Psychology and Aging
2007, Vol. 22, No. 2, 398–403

0882-7974/07/$12.00 DOI: 10.1037/0882-7974.22.2.398

Age-Related Differences in Timing With Breaks

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Two groups of participants differing in age were compared on a time production task during which timing was temporarily interrupted. Produced intervals lengthened with increasing delay before the break occurrence, and the effect was more pronounced in older than in younger adults. A reaction time response to the signal beginning the break period was required also. Older participants responded more slowly to this signal, but they benefited to a greater extent from a lengthening of the time preceding its presentation. These results suggest that performance of older participants is affected by attention sharing and preparation involved in timing with breaks.

Keywords: aging, timing, attentional control

Various studies have suggested that age-related differences in timing exist, often reporting decreased accuracy in time estimation with aging (Craik & Hay, 1999; Fernandez & Pouthas, 2001; Lustig & Meck, 2001; McCormack, Brown, Maylor, Richardson, & Darby, 2002; for reviews, see Block, Zakay, & Hancock, 1998; Lustig, 2003). Fluctuations in timing abilities with age might be expected given changes in brain structure and functions associated with aging (Raz, 2000), which may affect dopamine neurotransmission and other functions related to frontal–striatal circuits known to be involved in timing (Ivry & Spencer, 2004; Malapani et al., 1998; Meck & Benson, 2002). A deficit in timing abilities could have a significant impact on older adults given that timing is involved in a large number of everyday activities such as coordinating movements, crossing crowded streets, or even simply managing multiple cooking times when preparing a meal.

Although studies frequently show age-related deficits in timing, this is not always the case: Some studies have found no evidence of an age difference in timing. One major factor to be considered in explaining these discrepancies is the method used to study timing performance across studies (Block et al., 1998). For instance, Block et al. (1998) noted that in a prospective paradigm, that is, when participants know in advance that a time estimate will be required, age-related effects were found only with absolute duration judgment methods, verbal estimation, or production, not when participants had to reproduce a previously encoded target interval. Absolute judgments require participants to translate an experienced duration in formal units of time, for example when an experimenter asks "Please press this key when you think that 10 s have elapsed." There is no such translation in time reproduction, where participants are asked to reproduce a duration previously experienced, such as reproducing the duration of a stimulus that was presented for 10 s. In its basic form, time reproduction may not reveal age differences because "Even if the rate of physiological and cognitive processes varies with age, the same rate will subserve a person's experiencing the target duration and reproducing it" (Block et al., 1998, p. 586). Thus, if the rate of an internal timer results in three units accumulated over a 1-s interval, its reproduction will be based on accumulating again three units at the same rate. Faster accumulation in another individual may result in 10 units accumulated over the 1-s interval, but 10 units will also be accumulated at the same rate when the interval is reproduced. This way, the 1-s interval may be reproduced quite accurately by both individuals even though the rate of the temporal basis underlying their performance differs. This may explain why time reproduction may not reveal differences between older and younger people.

Another important factor is the possible involvement of attention in timing, which may contribute to impaired performance in older adults due to age-related attention deficits (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Hartley, 1992; Hasher & Zacks, 1979; Jennings and Jacoby, 1993; McDowd & Shaw, 2000). This might be more likely to be observed when temporal intervals of a few seconds are used because processing of intervals in the range of seconds seems cognitively mediated in contrast with shorter intervals which would be more sensory in nature (Rammsayer & Lima, 1991, see also Block, 1989). In the present study, younger and older adults performed a 2.5-s production task

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This research was supported by a scientist fellowship from the Fonds de Recherche en Santé du Québec and a grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Louis Bherer, a doctoral fellowship from NSERC to Samuel Desjardins, and by a grant from NSERC to Claudette Fortin.

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with breaks. Previous experiments revealed that expecting a break induced attentional shifts between timing and monitoring the source of the break signal (Fortin, 2003; Fortin & Massé, 2000; Fortin, Bédard, & Champagne, 2005). Attentional demands were thus manipulated in this task by varying the duration during which a break was expected (prebreak duration) while the interval was produced. This task is particularly suitable to studying age-related differences in timing since it allows manipulating attention while timing, without the burden of requiring participants to engage in a concurrent demanding task; this represents a serious advantage to studying timing abilities in populations with reduced attentional capabilities.

In previous experiments on time production[1] with breaks, participants were first presented with a tone of some duration, which then had to be reproduced (Fortin & Massé, 2000). The target time interval was produced by pressing a key twice, the first keypress triggering a tone presentation which lasted until the interval was terminated with a second keypress. In experimental trials, a silent break was introduced during the tone presentation. Participants had to interrupt and restart timing at the beginning and the end of the break, respectively, and to terminate the interval when the target duration was reached. In this task, participants ended the interval later (i.e., produced longer intervals) when the break occurred later, suggesting that expecting a break induced attentional shifts between timing and monitoring the source of the break signal, which delayed the time when the target interval was reached. This interpretation was confirmed by the critical finding that in trials where a break was expected but did not occur, produced intervals were even longer than in trials with breaks (Fortin & Massé, 2000, Experiments 3 and 4). This result with the expected but no-break trials suggests that in trials with breaks, the lengthening of produced intervals with increasing duration before the break was not dependent on the break occurrence, but to the mere expectation of the break. This empirical phenomenon fits well with current models of time perception. Assuming that timing involves accumulating temporal information (Gibbon, Church, & Meck, 1984) which requires attention (Zakay & Block, 1996), attention sharing during a period of break expectancy would result in some loss of accumulated temporal information, and hence shorter perceived duration (see also Casini & Macar, 1997; Rousseau, Picard, & Pitre, 1984). Shortening of perceived duration would result in longer produced intervals because more time is needed to reach the subjective target interval.

According to this interpretation attention shifts should increase with the duration for which the break is expected. Given the impairment reported in older adults in controlled attention-sharing under divided-attention conditions (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Li, Lindenberger, Freund, & Baltes, 2001), older adults should show larger effects compared to younger adults when a break is expected; this should result in larger age-related differences in temporal production as the duration of expectancy increases.

In the present study, participants were asked to produce intervals of 2.5 s on each trial by pressing a key to initiate a tone, and then pressing the key a second time to terminate the interval. Some trials included "breaks" in the tone; these breaks started 800, 1,300 or 1,800 ms after the tone started, and lasted for 2, 3 or 4 s. In these trials, the task was to terminate the tone after it resumed so that its total duration (before and after the break) was 2.5 s. The participant's second task was to press another key as rapidly as possible when the break occurred, that is, when the tone stopped by itself.

A recent study showed that in addition to attention sharing during break expectancy, preparatory processes took place during breaks in timing (Fortin et al., 2005). Two questions related to this issue were investigated in the present experiment. The first question was whether preparatory processes also took place during the prebreak period, when participants were waiting for the signal starting the break. Such preparatory processes during the brief period between initiation of the tone and the break signal would occur because participants were monitoring how long the tone had sounded so that he or she could add the rest of the 2.5 s after the break. Preparation for the break in the present study would lead to a reaction time (RT) function to the break occurrence similar to preparatory functions in typical RT tasks using variable preparatory intervals. The second question concerned a possible difference in preparatory processes between older and younger participants when these processes took place concurrently with timing. Indeed, given the differences in preparatory processes observed between older and young adults in RT studies (Bherer & Belleville, 2004a) if preparatory processes take place during prebreak, these two groups should present different functions relating RTs and prebreak duration.

Two main hypotheses were tested in the present experiment. The first hypothesis was that given the attentional declines observed in older adults (e.g., Craik et al., 1996) and the sharing of attention taking place before the break (Fortin & Massé, 2000) in timing with break, the lengthening of produced intervals with increasing prebreak duration should be more pronounced in older than in younger participants. A second hypothesis was that, assuming that preparation is taking place during the prebreak period, RTs should decrease with increasing prebreak duration, and RT functions should differ in the older and younger groups of participants as reported in previous studies of preparatory effect in older adults.

Method

Participants

Fifteen younger adults (8 men and 7 women, 20–31 years of age; $M = 25$, $SD = 3.1$) and 15 older adults (4 men and 11 women, 65–80 years of age; $M = 70.9$, $SD = 5.7$) participated in this experiment. They all reported good health (self-rating on a 5-point scale is reported in Table 1), and none of them had undergone major surgery in the year prior to testing. They had no history of neurological disease and did not take any medications known to affect cognition. To exclude persons with dementia, we had older participants complete a Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). Scores on the Mini-Mental State Examination ranged from 26 to 30. Participants were screened for

[1] In the experiment reported here, a variant of time reproduction was used in which—in contrast with usual reproduction tasks—the same target interval encoded at the beginning of the experiment is produced throughout the experimental session. Because participants rely on a single previously encoded target duration, we refer to this task as a time production task even though, as in a time reproduction task, participants reproduce a given target duration without referring to its value in formal units of time.

Table 1
Participant Characteristics (Education and Health Self-Ratings) and Psychometric Test Performances (Standardized Scores) of Older and Younger Adults

Characteristic	Younger adult *M*	Younger adult *SD*	Older adult *M*	Older adult *SD*
Mini-Mental State Exam (out of 30)			28.67	1.11
Education (years)	15.47	0.74	14.93	3.49
Health self-rating (out of 5)	4.43	0.62	4.53	0.61
Geriatric Depression Scale			3.5[a]	2.23
WAIS-III: Similarities[b]	11.67	3.13	11.6	3.92
Verbal fluidity[c]	46.87	10.27	45.33	12.08
WAIS-III: Matrix Reasoning[d]	13.87	1.85	10.21[e]	3.17
WAIS-III: Digit Span[f]	11.6	2.5	9.7	1.8

Note. WAIS–III = Wechsler Adult Intelligence Scale—3rd edition.
[a] Scores from 3 older adults are missing. [b] Verbal reasoning measure. [c] Total number of words in three trials with three different letters. [d] Nonverbal perceptual reasoning measure; group difference at .01. [e] Score from 1 older adult is missing. [f] Forward and backward total; group difference at .05.

perceptual impairment by completing questionnaires on auditory function and visual acuity. They were also tested for depression symptoms (only older adults completed the Geriatric Depression Scale), verbal abilities and reasoning (Similarities subtest of the Wechsler Adult Intelligence Scale, 3rd edition; WAIS–III; Wechsler, 1997), nonverbal perceptual reasoning (Matrix Reasoning subtest of the WAIS–III), verbal executive functions (total number of words in three trials with three different letters in the verbal fluidity test), and short-term memory (total score from forward and backward WAIS–III Digit Span subtest). Performances on these tests are reported in Table 1.

Apparatus and Stimuli

Participants were tested individually using a personal computer. Responses were recorded to the nearest millisecond. The index finger of the right hand rested on the “0” key, which was used to produce the target interval. In trials with breaks, the left index finger was used to provide the RT response, by pressing the space bar when the signal starting the break was presented.

Procedure

The experiment included one practice session and one experimental session. The practice session was composed of two types of trials: production of 2.5-s intervals without break and with feedback on production accuracy, and production of 2.5-s intervals during which there was a break in temporal production, with no feedback on production accuracy. The practice session was followed by the experimental session, which included one block of trials with no breaks and with feedback on production accuracy. After this first block, there were five experimental blocks in which time intervals with breaks were produced. Feedback was never provided in trials with breaks. Participants were informed that break location and duration would vary from trial to trial.

Practice Session

Participants were first presented with a 2.5-s tone five times and were told that this represented the target interval to produce throughout the experiment. The practice session was divided into two successive 16-trial blocks with no break, followed by two successive 32-trial blocks with break. In the first two blocks, the first keypress on the “0” key triggered a tone (550 Hz) presentation, which lasted until a second press was executed on the same key. Feedback was presented on the computer screen in the first 16-trial block, indicating whether the interval was too short, too long, or correct within a 100-ms window around the 2.5-s target interval. Participants were then familiarized with time production with breaks in the two following 32-trial blocks with no feedback.

Experimental Session

The practice session was followed by the experimental session, which began with one block of 40 practice trials with feedback. This block was followed by one 40-trial block in which participants produced intervals with no breaks and no feedback; these trials served as control trials, in which participants produced the target interval with no break and with no expectancy for a break. The four following 36-trial blocks included breaks but no feedback. There were therefore six blocks overall in the experiment. The data from the first block were not included in the statistical analyses. In trials with breaks, the break occurred 800, 1,300, or 1,800 ms after the beginning of the interval production. These three values defined the break location. The break lasted for 2, 3, or 4 s (break duration). Break location and duration varied randomly from trial to trial and were balanced within a block of trials.

Results

Means and standard deviations of produced intervals were computed for each participant. Intervals longer than three standard deviations from the individual means were discarded, which represented 49 observations out of 6,713. Mean produced intervals at each value of break location and duration were then computed. Mean RTs were also computed at each value of break location and duration.

Figure 1 shows mean intervals produced during the experimental session in both age groups, in trials with no breaks and no feedback (trials in the second block of the experimental session) and in trials with breaks (trials in the four following blocks with breaks). Produced intervals in trials with breaks are shown as a function of break location. This figure shows first that in control trials with no breaks, produced intervals did not differ among younger and older adults: Mean intervals in the two groups are superimposed in Figure 1. Another key finding with regard to age-related differences in attentional effects in timing is that, in trials with breaks, the lengthening of produced intervals with increasing value of break location was larger in older than in younger adults.

Results from statistical analyses confirmed these observations. In trials with no breaks, productions were equivalent in older adults (2,605 ms) and younger adults (2,610 ms), $t(28) = -0.08$, *ns*. An analysis of variance (ANOVA) on produced intervals in trials with breaks only—with group as a between-subjects factor

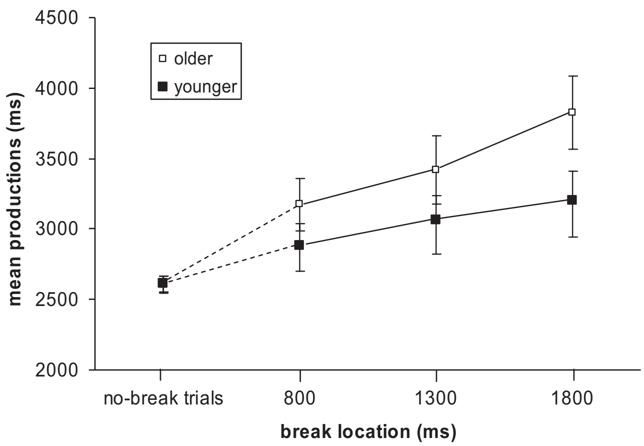

Figure 1. Mean productions as a function of break location in trials with breaks, and in control trials with no break, in older and younger participants. Error bars represent standard errors of the means.

(younger and older), and two within-subject factors (break location and break duration)—showed that although older adults produced longer intervals in trials with breaks, the difference did not reach significance, $F(1, 28) = 2.16$, *ns*, $\eta^2 = .07$. Productions did not vary with break duration, $F(2, 56) = 2.55$, *ns*, $\eta^2 = .08$. The effect of break location was significant however, showing a general lengthening of produced intervals as a function of increasing value of break location, $F(2, 56) = 41.95$, $p < .001$, $\eta^2 = .60$. More important, there was a significant interaction between the group and break location factors, $F(2, 56) = 5.67$, $p = .006$, $\eta^2 = .17$. Tests for simple main effects showed that the effect of location was significant in both groups, though effect sizes suggest a larger effect in older, $F(2, 56) = 38.68$, $p < .001$, $\eta^2 = .58$, than younger adults, $F(2, 56) = 8.93$, $p < .001$, $\eta^2 = .24$. There was no other significant interaction.

To verify whether the succession of blocks might have influenced performance differently in the two groups, possibly through some effect of fatigue that might be especially detrimental to performance in the older group, an ANOVA was performed with the group and block factors. The block factor included four levels corresponding to the four successive experimental blocks with break. Neither the effects of block, $F(3, 84) = 2.59$, *ns*, $\eta^2 = .09$, and age group, $F(1, 28) = 2.17$, *ns*, $\eta^2 = .07$, nor the interaction between these factors, $F(3, 84) = 1.5$, *ns*, $\eta^2 = .05$, was significant.

An ANOVA was also performed on mean RTs to the break occurrence, with age group as a between-subject factor (younger and older), and break location (800, 1,300, 1,800 ms) and duration (2, 3 and 4 s) as two within-subject factors. RTs were generally longer in older (559 ms) than younger adults (377 ms), $F(1, 28) = 10.36$, $p < .01$, $\eta^2 = .27$. Moreover, RTs decreased significantly with increasing value of break location (523, 468 and 412 ms), $F(2, 56) = 20.58$, $p < .001$, $\eta^2 = .42$; and increased as a function of break duration (443, 478 and 483 ms), $F(2, 56) = 8.22$, $p < .001$, $\eta^2 = .23$. More important for the purpose of the present study, the decrease in RTs as a function of break location differed in the two groups, as indicated by a significant Group × Location interaction, $F(2, 56) = 6.13$, $p < .01$, $\eta^2 = .18$; mean RTs for the three break locations (800, 1,300, 1,800 ms) were 648, 547, and 480 ms in older adults and 400, 389 and 344 ms in younger adults. Repeated contrasts further showed that the differential location effect between the two groups emerged between 800 ms and 1,300 ms, $F(1, 28) = 7.06$, $p < .01$, $\eta^2 = .20$. To rule out general slowing as a potential explanation for this interaction, as the main group difference in RTs might produce a proportionally larger effect of location in older adults, we performed an ANOVA with transformed RT data of younger adults as suggested by Madden (2001). Data were transformed using the equation (Young transformed = Young RT * 1.96 – 180) from a regression analysis on RTs of older and younger adults in all conditions (three location × three duration). Results with the transformed data of younger adults indicated that the interaction between the group factor and the two location values (800 and 1,300 ms) remained significant, $F(1, 28) = 4.48$, $p < .05$, $\eta^2 = .14$, despite the absence of a group difference, $F(1, 28) < 1$, $\eta^2 = .00$.

Discussion

The main finding of the present study is that in time production with breaks, older participants were more affected than younger participants by increasing delay between the beginning of the interval and the occurrence of a break. In contrast, the same two groups of participants produced similar time intervals in trials with no breaks and in which, importantly, no break was expected. The differential effect of break location in the older and younger groups can therefore not be attributed to differences in the ability to reproduce a target time interval stored in memory, but rather to differences related to the sharing of attention involved in break expectancy.

Attention requirements are minimal in control trials with no breaks. In an attentional framework commonly used to interpret data in prospective timing (Gibbon, Church, & Meck, 1984; Zakay & Block, 1996), temporal information (pulses, in internal clock models) is accumulated when time is estimated; the amount of information reached at the end of the timed interval is compared to a criterion stored in memory. These processes seem to be performed by older adults as efficiently as by younger adults in control trials. Actually, similar performance in the two groups might be expected given that our task involved a comparison of experienced durations (see Block et al., 1998).

Performance differed in the two groups, however, in trials with breaks, which involved attention sharing in the timing task as well as executing an additional RT response to the break signal. Assuming that the lengthening of produced intervals with increasing prebreak duration results from attention shifts between timing and monitoring for the break signal as suggested in previous studies (Fortin & Massé, 2000; Fortin et al., 2005), the stronger effect of break location in the older group would imply that these shifts are longer or more numerous in older than in younger participants. This hypothesis is in agreement with the claim that controlled aspects of attention are subject to age-related declines (e.g., Hasher & Zacks, 1979; Jennings and Jacoby, 1993; McDowd & Shaw, 2000) and may explain why older adults overproduce temporal intervals under divided-attention conditions (Craik & Hay, 1999).

The interpretation linking the break location effect to break expectancy in the present study is supported by results from previous studies of preparatory effects in RT tasks. With break location varying from trial to trial, and the three location values having equal probability within a block of trials, participants could use the prebreak period as they would use a foreperiod by estimating the conditional probability of the signal occurrence given that it has not already occurred (Requin, Granjon, Durup, & Reynard, 1973; for a review, see Luce, 1986, and Niemi & Näätänen, 1981). In the present experiment, the negative relationship in RT functions shows that the prebreak duration was used as a foreperiod. In two different studies, Bherer and Belleville (2004a, 2004b) showed larger preparatory effects in older adults compared to younger adults in an RT task with a variable foreperiod. The effect was due to reduced preparation in older adults for the shortest interval, with both short (1–5 s) and long (5–9 s) time windows (Bherer & Belleville, 2004a), which suggests age-related difficulties in response preparation for uncertain events (see also Salthouse, 1985). A similar effect was observed in the present study. Important to our concern, the larger preparation effect in the older group compared to the younger group is consistent with the interpretation that lengthening the prebreak interval leads to greater overproduction of the target interval in older adults.

RTs were shorter when the break was shorter and, in particular, at the shortest break duration. It is difficult to explain this result because RT responses produced at the beginning of the break should not be affected by its duration. This result should therefore be replicated before its significance can be concluded.

Overall, the results of the present experiment support the idea, proposed in previous studies (Block et al., 1998; Craik & Hay, 1999; Lustig, 2003), that increasing attentional demands in a timing task may reveal changes associated with aging. The results obtained in the present study show that similarities and differences in timing between older and younger adults may be defined even with very minor changes in experimental conditions. This underscores the usefulness of timing tasks that, in very elementary conditions of stimulus presentation and response production, may provide ideal conditions for studying attentional, memory, and decisional processes in various populations.

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Received March 15, 2006
Revision received January 18, 2007
Accepted January 22, 2007 ■