AGE-RELATED SLOWING OF CONTROL PROCESSES: EVIDENCE FROM A RESPONSE COORDINATION TASK

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ABSTRACT

Normal aging is associated with slowing of performance mostly due to a slowed functioning of central response-related processes. In this paper we set out to discover whether slowing occurs also when the process controlling the coordination of responses is engaged by the task. To this end, we compared the mean-reaction time performance of two groups of subjects (young vs. elderly) in single- and dual-task experimental paradigm. The response coordination process is required only by the dual-task paradigm. The results indicate that, in the dual-task situation, the elderly are markedly slower than young subjects. The eventual relevance of information-processing speed in determining the cognitive performance of the elderly is considered in the discussion of the results.

Keywords: aging, cognitive slowing, control process, dual-task

INTRODUCTION

One of the most amply documented features of aging is the gradual slowing of performance (Birren, 1965; Cerella, 1985; Salthouse, 1985; Vercruyssen, 1993; Welford, 1981; for reviews see Craik and Salthouse, 1992, and Salthouse, 1991a). More than thirty years ago, Brinley (1965) showed that the response time of older adults can be expressed as a simple linear function of the time of response of younger adults, regardless of the specific nature of the task (e.g., verbal, arithmetic, perceptual, etc.). It was therefore suggested that age-related slowing was a general rather than task-specific process.

Interestingly, Brinley (1965) found that an important factor in determining age-related slowing was the complexity of the task (Complexity Hypothesis). This notion was confirmed and further refined in the course of a wide variety of information processing tasks. Variations in the slowing model have been proposed, such as multilayered slowing (Cerella, 1985), overhead slowing (Cerella, 1990) and information loss (Meyerson, Hale, Wagstaff et al., 1990).

An explanation for age-related slowing is that older adults experience a reduction in the processing resources that are fundamental for cognitive processing (Salthouse, 1985, 1988). Processing resources can be characterized as attentional capacity, working memory capacity and speed of processing.

Age-group differences in attentional capacity have been demonstrated by

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means of the divided-attention paradigm. Older adults have more difficulty than young adults when performing two different tasks simultaneously (Greenwood and Parasuraman, 1997; Hartley, 1992; for reviews see Kramer and Larish, 1996). Evidence of an age-group difference in working memory has been found in a variety of measures, including digit span (Salthouse, 1988), the sentence span (Light and Anderson, 1985; Gick, Craik and Morris, 1988), and other types of computation spans (Dobbs and Rule, 1989; Salthouse, 1990, 1994). Finally, a reduction in the processing speed leading to a slowing of all cognitive operations has been proposed as a general characteristic of adult aging (Salthouse and Somberg, 1982).

There is broad general agreement that the elderly perform much more slowly than the young when the complexity of the task is increased (e.g., Bashore, 1994). However, investigators in the field are now differentiating the relevance that each information processing stage has in determining the general cognitive slowing. In other words, greater effort is now going into determining process-specific slowing by manipulating the complexity of the task (Fisk and Fisher, 1994), and task difficulty has been used to determine the specific cost of each cognitive operation in order to assess whether slowing is uniform across all components of information processing or not. Task difficulty has been manipulated (a) by increasing the number of processing steps involved in the solution of a given task or (b) by rendering the operations performed by a particular information processing stage more complex.

By increasing the number of steps in a task, it has been demonstrated that central (elaborative) processing speed slows more with age than peripheral (sensory-motor) processing speed. An extensive longitudinal study on reaction time (RT) performance has shown that even simple RTs increased at a rate of about 0.5 ms/yr. beginning from the age of 20, but the slowing is more evident for more demanding RT tasks (e.g., Fozard, Vercruyssen, Reynolds et al., 1994). Thus, both peripheral and central processing speed slows with age, but greater slowing occurs when central processing is required by the task.

By increasing the complexity of the operations to be computed at the processing stage, it has been shown that, of the central components of information processing, response selection-related processes slow selectively with age (Bashore, 1990; Lorsbach and Simpson, 1988). For example, by reducing the degree of compatibility in a stimulus-response compatibility task (which affects the response selection stage, see Lu and Proctor, 1995), older adults show increased RT compared with young adults (Simon, 1967). In addition, the performance of the elderly slows down more than that of the young when the difficulty of the response selection operations is enhanced by increasing the number of stimulus-response alternatives (McDowd and Craik, 1988).

The notion that the response selection stage is the main cause of slowing also arises from psychophysiological studies without the manipulation of task difficulty. For example, Zeef and Kok (1993), in a study combining RT performances and psychophysiological parameters such as P3 latency, the onset of the lateralized readiness potential, and the electromyogram of hands, concluded that, in young subjects, central and peripheral response-related
processes appear to coincide, whereas, in the elderly, response selection precedes response execution. This conclusion is in agreement with previous findings suggesting that in the elderly the onset of response selection is slower than in young adults (e.g., Bashore, Osman and Heffley, 1989), that is, even though slowing of information processing also occurs in stimulus processing, it is greater in the response selection stage (Bashore, 1994). It is worth noting that time restriction in stimulus processing by itself does not account for age-related differences. Given unlimited time, but no specific strategy instruction, the elderly still perform substantially less well than their younger counterparts (for review see Craik, Anderson, Kerr et al., 1995).

Accordingly, the above-mentioned studies have focused mainly on the efficiency of the information processing stages, while control processes have received less attention. By control processes we mean that set of cognitive operations that are not directly involved in the representation of cognitive states, but rather with the organization of such states towards attaining a specific goal. In other words, the term “control” refers to those processes by which an individual optimizes his performance in multicomponent tasks. The basic idea is that a number of mental representations are normally active simultaneously and in parallel, but, at any given time, only some of them guide action and thought. An essential feature of control processes is that they are functionally separated from a multitude of processes that can be controlled by them. Control processes are therefore considered to be fundamental for top-down control of behavior (Norman and Shallice, 1986). Moreover, it is generally accepted that normal aging implies a decline in frontal cortex functioning, which supports control processes (Moscovitch and Winocur, 1995; Rafal and Henik, 1994).

Considering that cognitive slowing in the elderly is mostly attributable to the slowed functioning of the response selection stage, the aim of the present work was to determine whether older adults exhibit slowing in the control processes involved in the coordination of two responses. An experimental paradigm developed to study how control processes operate in the scheduling of behavior has been proposed by Umiltà, Nicoletti, Simion et al. (1992). In it, the same stimulus requires either one or two responses, depending on the experimental condition. In the first block (single-task), subjects are required to make a speeded manual response (to right or left) depending on the stimulus position (right or left). In the second block (dual-task), subjects are also instructed to say aloud, after the manual response has been produced, whether the two letters which composed the stimulus are the same or different. For the second task there is no time constraint (unspeeded response). Thus, in the dual-task condition, the response sequence has to be coordinated. This is a basic mental operation that is crucial for efficient performance in cognitive tests and, more important, for everyday activities (De Jong, 1995).

Young subjects displayed a longer RT to the stimulus position in the dual-than in the single-task condition. According to the authors, given that in the dual-task condition the two responses are relative to different features of the same stimulus, RT slowing occurs because the control process of response coordination acts as a bottleneck, causing postponement of the speeded response to the stimulus position when engaged in the decision about the coordination of
the two responses (see Pashler, 1984, 1989, 1994, for the decision and response-selection bottleneck model).

This paradigm has proved to be a very powerful tool in detecting the residual attentional deficit in both severe and mild closed-head injury (Stablum, Leonardi, Mazzoldi et al., 1994; Stablum, Mogentale and Umiltà, 1996). Interestingly, in the mild closed-head injury group, the response coordination process is impaired only for the patients over the age of 30. This finding leads us to hypothesize that normal aging per se could produce an impairment in the response coordination process.

In the present study, we applied the Umiltà et al. (1992) paradigm to young and old adults to find out whether response coordination is particularly slowed in the elderly. Note that in this paradigm task difficulty is not manipulated by increasing the complexity of the operations to be computed at an information processing stage. Rather, task difficulty is manipulated by the insertion of the response coordination process that is required only by the dual-task condition. In this manner we are able to determine whether the time cost of this process is greater for the elderly than for the young. Bearing in mind the psychophysiological and behavioral data reported above, we expected to find longer RTs for both single- and dual-task conditions in the elderly than in young adults. However, if the response coordination process were impaired in older adults, we would expect to find an overadditive interaction between age and task.

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Subjects

Two groups of subjects participated in the experiment. One consisted of 10 young subjects (5 male and 5 female; mean age = 28.2 years, S.D. = 4.3; mean years of education = 15.5, S.D. = 2.6) working at the Geriatric Department of the University of Modena. The other group consisted of 10 elderly subjects (5 male and 5 female; mean age = 72.3 years, S.D. = 2.5; mean years of education = 8.3, S.D. = 3.5) recruited from the center of motor and leisure activity at the same Geriatric Department. Subjects were all right-handed, had normal or corrected-to-normal visual acuity (Salthouse, Hancock, Meinz et al., 1996), and were naive as to the purpose of the experiment.

In normal aging there is increasing heterogeneity (Berkman, 1988) due to a set of conditions, including the presence of subtle, subclinical or well-controlled chronic diseases that do not interfere functionally with everyday activities (Fried, Storer, King et al., 1991). These conditions are able to impair performance in many physical and mental tasks by comparison with subjects who age “successfully”, that is, those who are free of such limitations (German, 1995).

For these reasons, in the case of elderly subjects, both the following inclusion criteria were taken into account:

(a) A score on the Cumulative Illness Rating Scale (CIRS) of 14 (Parmalee, Thuras, Katz et al., 1995). CIRS is a standardized instrument for obtaining the physician’s rating of a patient’s health status according to 14 major organ/system groups. The item score ranges from 1 to 5 along with the presence and severity of the disease. A score of 14 means the absence of either subclinical disease or functional impairment.

(b) Mini Mental State Examination (MMSE) score of 27 or more. MMSE is an interviewer-administered measure out of 30-point of overall cognitive functioning (Folstein, Folstein and McHugh, 1975). A score of 24 has traditionally been considered as the cut-off point for “normality”. However, there is recent evidence to show that a score of 27 or more is a better guarantee that subjects with incipient dementia, or at risk of developing dementia,
are not recruited into the study (Hanninen, Hallikainen, Koivisto et al., 1995; Braekhus, Laake and Engedal, 1995).

**Task**

The experiment took place in a dimly-lit room. Each participant seated in front of a cathode-ray tube screen driven by a Tulip dt 386sx personal computer. The head was positioned on an adjustable head-and-chin rest, and the distance between the eyes and the screen was approximately 40 cm. The stimuli (1.5° × 5.5°) were shown for 2000 ms 10° to the left or right of a central fixation cross (1° × 1°). The stimuli consisted of two letters, one above the other: the letters were either the same or different. The responses were made by pressing one of two keys on the computer keyboard. One key (the character “z”), located to the left of the body midline, was pressed by the left index finger, whereas the other (the character “\”), located to the right of the body midline, was pressed by the right index finger. The software was based on MEL Professional (Schneider, 1988).

**Procedure**

Each subject took part in a single experimental session comprising 2 blocks of 72 trials each, with a 5-min block-rest in between. The task of the first block was location discrimination only (i.e., single-task) while that of the second block was for the location plus identity discriminations (i.e., dual-task). For each block, the experimental trials were preceded by some practice trials. The stimuli appeared in a quasi-random sequence, with the proviso that there should be an equal number of left- or right-side presentations and an equal number of same- and different-letter pairs.

In each trial, the central cross was presented for 2000 ms, followed by the stimulus for 2000 ms. Participants were instructed to make the speeded keypress for location discrimination the moment the stimulus was presented. The intertrial interval was 2000 ms.

The instructions differed according to the experimental condition. In the single-task, subjects were required to press the right-hand key if the stimulus appeared on the right, and to press the left hand key if the stimulus appeared on the left. In the dual-task, subjects were also instructed to say aloud, after making the manual response, whether the two letters were the same or different. It must be noted that the subjects were instructed to postpone the same-different decision until after the manual response for the location task had been made. The instructions stressed that there was no time constraint for uttering the verbal response.

**Results**

The mean level of education of the two groups proved to be different, t = 5.20, p < .001. Even if education was found to be non-predictive of RT performance over the age of 70 years (Christensen, Korten, Jorm et al., 1997), we preferred to take it as covariate for the following analysis. On the whole, errors in the left-right discrimination task were 0.3% for the young adults group and 1.7% for the elderly adults group.

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1 Since we did not counterbalance the block order of the experimental conditions, one might argue that fatigue could have skewed the results obtained in the elderly subjects. However, in a pilot session, some elderly subjects failed to achieve optimum performance during the practice trials on the dual-task block when it was performed first. Accordingly, we decided to keep the same block order for all subjects (that is, one block for the single-task followed by one block for the dual-task) and to insert a 5-min rest between blocks, thereby avoiding the risk of fatigue in the elderly subjects. Indeed, none of the subjects complained of fatigue; rather, the single-task block served as practice for the dual-task block in all cases.
Errors and mean RTs of correct manual responses were submitted to two identical analyses of covariance (ANCOVA) with group as between-subjects factor (elderly vs. young subjects), task as within-subjects factor (single- vs. dual-task) and education as covariate. The error analysis did not yield any significant finding. A multivariate Box test for the homogeneity of the variance-covariance matrices showed that the assumption of homogeneity of the dispersion matrices in young and elderly adults, for the two RT measures, cannot be accepted, Box’s $M = 21.45$, $\chi^2 = 18.87$, $p < .001$, rendering questionable any further analysis based on mean values. However, the standard deviations were lower in young subjects (32.3 and 36.1, for the single- and dual-task, respectively) than in elderly subjects (81.9 and 176.7, for the single- and the dual-task, respectively), thus indicating a smaller RT variability in young adults. This finding is consistent with previous research on large samples (Fozard et al., 1994), and corroborates the claim of age-related differences in RT performance. In addition, as already stated by Myers (1972), the deviation from the homogeneity of variance assumption has relatively small effect. Accordingly, we decided to go on with the ANCOVA previously set up.

The main effects of group ($F = 18.87$; d.f. = 1, 17; $p < .001$), task ($F = 54.46$; d.f. = 1, 17; $p < .001$) and interaction ($F = 34.73$; d.f. = 1, 17; $p < .001$) were significant, whereas the covariate did not yield any significant effect.

The first main effect indicated that the elderly subjects were on the whole slower than the young subjects (540 vs. 304 ms, respectively), whereas the second source showed that the RT for the dual-task was slower than that for the single-task (496 vs. 348 ms, respectively).

More important were the results of the overadditive interaction, which showed that, in elderly subjects, slowing was particularly marked in the dual-task (see Figure 1). Planned multiple comparisons computed with the Newman-Keuls method ($p < .01$) showed that mean RTs for the single-task were significantly faster than those for the dual-task in both the young and the elderly subjects. Also, the young subjects were significantly faster than the elderly in both the single- and the dual-task conditions.

When the performances of the two different age groups are compared, some constraints have to be borne in mind. In particular, given that the elderly subjects were slower than the young ones even in the single-task, the differences between the RTs for the two conditions have to be adjusted taking the single-task RT as a baseline (Guttentag, 1989). To this end, we computed the difference between mean dual- and single-task RTs divided by the single-task RT for each subject. Then we performed an additional one-way ANOVA on these values considering the group as a between-subjects factor. The analysis yielded a significant result ($F = 37.0$; d.f. = 1,18; $p < .0001$), slowing that younger subjects had a lower value than elderly ones (0.11 vs. 0.65, respectively).

**Discussion**

The aim of the this study was to assess, in terms of an increase in RT, the presence of a deficit in the response coordination process in the elderly, when
this process is required by the task. Clearly, the results support our prediction. The response coordination time cost is indexed by the difference in RT for the location task in the dual- and single-task conditions. In elderly people, the response coordination time cost (267 ms) was greater than in the young subjects (30 ms).

The theoretical relevance of this result arises from the importance of processing speed in determining the impaired performance of the elderly in cognitive tasks. It has been shown how processing speed shares considerable variance with age, memory (Salthouse, 1991b, 1992, 1996; Salthouse and Babcock, 1991; Salthouse and Coon, 1993) and intelligence (Hertzog, 1989; Linderberger, Mayr and Kliegl, 1993). More precisely, Salthouse (1996) concluded that the greatest reduction in age-related variance is due to the control of a general speed factor rather than to the control of speed measures reflecting the duration of specific memory processes. The general speed factor actually reflects how quickly elementary processing operations are executed. As pointed out in the Introduction, the process-specific approach has established that the operations related to the response-selection stage are the main cause of cognitive slowing in the elderly. Here it is demonstrated that the control process of response coordination also contributes to the general slowing.

The age-related slowing in the performance of two concurrent tasks has recently been questioned by Salthouse, Fristoe, Lineweaver et al. (1995). The authors point out that it is difficult to understand what generates the slowing because it is not always clear what elementary processes are involved in a
particular complex cognitive activity. In our experiment, the information processing stages involved in dual- and single-task are the same. What is needed by the dual-task is the coordination of output behavior. The coordination process is functionally independent of the information processing system, and it is reasonable to assume that it plays a role in the organization of behavior whenever a stimulus requires a response composed by more than one single act.

What we are claiming here is that response selection and organization of output behavior are fundamental for all complex cognitive tasks and for everyday activities. Therefore, they determine the general processing speed and should be considered as two of those elementary processing operations that determine cognitive slowing (Salthouse, 1996), which in turn is fundamental for cognitive performance of the elderly.

Interestingly, Umiltà et al. (1992) ascribed the response coordination process to the central executive of the working memory model (Baddeley, 1996, 1986), that is, the structure in which the control processes of planning and decision-making take place. Baddeley (1986) pointed out that the tasks in which the elderly perform poorly are those requiring most resources from the central executive. This being so, our work directly supports the assumption of Umiltà et al. (1992), given that the elderly responded much more slowly when the response coordination process was involved. Future research should be directed at ascertaining whether different kinds of control process (e.g.: resource allocation and task shifting) are slowed in the elderly.

It is worth noting that a modified version of this task was carried out with 6 groups of children ranging from 3 to 8 years of age (Tagliabue, Simion, Umiltà et al., 1994). The authors recorded a progressive decrease in the response coordination time cost with increasing age (from 538 to 160 ms). They argued that this pattern is consistent with the development of executive functions and frontal lobes in children (Welsh and Pennington, 1988). Although we investigated only one group of elderly subjects, the increase in the response coordination time cost is in complete agreement with the less efficient functioning of frontal lobes and impairment of executive functions that take place in normal aging (Moscovitch and Winocur, 1995).

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