to the task. Whereas it may still be the case that older are unable to sustain attention to the whole set of PIs, our findings do not support this. When the condition yielded greater preparation for the shortest PI, as in Blocks 2–3 of the experimental condition, older participants although faster at the shortest PI relative to an equal probability condition, were still quite effective in responding to the longest PIs. Moreover, this does not result in a larger age-related slowing, since the magnitude of the age-related slowing remained the same through all four blocks in the experimental condition. In sum, preparing better for the shortest PI did not incur additional costs. In contrast, the procedure resulted in improving attentional modulation in older adults to encompass the whole temporal window, or all actual PI values.

The third main finding of the present study was that after training in a skewed probability condition, older and younger adults showed a comparable pattern of results (parallel RT-PI functions) once exposed to a condition in which each PI had the same likelihood (Block 4). Thus, it seems that the preparatory strategy to perform faster at the shortest PI, with no extra cost at the longest PIs, can be adopted irrespective of the actual PI distribution. This suggests that the temporal preparatory pattern observed in the RT task reflects a preparatory strategy based on flexible endogenous processes that can be improved in older and younger adults.

The results of the present study suggest that the control of attentional behavior can be modulated and enhanced in older adults and that this can be generalized to other conditions. When elderly participants are in a position to experience proper preparatory abilities, they can re-adjust their strategy and show evidence of accurate preparation even in a condition that does not favor the earliest items. This also seems to support the notion that impairment in the control of attentional behavior may explain the attentional deficits of older adults in some conditions (McDowd & Shaw, 2000). Other studies have shown that attentional control can be enhanced in older adults. Kramer, Hahn, and Gopher (1999a) reported that with practice, the task-switching cost of older participants could be reduced to that of young adults. It has also been observed that older adults can benefit from training in dual-task performance (Kramer, Larish, Weber, & Bardell, 1999b). Interestingly, the dual-task training procedure used by Kramer et al. (1999b) that produced the greater improvement requires a change in priority between concurrent tasks. Thus, participants in this variable priority condition could experience the effectiveness of different strategies. Although different paradigms were used, an important similarity between the variable priority training used by Kramer et al. (1999b) and the training condition used in the present study was that the experimental condition imposed a greater challenge to the participants and forced them to experience the efficacy of a different strategy. In contrast, the control group (who practiced the task repeatedly) did not overcome the age-related decrement. One potential explanation for the efficacy of a training protocol that emphasizes different strategies could be that it leads to improvement in attentional control processes by the adoption of a less conservative, or more daring strategy.

Rabbitt (1996) recently suggested that RT slowing in seniors may be due to impairments in control and monitoring processes. Our data is congruent with this hypothesis. The tendency of older adults to prepare only for the moment when the stimulus is most likely to occur in a RT task (e.g., Lahtela et al., 1985) reflects a strategic choice. As a result of this preparatory strategy, disproportional slowing occurs. The underlying reason for adopting this conservative strategy needs to be explored further. However, data from the present study allow us to draw a potential account. As discussed earlier, an inability to prepare for the whole temporal window can be ruled out, at least according to our data. However, being able to prepare for all possible PI values does not mean that older adults would actually adopt this strategy. In the present paradigm, one explanation for their strategic choice of favoring the longest PI is that older responders estimate not being able to attend to the entire temporal window. It may also be the case that older adults estimate not being able to respond quickly at the shortest PI. The efficacy of a training condition in which the probability of the shortest PI is increased could thus rely on the fact that it forces them to produce quick responses or that they learn that they can prepare effectively and at no cost to the shortest PI. In both accounts, older adults underestimate their cognitive capabilities, leading them away from optimal behavior. These explanations suggest a failure in meta-cognitive abilities. Memory studies have suggested that older adults can monitor different aspects of cognition (Hertzog & Hultsch, 2000). However, it is not yet clear whether they spontaneously use the most effective strategy when engaged in cognitive tasks. Thus, the use of effective strategies when performing cognitive tasks as used in experimental settings needs further investigation. This may help to account for age-related differences even in simple RT performance. Meta-cognitive difficulties could also partially explain older participants' tendency to adopt a conservative strategy on many cognitive tasks. One important practical implication is that providing older adults with precise information about their cognitive capabilities and reducing misunderstandings about their cognitive decline may lead them to adopt strategies that maximize their cognitive performance. This would confer them a great advantage for meeting external constraints in real world situations.

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