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Age Differences in the Maintenance and Restructuring of Movement Preparation

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In 2 experiments, elderly and young subjects performed simple reaction time, choice reaction time, and movement plan restructuring tasks, using a stimulus precuing paradigm. In Experiment 1, the precue display (200 ms) and preparation interval (250, 500, 750, or 1,000 ms) were experimentally determined. In Experiment 2, the precue display interval was subject determined. For the restructuring task, the precue specified the response on 75% of the trials, enabling movement plan preparation with respect to movement parameters of arm and direction. On remaining trials, the precue incorrectly specified the response, requiring movement plan restructuring. Elderly, but not young, subjects restructured a movement plan for direction more quickly than for arm or for both parameters. These findings indicate that elderly individuals have poorer movement plan maintenance for direction than for arm and thus exhibit functional change in movement preparation processes relative to young individuals.

Motor act production can be characterized as involving the preparation of an appropriate movement plan, maintenance of that plan until execution, possible restructuring of that plan under expected or unexpected response contingency change, and, finally, proper execution of that plan (Stelmach, Goggin, & Amrhein, 1988). Recent studies using a movement plan restructuring task (Rosenbaum & Kornblum, 1982) have shown that elderly and young subjects prepare and restructure a movement plan in a qualitatively similar manner with respect to the movement parameters of arm (Stelmach et al., 1988) and direction (Larish & Stelmach, 1982; Stelmach et al., 1988). Only proportional slowing distinguished elderly from young subjects in these studies.

Briefly, in the movement plan restructuring task, a precue stimulus specifies the target stimulus response on 75% of the trials, enabling specific movement plan preparation. On the remaining trials, the precue stimulus incorrectly specifies (partially or entirely) the target stimulus response with respect to levels of movement parameters such as arm (left or right) and direction (away or toward the body) and thus requires restructuring of the prepared movement plan. Furthermore, this task provides two latency measures to separately assess movement plan preparation, maintenance and restructuring (reaction time [RT]), and execution (movement time [MT]).

A methodological concern with the interpretation of the aforementioned studies concerns the lengthy duration of the precue stimulus display and subsequent preparation interval (PI, measured from precue stimulus offset until target stimulus onset). Because the precue display interval and PI were each fixed at 1,000 ms (yielding an effective preparation interval of 2,000 ms), it is possible that the finding of qualitative similarity of the two age groups was fortuitous: Differential loss of specific parameter preparation (either loss of the use of that preparation or loss, per se) on the part of elderly subjects may have reached a collective asymptotic level before the target response was made.

This preparation loss would correspondingly decrease differences in RT to alter the specific parameters of the movement plan (because parameter preparation is greatly reduced or no longer exists) at time of response yielding a pattern of results resembling that of young subjects, who do not appear to lose this preparation. This pattern of results for young subjects can be characterized as a set of relatively small, though systematic, differences among parameter alteration conditions (see, e.g., Larish & Frekany, 1985; Stelmach et al., 1988).

Differential preparation loss on the part of elderly individuals, therefore, may be measurable by means of shorter precue display and preparation intervals. For example, following a brief precue interval (e.g., 200 ms), parameter-specific patterns of preparation loss may be found as PI increases, using a range of relatively short durations (e.g., 250, 500, 750, or 1,000 ms). Because of this loss, there would be a lessened need to alter the movement plan when a response is required; with increases in PI, RT for invalid precue trials would therefore decrease. This RT decrease might occur for all or only specific types of parame-

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ter alteration (i.e., changing arm and direction, changing arm, and changing direction), depending on the scope of change in these parameters (related structures and processes) due to age. Last, as this preparation loss progresses with increasing PI, valid precue trials would lose the benefit of a prepared movement plan resulting in increased RT.

The present article presents two experiments that extend the investigation of the similarities and differences between elderly and young persons in the performance of a movement restructuring task reported by Stelmach et al. (1988). The specific goal of the experiments was to determine whether elderly and young individuals differ in their time course of movement plan preparation, maintenance, and alteration. To assess existence of different time courses of movement plan preparation and maintenance for elderly and young individuals, simple reaction time (SRT) and choice reaction time (CRT) tasks were also included in the experimental procedure.

The SRT task was devised to provide an estimate of the degree of preparation of a movement plan in the restructuring task. In the SRT task, the precue and target stimuli were always identical and thus always specified the same movement parameter values. Given that subjects fully prepare the precued response in the restructuring task, no difference would be expected between RTs of the valid precue trials and the SRT task, a task in which this full preparation is presumed to occur. If a difference favoring the SRT task was found, then less than maximal preparation for the valid precue trials would be indicated. Importantly, the SRT task allowed an inspection of possible age-related differences in this degree of response preparation. Furthermore, if there is a measurable loss of response preparation in the elderly subjects, then there should be time course effects for performance on the SRT task similar to those for the valid precue trials for analogous reasons.

The CRT task provided a baseline measure that assessed mental operations concerned with target stimulus uncertainty (as well as perceptual encoding and certain movement planning factors) underlying the processing on invalid precue trials. Importantly, the difference between the invalid precue trial and CRT task RTs provided an estimate of the additional time needed to alter a prepared movement plan, because in a CRT task, such a plan is not prepared until target stimulus presentation (Klapp, Wyatt, & Lingo, 1974). Although it is clear that both elderly and young individuals make use of stimulus uncertainty information in a CRT task (e.g., Salthouse, 1985; Welford, 1977), it is unclear whether the reported increased RT for invalid over valid precue trials (Larish & Stelmach, 1982; Stelmach et al., 1988) is due to the same processes for the two age groups. Given the possibility that the loss of movement preparation over time renders the alteration of an existing movement plan unnecessary, the elderly RT increase may be primarily due to additional time to process target stimulus uncertainty on invalid precue trials. However, assuming no preparation loss occurs for young subjects, their RT increase for invalid precue trials would likely be due to both the processing of target stimulus uncertainty and the alteration of an intact movement plan.

Accordingly, differences between CRT and invalid precue trials for both age groups, at any PI, would suggest that both groups have some form of intact movement plan available at the time of target stimulus response. However, if differential preparation loss does occur for the movement parameters in the elderly subjects, then the additional RT for a given parameter change condition beyond that of the CRT task would decrease with increases in PI, whereas the additional latency for another change condition would remain constant or decrease to a lesser or greater extent.

Experiment 1

Method

Subjects

Two age groups, one elderly (range, 65–78 years; $M = 69.4$ years) and one young (range, 21–28 years; $M = 22.6$ years), participated. Each group consisted of eight men and eight women. Subjects in both groups were in good mental, neurological, and physiological health (subjects were screened by means of a self-report questionnaire for instances of stroke, dementia, or Parkinson's disease) and equivalent on education: elderly, 14.8 years; young, 15.4 years, $t[30] = .99$, $p > .05$. All but two elderly and four young subjects were right-handed. To assess age-group sample representativeness, subjects performed the Digit Symbol Substitution Test (DSST), a Performance scale subtest of the Wechsler Adult Intelligence Scale–Revised. DSST scores provide an indication of overall psychomotor speed (Salthouse, 1985). Mean scores were 46.8 (52% of maximum) and 72.6 (80% of maximum) for elderly and young groups, respectively. These scores are negatively correlated with increases in age, $r(30) = -.79$, $p < .01$, and are consistent with those reported in the aging literature (e.g., Salthouse, 1985; Stelmach et al., 1988).

Apparatus

In a sound-attenuated testing chamber, subjects sat in a chair positioned in front of a table that was 80 cm in height. Subjects fixated on a visual light display (see Figure 1) consisting of a nearly square configuration of four red light-emitting diode (LED) lights (6.35 cm wide by 6.99 cm tall) with three yellow LED lights centrally embedded. Lights were positioned 70 cm from the subjects on a vertical black panel. The light display subtended 2° of visual angle. Response keys mounted on the table were configured so that there were columns of three keys 21 cm apart and parallel to the sagittal plane. The keys were elevated 1 cm from the surface of the table and were mounted in ball-bearing sleeves attached to Snap-Action momentary switches requiring an approximate closure force of 40 g. Target and home keys were 3 cm and 1.5 cm in diameter, respectively. Target keys were positioned 7 cm above and below the home keys, yielding a response key configuration compatible with the stimulus display. With this configuration, two movement parameters were manipulated, arm (left or right) and direction (away from or toward subject). Subjects wore a set of eye goggles that occluded vision below the horizontal plane of gaze, thus precluding visual guidance of the responses. Stimulus presentation and response recording were controlled by a LSI 11/03 minicomputer.

Design and Procedure

Each subject performed three tasks (movement plan restructuring, SRT, and CRT) in a counterbalanced order across two sessions, each lasting 2 hr, that took place on consecutive days. On a given day, subjects performed either the restructuring task or the SRT and CRT tasks. This mode of task assignment allowed for control of the total

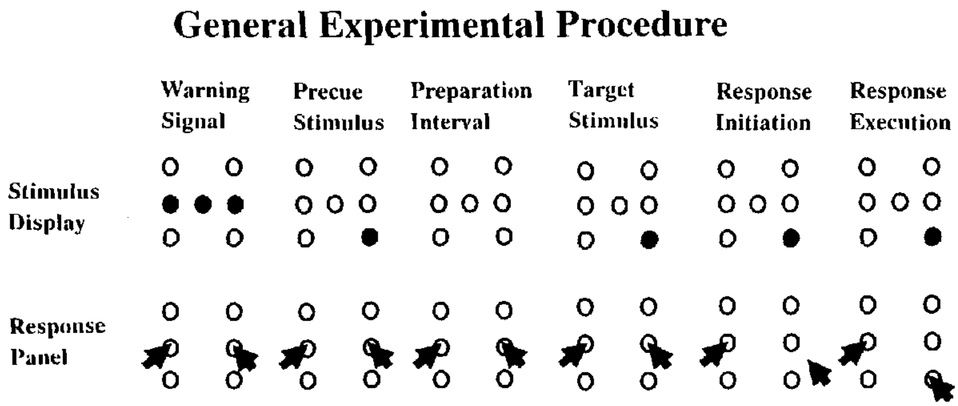

Figure 1. Schematic diagram of the apparatus and sample trial (valid precue trial) procedure. (Arrows represent index fingers corresponding to left and right arms.)

number of trials per session and maximization of practice effects for each task.

Across all tasks, a trial was initiated by pressing the home keys with the left and right index fingers (see Figure 1). The warning lights were then illuminated for 1.2 s. One second after onset of the warning lights, the precue light was illuminated for 200 ms. Following a blank variable PI that lasted 250, 500, 750, or 1,000 ms, the target light was illuminated. Subjects were instructed to quickly and accurately respond to the target stimulus by releasing the home key corresponding to its lateral position (left or right). Subjects were also instructed to continue pressing, throughout the trial, the remaining home key. RT was measured as the interval from onset of the target stimulus until release of the home key. MT was measured as the interval from the release of the home key until the target key was pressed. Thus, in this experimental design, RT represents a measure of response initiation and MT represents a measure of the remaining latency to complete the response.

In the movement restructuring task, the target stimulus matched the precue stimulus on 75% of the test trials; these trials constituted the *valid precue trials.* For these trials the precue stimulus correctly indicated the values of the arm and direction parameters to be used in the planning of a response to the following target stimulus. The target stimulus differed from the precue stimulus on the remaining 25% of the test trials; these trials constituted the *invalid precue trials.* In these trials, the target stimulus indicated a response different from that indicated by the precue stimulus with respect to values of the arm (left or right) and direction (away from or toward the body) parameters.

For all three tasks, a trial block consisted of 48 test (precue followed by target) trials and 6 catch (precue only) trials. In the restructuring task there were eight experimental trial blocks, resulting in a total set of 384 trials. For each trial block, the test trials consisted of 36 valid and 12 invalid precue trials. The 288 valid precue trials consisted of 18 replications of the 4 possible precue–target stimuli pairs at each of the four PI values. The 96 invalid precue trials consisted of 2 replications of the 12 possible precue–target stimuli pairs at each of the four PI values. For each PI, this resulted in three parameter change conditions: arm, direction, and arm and direction, each consisting of the four corresponding combinations of precue–target stimuli pairs. For example, the arm change condition was represented by the 4 precue–target stimuli pairs: upper left–upper right, upper right–upper left, lower left–lower right, and lower right–lower left.

For the SRT and CRT tasks, number and composition of trials was chosen to match, respectively, the total number of valid and invalid precue trials in the restructuring task. Thus, in addition to the experimental trials of the restructuring task, subjects received six experimental trial blocks for the SRT task and two experimental blocks for the CRT task. Before starting the experimental trials for each of the three tasks, subjects were given a practice trial block consisting of a random sample from the set of experimental trials devised for each task.

Results

Errors

We removed data from trials on which errors were committed from analysis. Errors consisted of cases of premature responding before onset of precue or target stimuli, releasing both home keys at time of response initiation, and pressing an incorrect target key. Elderly (5.7%) and young (4.3%) subjects had equivalent overall error rates, $F(1, 30) = 2.29$, $p > .14$. Error rates across trial types were as follows: valid precue, 3.7%; arm change, 5.2%; direction change, 5.6%; arm and direction change, 5.6%; SRT, 5.3%; and CRT, 4.5%; $F(5, 150) = 1.11$, $p > .35$. Importantly, further analysis of these error rates indicated no significant main effect for PI (250, 500, 750, and 1,000 ms) or interactions with age group for PI or trial type (all $ps > .07$). Also removed from analysis were MT and corresponding RT latencies for trials where MT was either less than 50 ms (representing cases where subjects accidently pressed the target key with their thumbs rather than moving their index finger to press the target button) or greater than 1,000 ms (representing cases where subjects failed to exert sufficient force to press the target button on initial contact). These cases constituted 1.3% and 0.9% of the elderly and young subject data sets, respectively.

Response Latencies

Main analyses of variance (ANOVAs) conducted on the RT and MT data concern the effects of age group (young or elderly); PI (250, 500, 750, or 1,000 ms); trial type—four restructuring task trials (valid precue trials and the three parameter change conditions of the invalid precue trials, arm, direction, and arm and direction), and the SRT and CRT tasks—collapsed over specific levels of the two movement parameters—arm (left or right) and direction (toward or away from body)—and trial

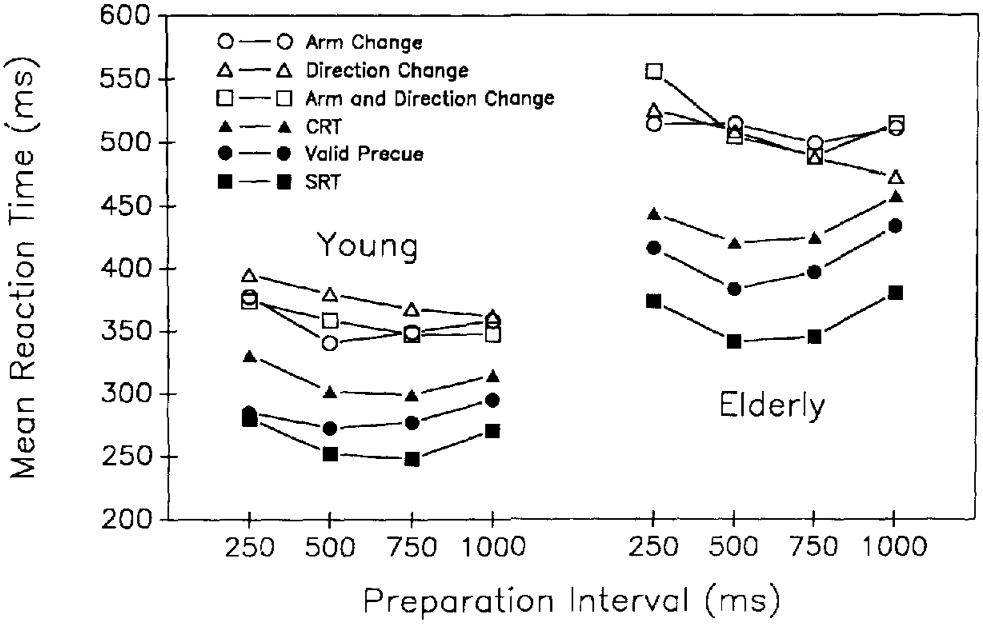

Figure 2. Mean reaction time for Experiment 1 plotted as a function of age group, preparation interval, and trial type (i.e., valid precue, simple reaction time [SRT] task, choice reaction time [CRT] task, and invalid precue, with parameter change conditions plotted separately).

blocks. We also conducted secondary analyses to further test age group effects and interactions found in the main analyses with respect to the specific levels of the arm and direction parameters. The complete RT and MT data set, averaged over subjects, is given in Appendix A.

RT. RT data are plotted in Figure 2, averaged over subjects and specific parameter levels, for each age group. Analysis yielded a large effect for age group, $F(1, 30) = 18.8$, $p = .0001$, with elderly subjects (455 ms) responding 131 ms slower than young subjects (324 ms). Further analysis indicated that this effect did not interact with level of the specific parameters (all $ps > .05$).

There were also differences among the various types of trials, $F(5, 150) = 60.8$, $p < .0001$. Overall, mean SRT task latency (311 ms) was shortest, followed by mean latencies of the valid precue trials (345 ms), CRT task (374 ms), and parameter change conditions of the invalid precue trials: arm (433 ms), direction (437 ms), and arm and direction (437 ms). Furthermore, there were differences across levels of PI, $F(3, 90) = 19.4$, $p < .0001$, with shorter mean latencies for the middle PI values of 500 ms and 750 ms (382 ms and 377 ms, respectively) than for the extreme PI values of 250 ms and 1,000 ms (406 ms and 393 ms, respectively). However, trial type interacted with PI, $F(15, 450) = 5.30$, $p < .0001$, indicating differences in this pattern of latencies across the four PI values among the various trial types.

Interpretation of the above interaction and main effects is qualified by the finding of two important interactions concerning age group: Age × Trial Type, $F(5, 150) = 2.61$, $p < .03$, and Age × Trial Type × PI, $F(15, 450) = 1.97$, $p < .025$, neither of which interacted with the specific levels of the parameters (all $ps > .09$). Subsequent analysis of these two interactions was carried out with respect to three specific comparisons:

1. There was a significant interaction between age group and the specific parameter change conditions, $F(2, 60) = 6.17$, $p < .005$. For elderly subjects, a direction change (498 ms) required on average 15 ms less time than an arm (510 ms) or arm and direction change (516 ms), whereas for young subjects, a direction change (376 ms) required on average 19 ms more time than an arm or arm and direction change (both 357 ms). However, this result is contingent on level of PI; the Age × Parameter Change Condition × PI interaction was also significant, $F(6, 180) = 2.25$, $p < .05$. For elderly subjects, there was a significant interaction between parameter change condition and PI, $F(6, 90) = 2.70$, $p < .02$, but not so for young subjects, $F(6, 90) = 2.12$, $p > .05$.

The loci of this interaction for elderly subjects appear to be at PI values of 250 ms and 1,000 ms. However, whereas the differences among the parameter change conditions at 250 ms are not significant, $F(2, 30) = 3.21$, $p > .05$ (or for that matter at PI values of 500 and 750 ms, both $Fs < 1$), differences at 1,000 ms are significant, $F(2, 30) = 7.05$, $p = .003$. At this PI, a direction change (472 ms) is 41 ms faster, $F(1, 15) = 12.1$, $p = .003$, than average arm and arm and direction changes (which are equivalent, 511 ms and 514 ms, respectively; $F < 1$).

2. Across age groups, RT for the CRT task was 54 ms shorter than RT for the invalid precue trials (collapsed over parameter change conditions), $F(1, 30) = 16.7$, $p < .0005$. However, as can be seen in Figure 2, RT differences for the CRT task and specific parameter change conditions vary as a function of age group and PI, $F(9, 270) = 2.31$, $p < .025$. For elderly subjects,

CRT task and parameter change conditions interacted with PI, $F(9, 135) = 3.51$, $p = .0006$. This interaction is primarily due to a convergence of CRT and direction change RTs with increases in PI, $F(3, 45) = 8.17$, $p = .0002$. The convergence is such that at a PI of 1,000 ms, CRT task (458 ms) and direction change RTs (472 ms) are nearly equivalent ($F < 1$). Although the arm and arm and direction change conditions also exhibit, on average, significant differences relative to the CRT task across PI, $F(3, 45) = 3.08$, $p < .05$, the patterns differ from the degree of convergence seen for the direction change condition. The distinguishing difference is seen most notably at a PI of 1,000 ms where, unlike a direction change, average RT for these two conditions remains significantly greater than RT for the CRT task, $F(1, 15) = 4.73$, $p < .05$. These findings are in strong contrast to young subjects, who do not exhibit any differential pattern among the CRT and parameter change condition RTs with changes in PI, $F(9, 135) = 1.85$, $p > .06$.

3. RT for the SRT task was 34 ms shorter than RT for the valid precue trials, $F(1, 15) = 16.4$, $p = .0003$, an effect that did not interact with age group or PI (all $ps > .10$).

MT. MT analysis yielded a large effect for age group, $F(1, 30) = 16.8$, $p < .0005$, with elderly subjects (318 ms) 148 ms slower in completing their responses than young subjects (170 ms). Further analysis indicated that this effect did not interact with the specific levels of the parameters (all $ps > .05$). There were small, but significant, differences among the various types of trials, $F(5, 150) = 3.36$, $p < .01$. Overall, mean SRT task MT (223 ms) was shortest, followed by mean MTs of the CRT task (241 ms), valid precue trials (245 ms), and parameter change conditions of the invalid precue trials: arm and direction (247 ms), arm (251 ms), and direction (257 ms). Furthermore, there were also small, but significant, differences across levels of PI, $F(3, 90) = 5.02$, $p < .005$: 239, 242, 247, and 248 ms, for PI values of 250, 500, 750, and 1,000 ms, respectively. All remaining effects and interactions were nonsignificant (all $ps > .05$).

Discussion

The results indicate general age-related similarities but also specific age-related differences in the performance of a movement plan restructuring, SRT, and CRT tasks. Overall, elderly subjects exhibited the general slowing of RT and MT typically reported in the aging literature (see, e.g., Salthouse, 1985; Stelmach et al., 1988; Stelmach, Goggin, & Garcia-Colera, 1987). Furthermore, for both groups, RT on the valid precue trials was greater than on the SRT task, indicating that elderly and young subjects are similarly sensitive to differences in precue validity. One explanation for the slower valid precue RTs for the two age groups is that precue validity less than 100% (in this case 75%) induces mixing of preparation for both precued and nonprecued responses (see Falmagne, 1965; Lupker & Theios, 1975). If we assume a limit to resources available for response preparation, this mixing would cause less than maximal preparation of the precued response and a corresponding elevation in RT for that response.

For both groups, there was also evidence of initial preparation of a movement plan. Overall, invalid precue trials were slower than the CRT task. However, using CRT task performance as a baseline measure for the processing of target stimulus uncertainty (as well as other perceptual and motor aspects common to both CRT and invalid precue trials of the movement plan restructuring tasks), distinct differences for the two age groups were found when the specific parameter change conditions were compared. For elderly subjects, with increases in PI, RT for a direction change decreased relative to arm and arm and direction changes. The decrease for the direction change was to the extent that at a PI of 1,000 ms, there was no longer a significant difference between latencies for a direction change and the CRT task. In addition, analysis of the parameter change conditions alone indicated that at a PI of 1,000 ms, not only is the direction change made 40 ms faster than the other parameter change conditions, but also these other parameter changes were made with the same RT. Furthermore, these results generalize to both levels of the arm and direction parameters and, more important, cannot be simply explained as resulting from speed–accuracy trade-off differences between the age groups. Last, we should note that for young subjects, no such differences occurred for any of the parameter change conditions across PI. These age effects are specific to RT, reflecting preparation, maintenance, and restructuring processes that operate before the execution (as measured by MT) of the movement plan. In contrast, across trial type and PI levels, the MT data corroborate the finding of qualitative similarity for movement plan execution for the two age groups reported by Stelmach et al. (1988) concerning these movement parameters.

We take these findings to suggest distinct age differences in the maintenance of a movement plan with regard to performance on a movement restructuring task. Unlike young subjects, who exhibited a constant relative latency to change direction compared with the other parameter change conditions with increases in PI, elderly subjects exhibited a relative latency decrease. The equivalence of the arm and arm and direction change conditions at a PI of 1,000 ms suggests something more: Preparation for direction is lost to such an extent that changing arm and direction is reduced to a case of changing arm alone. That is, for both these parameter change conditions, only arm needs to be altered; preparation for direction is initiated as if it had not taken place earlier. The convergence of the direction change and CRT latencies at a PI of 1,000 ms underscores this suggestion; the preparation for direction is lost to the degree that a direction change trial is similar to a trial on the CRT task, a task where no prior movement preparation occurs. Last, the overall similarity of the pattern of latencies across PI for all trial types except direction change indicates that it is primarily the direction parameter rather than the arm parameter that is exhibiting change for the elderly subjects (at least for the range of PI values used in Experiment 1).

Finally, one curious finding concerning elderly subjects is the lack of increase with increases in PI for SRT and valid precue latencies relative to CRT task latency. Here, it appears that no preparation loss is occurring. However, one explanation that retains the claim of preparation loss is possible: Given the substantially greater number of valid precue and SRT task trials, well-practiced orienting to the precued target stimulus allows earlier repreparation of the initial movement plan. The point is that attentional processes may act to compensate for movement preparation loss by exploiting the spatial redundancy of precue and target stimuli in the valid precue and SRT task trials (for a related discussion, see Posner, 1978). Given the similarity of the valid precue trial RT and SRT task difference for both age groups previously reported, it seems likely that the potential for compensation is present, regardless of age. However, because of the loss of direction preparation, elderly subjects may be especially likely to benefit from this orienting redundancy. Although beyond the scope of the current report, this attentional compensation clearly deserves further investigation. The explanation above does not compromise the interpretation of the parameter change conditions of the invalid precue trials, because any orienting practice for the target stimuli was equally distributed across the three change conditions.

Experiment 2

One of the basic characteristics of the research paradigms that have been used in the study of response preparation in elderly individuals has been the experimental control of the precue display interval and PI (e.g., Experiment 1; Larish & Stelmach, 1982; Stelmach et al., 1988). At issue is whether the loss of response preparation for the parameter of direction seen in Experiment 1 is due to an inability to optimize preparation given the temporal demand characteristics of the task or to an inability to maintain preparation, per se. Generally speaking, in a RT task using an experimenter-determined precue display interval or PI (variable or fixed), elderly subjects may have difficulty maximizing the use of response preparation (for any or all parameters) because of an inability to anticipate the onset of the target stimulus (Gottsdanker, 1982).

Alternative methods such as using nonaging foreperiods (Naatanen, 1971) and the transient signal methodology of Gottsdanker (1980a, 1980b, 1982) have been proposed as remedies for problems associated with using a fixed interstimulus interval or a fixed set of interstimulus intervals. Another, seemingly more straightforward approach to the study of movement plan restructuring is to give subjects active control of their preparation by allowing them to determine the duration of the precue stimulus. Dixon and Just (1986) used such a paradigm to study strategic response preparation. In Experiment 2, an adaptation of this paradigm was used. In this paradigm, three contiguous responses were made on a given trial. As in Experiment 1, on a given trial a precue stimulus was presented, followed by the target stimulus. However, subjects in Experiment 2 were allowed to view this precue until they felt ready to respond to the target stimulus. After making a response indicating attainment of this prepared state, subjects were presented, shortly thereafter, with the target stimulus. The time taken to study the precue stimulus constituted the precue viewing time (PT). The two remaining responses to the target stimulus determined the RT and MT intervals as defined earlier for Experiment 1.

Of interest in this study was whether a subject-selected precue stimulus display interval would allow elderly subjects to maximize response preparation control and thus mitigate the apparent loss effect for the parameter of direction observed in Experiment 1. Given sufficient control over the planning of a response, preparation for direction might be better preserved up to the time of response. Of further interest was the influence of the degree of precue stimulus validity on PT. In the CRT task used in Experiments 1 and 2, the precue was never valid, whereas it was valid 75% of the time in the movement plan restructuring task and valid 100% of the time in the SRT task. It was expected that increases in the level of the validity of a precue would increase its pertinence in the making of a movement plan, and consequently would induce longer PT. Furthermore, this prediction was made for both age groups, given the findings of aging studies investigating precue validity by means of related tasks (e.g., Larish & Stelmach, 1982; Nissen & Corkin, 1985; Stelmach et al., 1988).

Method

Subjects

Two age groups of 12 subjects each, one elderly (70–77 years; M = 72.3 years) and one young (20–24 years; M = 21.8 years) participated. The elderly group consisted of seven women and five men; the young group consisted of eight women and four men. Subjects in both groups were in good mental, neurological, and physiological health (subjects were screened by using a self-report questionnaire for instances of stroke, dementia, or Parkinson's disease) and equivalent on years of education: elderly, 14.5 years; young, 15.8 years, $t(22) = 1.96$, $p > .05$. All but one elderly and two young subjects were right-handed. None of these subjects participated in Experiment 1.

As in Experiment 1, subjects performed the DSST task before their participation. Mean DSST scores were 44.8 (49% of maximum) and 71.3 (79% of maximum) for elderly and young groups, respectively. These scores are consistent with those found in Experiment 1. Finally, DSST scores were again negatively correlated with age, $r(22) = -.88$, $p < .01$, indicating that the scores declined with increasing age.

Apparatus

The apparatus was the same as that used in Experiment 1 with the addition of a foot pedal device. The foot pedal, when depressed, activated a momentary switch. Responses made with the foot pedal were recorded by the LSI 11/03 minicomputer that controlled the experiment.

Design and Procedure

The design and procedure were identical to those of Experiment 1, with the following exceptions. In Experiment 2, the manipulation of the precue stimulus duration (measured as PT) was under subject control. Subjects were instructed to depress the foot pedal, study the precue stimulus, and release the foot pedal when they felt ready to respond to the target stimulus. As in Experiment 1, subjects were instructed to subsequently respond to the target stimulus by releasing the appropriate home key and pressing the target key corresponding to the position of the target stimulus as quickly and as accurately as possible. The target stimulus always appeared after a PI of 250 ms following the foot pedal release.

Results

Errors

We removed data from trials on which errors were committed from analysis. Errors consisted of failures to perform the task in the proper response sequence (i.e., releasing home key before releasing the foot pedal, responding to the precue or target stimulus before onset, or failure to depress the foot pedal before precue stimulus onset) and making an incorrect response to the target stimulus. Across all three tasks, elderly and young subjects made 21.7% and 11.5% errors on their respective trials, $F(1, 22) = 6.47$, $p < .02$. The elderly error rate was inflated by 3 subjects who exhibited a substantially higher error rate ($M = 37.3\%$); the error rate for the remaining elderly subjects was 16.5% and not significantly different from that for the young subjects, $F(1, 19) = 2.18$, $p > .15$. Because of the large number of condition replications per subject in this experiment, sufficient error-free trial data were available to allow the data for these 3 subjects to be retained. There were significant differences among the error rates across trial types: valid precue, 11.2%; arm change, 24%; direction change, 14.5%; arm and direction change, 21.9%; SRT, 14.3%; and CRT, 13.5%; $F(5, 110) = 7.91$, $p < .0001$, due to elevated arm and arm and direction change trials. With these trial types removed, the differences among the remaining trial types were nonsignificant ($F < 1$). Importantly, further analysis of these error rates indicated no significant Age Group × Trial Type interaction ($F < 1$). Also removed from analysis were MT and corresponding RT and PT latencies for trials where MT was either less than 50 ms (representing cases where subjects accidently pressed the target key with their thumbs rather than moving their index finger to press the target key) or greater than 1,000 ms (representing cases where subjects failed to exert sufficient force to press the target button on initial contact). These cases constituted .2% and .3% of the elderly and young subject data sets, respectively.

Response Latencies

Main ANOVAs conducted on the RT and MT data concern the effects of age group (young or elderly); trial type—four restructuring task trials (valid precue trials and the three parameter change conditions of the invalid precue trials, arm, direction and arm and direction) and the SRT and CRT tasks—collapsed over specific levels of the two movement parameters, arm (left or right) and direction (toward or away from body), and trial blocks. We also conducted secondary analyses to assess age group effects and interactions found in the main analyses with respect to the specific levels of the arm and direction parameters. The complete RT and MT data set, collapsed over subjects, is given in Appendix B. Last, we conducted separate analyses on PT, task and precue validity, and the relationship between PT and RT and between PT and MT with respect to task and parameter change conditions.

RT. RT data are plotted in Figure 3, collapsed over subjects within each age group. Overall, there was a large effect for age group, $F(1, 22) = 14.3$, $p = .001$, with elderly subjects (377 ms) responding 95 ms slower than the young subjects (282 ms). Further analysis indicated that this effect was independent of the specific levels of the parameters (all $ps > .05$). There were also significant differences among the various types of trials, $F(5, 110) = 68.9$, $p < .001$. Across age group, mean latency for the SRT task was shortest (229 ms), followed by the valid precue trials (276 ms), the CRT task (332 ms), and the three parameter

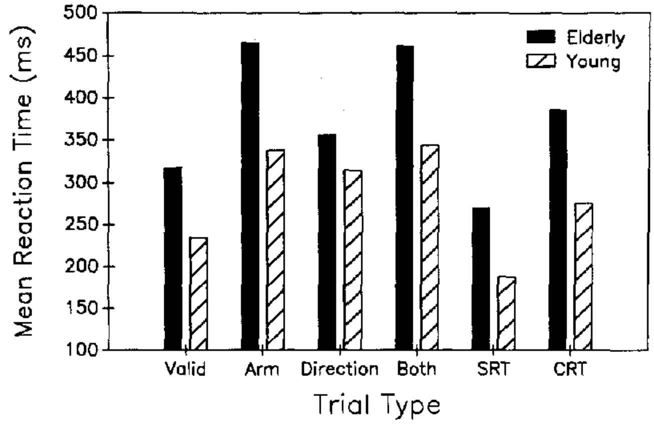

Figure 3. Mean reaction time for Experiment 2 plotted as a function of age group and trial type. (SRT = simple reaction time; CRT = choice reaction time.)

change conditions of the invalid precue trials: direction (336 ms), arm (402 ms), and arm and direction (403 ms).

There was also an important interaction between age group and trial type, $F(5, 110) = 3.37$, $p < .01$, which occurred independent of specific parameter levels (all $ps > .38$). As in Experiment 1, subsequent analysis of this interaction was carried out with respect to three specific comparisons:

1. Analysis of the differences among the three parameter change conditions yielded a significant Age × Parameter Change Condition interaction, $F(2, 44) = 12.6$, $p < .0001$. For elderly subjects, a direction change (357 ms) occurred on average 107 ms faster than arm (466 ms) and arm and direction (462 ms) changes; however, for young subjects, a direction change (314 ms) occurred on average only 27 ms faster than arm (338 ms) and arm and direction (344 ms) changes. Furthermore, the direction change effect for young subjects was completely compensated by their MT data; in a total time analysis, the effect was not found ($M = -10$ ms; $F < 1$), indicating that young subjects' direction change effect was due to initiating the response before complete movement plan preparation had occurred. By contrast, this effect for elderly subjects was minimally compensated by their MT data in this regard; the effect persisted in a total time analysis ($M = 67$ ms), $F(1, 11) = 11.3$, $p < .01$. As these age group differences suggest, the Age × Parameter Change Condition interaction reported for the RT data was also found for the total time data, $F(2, 44) = 6.04$, $p < .005$.

2. Across age groups, latency for the CRT task was 49 ms shorter than latency for the invalid precue trials (collapsed over parameter change conditions), $F(1, 22) = 13.8$, $p = .001$. However, as can be seen in Figure 3, latency differences for the CRT task and specific parameter change conditions vary as a function of age group and trial type, $F(3, 66) = 5.10$, $p < .005$. This interaction can be described as follows: For elderly subjects, the latency of the direction change condition was 30 ms less than CRT task latency, although this difference was not significant, $F(1, 11) = 2.39$, $p > .15$. The latencies of the remaining parameter change conditions, however, were each greater than CRT

task latency. This difference from CRT task latency was significant for arm change (79 ms), $F(1, 11) = 12.0$, $p = .005$, and arm and direction change (75 ms), $F(1, 11) = 7.92$, $p < .02$. For young subjects, all three parameter change conditions had longer latencies when compared with the CRT task. Differences from CRT task latency were significant for direction change, 38 ms, $F(1, 11) = 5.03$, $p < .05$; arm change, 62 ms, $F(1, 11) = 17.7$, $p < .002$; and arm and direction change, 68 ms, $F(1, 11) = 17.4$, $p < .002$.

3. Latency for the SRT task was 47 ms shorter than latency for the valid precue trials, $F(1, 22) = 20.8$, $p < .0005$, an effect that did not interact with age group ($F < 1$).

PT, task, and precue validity. In Figure 4, mean PT latencies are plotted as a function of precue validity for the CRT, movement plan restructuring, and SRT tasks and age group, collapsed over subjects within each group. We analyzed mean group latencies by means of multiple regression with these variables as factors. As can be seen, there is a large (113 ms) increase in PT for elderly (652 ms) over young (539 ms) subjects, $t(3) = 24.2$, $p < .001$. In addition, there were equivalent increases in PT, for elderly and young subjects, with increases in precue validity, $t(3) = 7.61$, $p < .003$. For elderly subjects, mean PT latencies for the CRT, movement plan restructuring, and SRT tasks were 627 ms, 654 ms, and 676 ms, respectively. For young subjects, mean PT latencies for these three tasks were, respectively, 516 ms, 549 ms, and 552 ms. Finally, best-fitting lines computed conjointly for both groups, using these two variables, accounted for over 99.5% of the group mean variance, $F(2, 3) = 322.0$, $p < .001$.

PT, RT, and parameter change conditions. An analysis was also carried out to determine the relationship between PT and RT for the parameter change conditions of the invalid precue trials. This analysis provided a measure of the ability of both age groups to optimize preparation of the precue stimulus for the response to the target stimulus. We analyzed these data by means of linear regression; subject mean PT (pooled over all trials of the movement plan restructuring task) and subject

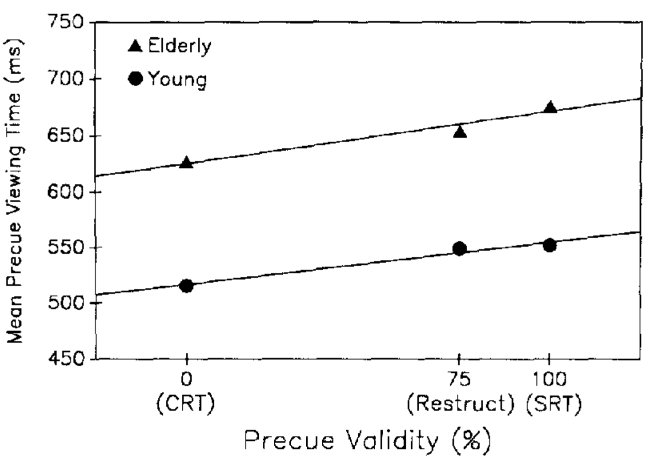

Figure 4. Mean precue viewing time and best-fitting lines for Experiment 2 plotted according to age group and precue validity for the choice reaction time (CRT), movement restructuring, and simple reaction time (SRT) tasks.

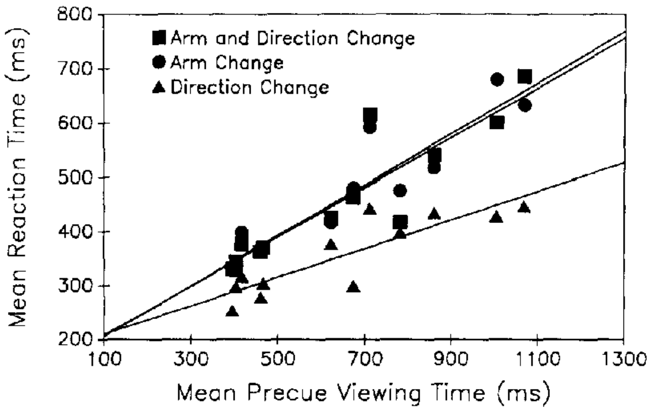

Figure 5. Scatter plot for Experiment 2 of elderly subject mean precue viewing time and reaction time for the three parameter change conditions of the invalid precue trials. (Best-fitting lines were computed for each change condition.)

mean RT, for each of the parameter change conditions (arm, direction, arm and direction) were treated as variables. Separate best-fitting lines were computed for each age group and are plotted in Figures 5 and 6. For the elderly group (see Figure 5), across increasingly slower subject PT, there is a slower rate of increase in direction change RT relative to the other change conditions, which have the same rate of increase. The slopes for these best-fitting lines were .265, .469, and .457 for direction, arm, and arm and direction change conditions, respectively. Correlations for these lines were highly significant: For direction change, $r(10) = .87$, $p < .001$; for arm change, $r(10) = .93$, $p < .001$; and for arm and direction change, $r(10) = .90$, $p < .001$.

Analysis of the young group data for the parameter change conditions yielded equivalent, though negligible, rates of increase in RT with increasing subject PT (see Figure 6). The slopes for these best-fitting lines were .031, .085, and .075 for direction, arm, and arm and direction change conditions, respectively. Furthermore, correlations for all three lines failed to reach statistical significance: For direction change, $r(10) = .52$, $p > .05$; for arm change, $r(10) = .18$, $p > .10$; and for arm and direction change, $r(10) = .48$, $p > .05$.

MT and PT. MT analysis yielded a large effect for age group, $F(1, 22) = 41.0$, $p < .0001$, with elderly subjects (405 ms) 205 ms slower in completing their responses than young subjects (200 ms). Further analysis indicated that this effect did not vary as a function of specific parameter level (all $ps > .05$). There were also small but significant differences among the various types of trials, $F(5, 110) = 3.96$, $p < .005$. Overall mean MTs for the valid precue trials, three parameter change conditions of the invalid precue trials (arm, direction, and arm and direction) and the SRT and CRT tasks were 293 ms, 293 ms, 333 ms, 299 ms, 303 ms, and 293 ms, respectively. This effect is due to an elevated MT for direction change trials; with these trials excluded, the effect is nonsignificant ($F < 1$). Importantly, this effect did not interact with age group ($F < 1$). All remaining effects and interactions were nonsignificant (all $ps > .05$). Last, we conducted a parallel set of regression analyses concerning

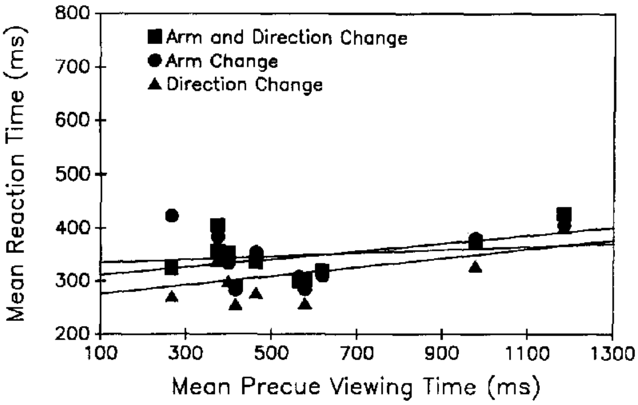

Figure 6. Scatter plot for Experiment 2 of young subject mean precue viewing time and reaction time for the three parameter change conditions of the invalid precue trials. (Best-fitting lines were computed for each change condition.)

MT and PT; no significant correlations were found (all *ps* > .05).

Discussion

Overall, the findings of the present experiment corroborate the results of Experiment 1. Beyond an overall increase in RT and MT response latencies for elderly subjects, both age groups showed similar evidence of preparation of a movement plan; although, for both groups, this plan is not prepared to the same extent as that prepared in the SRT task, it is sufficient to incur additional processing time when it needs to be altered. Furthermore, PT was found to increase with increases in precue validity in the same manner for both age groups. This finding indicates that in a speeded precued response task, the time spent viewing a precue stimulus is determined by the extent to which it validly specifies the movement plan for a response to the target stimulus. Importantly, these results indicate that elderly subjects are indeed as sensitive to precue validity as young subjects. We believe this is particularly important evidence of the use of probability information by elderly individuals because they were given active control over the processing of information that is influenced by the level of precue validity.

However, as was also the case in Experiment 1, this conclusion of similarity between age groups needs to be qualified. For the elderly subjects, evidence was again found for the loss of preparation for the parameter of direction, whereas for young subjects this preparation remains consistent across all movement parameters. The characteristics of the elderly subject RT results replicate those of Experiment 1 at a PI of 1,000 ms: (a) there was a substantially shorter latency to change direction compared with changing arm or both parameters; (b) there was equivalent latency to change arm or both parameters; (c) relative to the CRT task, there was significant additional latency to make an arm or arm and direction change, but no significant difference in latency to make a direction change; (d) these effects occur independent of specific levels of arm and direction parameters; and (e) these effects cannot be explained by a differential speed–accuracy trade-off between the two groups across trial types. Taken together, these characteristics again suggest that elderly subjects are unable to maintain direction preparation to such an extent that changing arm and changing arm and direction become instances of the same case (i.e., both conditions involve only making an arm change). Furthermore, processing on direction change trials becomes similar to that of a CRT task, a task where a movement plan is not typically prepared in advance of target stimulus onset (Klapp et al., 1974).

What the findings from Experiment 2 underscore is that even when given the opportunity to optimally prepare a precued movement, elderly subjects are unable to prevent this loss for direction preparation. This is in stark contrast to young subjects, who fail to show any differences in preparation maintenance for the two parameters when given this opportunity. The differences in PT among elderly (and young) subjects are likely due to individual perceptual, cognitive, and motor execution factors in addition to movement plan preparation factors. However, given the pattern of PT for increasing levels of precue validity, it appears that elderly subjects did indeed use the precue display interval (apparently to the same extent as young subjects) to prepare a movement plan. Why the subject-selected precue stimulus interval did not prevent the loss of direction preparation could be due to (at least) two reasons: (a) Elderly subjects were not aware of the loss and thus made no attempt to prevent it or (b) they were aware of it and tried to prevent it, but to no avail. What is important is that the loss effect is found for all elderly subjects regardless of increases in PT, suggesting that it is not under subject control. The variance in individual latency differences seen in Figure 5 between direction change and the other parameter change conditions is generally consistent with the pattern of mean subject PT; elderly subjects with slower PT exhibit proportional increases in their RT, thus accentuating differences among conditions. Finally, this loss effect appears to be due to an age group difference as opposed to a time-based difference, where direction loss occurs for both groups with increases in time on task: Slower young subjects are no more likely to exhibit it than are faster young subjects.

General Discussion

The findings from these two experiments indicate that there are qualitative similarities and differences in elderly and young individuals' control of movement preparation and execution. The similarities consist of the manner in which a movement plan is initially prepared, with respect to how information about precue probability and stimulus uncertainty influence that preparation. Of course, elderly subjects are much slower in their processing of precue probability and stimulus uncertainty as well as in their execution of a movement plan, but this slowing appears to be proportional and indicative of a general slowing of processes that remain intact with changes in age (see Salthouse, 1985).

What is so compelling about the findings of the present experiments is that elderly and young individuals differ markedly in their maintenance of movement preparation for direction. The results of Experiment 1 indicate that after a PI of only 1,000 ms, elderly subjects have lost direction preparation to the extent that when required to alter the originally prepared movement plan, they prepare the new plan (with respect to direction) as if the original plan had never been prepared. This finding is in contrast to the results of the young subjects, who showed slightly better preparation maintenance for direction than for arm. Furthermore, the results of Experiment 2 suggest that the loss of direction preparation for elderly subjects occurs even when they select the duration of the precue stimulus display and thus determine the effective preparation interval (PT + 250 ms PI). The implication of this finding is that preparation loss for direction is due to changes in movement preparation processes concerning this parameter that are not readily available to, or altered by, subject control. Importantly, this profile for preparation loss, as measured by RT, occurs independent of the specific levels of the arm and direction parameters.

We do not believe a spatial attention shift account of these data is tenable for two reasons: (a) Concerning the corresponding stimulus displays for precue and target stimuli, an arm and direction change would seem to be more complex because it involves a diagonal spatial shift (e.g., upper left–lower right) as compared with an arm change or a direction change that involves horizontal (e.g., upper left–upper right) and vertical (e.g., upper left–lower left) spatial shifts, respectively. However, arm and arm and direction changes had equivalent response latencies where the difference between them and a direction change occurred in these studies; (b) Hartley (1987) reported finding no apparent qualitative differences between elderly and young individuals in their allocation or reallocation of attention in precuing tasks. Hartley's finding supports earlier research (e.g., Nissen & Corkin, 1985) and argues against the age differences found in the current experiments for the restructuring of direction as being due to qualitative differences in the way that elderly and young individuals shift spatial attention.

That elderly preparation loss effects were not found to the same degree for the parameter of arm in these studies may be due to the effective preparation intervals chosen. Given that the RT difference (at least the magnitude) in restructuring arm and direction parameters reported here was not found by Stelmach et al. (1988) when using an effective preparation interval of 2,000 ms suggests that arm preparation loss does ultimately occur; indeed, the findings from Experiment 1 indicate that it does occur to some degree. However, to observe it occurring to the same extent as it does for direction would appear to require an effective preparation interval longer than 1,200 ms (from Experiment 1: 200 ms precue stimulus display + 1,000 ms PI) when that interval is experimenter controlled or longer than 902 ms (from Experiment 2: 652 ms mean elderly PT + 250 ms PI) when it is subject controlled. In this regard, the important finding here is that for elderly subjects, direction loss at least precedes arm loss (if extensive arm loss does in fact occur).

Why there are substantial age differences for direction preparation maintenance but not for arm, given the time frame of preparation maintenance used in the present studies, is an intriguing question. One possibility is that it is a matter of the complexity of the direction parameter. Whereas arm is inherently a binary parameter (i.e., left or right), direction is a (potentially) continuous parameter (i.e., 0°–360°). This difference in complexity may explain the findings reported in the present experiments: For an elderly individual, the more complex the parameter structure, the more likely that its preparation will not be maintained over time. Corroborative support for such a claim is provided by a study of age and movement parameter specification by Stelmach et al. (1987). In that study it was found that especially for elderly subjects across age, specification of direction (away from or toward the body) required the most time, followed by arm (left or right) and extent (short or long distance).

Direction also appears to be a relatively complex parameter with respect to neurological functioning. There is evidence that direction is coded at some of the highest cognitive regions of the brain, such as the prefrontal cortex (Kubota, 1978; Niki, 1974a, 1974b; Niki & Watanabe, 1976). Furthermore, there is evidence of sizable neuronal loss in the prefrontal cortex for elderly individuals when compared with young individuals (Haug et al., 1983). Taken together, these findings suggest that direction is a parameter particularly likely to undergo age-related change with respect to motor preparation processes. The findings from the present studies, therefore, provide further insight into the functional aspects and age-related changes in the cognitive–motor system with respect to specific movement parameters involved in the control and execution of simple movements. Finally, these findings also suggest possible directions for research concerning performance differences on the movement plan restructuring task due to various types of elderly dementias that affect higher level cognitive processes (e.g., Alzheimer's disease).

References

Dixon, P., & Just, M. (1986). A chronometric analysis of strategy preparation in choice reactions. *Memory & Cognition, 14,* 488–500.

Falmagne, J. C. (1965). Stochastic models for choice reaction time with application to experimental results. *Journal of Mathematical Psychology, 12,* 77–124.

Gottsdanker, R. (1980a). Aging and the maintaining of preparation. *Experimental Aging Research, 6,* 13–27.

Gottsdanker, R. (1980b). Aging and the use of advance probability information. *Journal of Motor Behavior, 12,* 133–143.

Gottsdanker, R. (1982). Age and simple reaction time. *Journal of Gerontology, 37,* 342–348.

Hartley, A. (1987, November). *Aging and the allocation of attention.* Paper presented at the National Institute on Aging Working Conference on the Aging of Attention, Washington, DC.

Haug, H., Barmwater, U., Eggers, R., Fischer, S., Kuhl, S., & Sass, N. L. (1983). Anatomical changes in the aging brain: Morphometric analysis of the human prosencephalon. In J. Cervos-Navarro & H. I. Sarkander (Eds.), *Brain aging: Neuropathology and neuropharmacology* (Aging, Vol. 21, pp. 1–12). New York: Raven Press.

Klapp, S. T., Wyatt, E. P., & Lingo, W. M. (1974). Response programming in simple and choice reactions. *Journal of Motor Behavior, 6,* 263–271.

Kubota, K. (1978). Neuron activity in the dorsolateral prefrontal cortex of the monkey and initiation of behavior. In M. Ito (Ed.), *Integrative control functions of the brain* (Vol. 1, pp. 407–417). Amsterdam: Elsevier.

Larish, D., & Frekany, G. (1985). Planning and preparing expected and unexpected movements: Reexamining the relationship of arm, direction, and extent of movement. *Journal of Motor Behavior, 17,* 168–189.

Larish, D., & Stelmach, G. E. (1982). Preprogramming, programming, and reprogramming of aimed hand movements as a function of age. *Journal of Motor Behavior, 14,* 322–340.

Lupker, S., & Theios, J. (1975). Tests of two classes of models for choice reaction times. *Journal of Experimental Psychology: Human Perception and Performance, 104,* 137–146.

Naatanen, R. (1971). Non-aging foreperiod and simple reaction-time. *Acta Psychologica, 35,* 316–327.

Niki, H. (1974a). Prefrontal unit activity during delayed alternation in the monkey, I. Relation to direction of response. *Brain Research, 68,* 185–196.

Niki, H. (1974b). Prefrontal unit activity during delayed alternation in the monkey, II. Relation to absolute versus relative direction of response. *Brain Research, 68,* 197–204.

Niki, H., & Watanabe, M. (1976). Prefrontal unit activity and delayed response: Relation to cue location versus direction of response. *Brain Research, 105,* 79–88.

Nissen, M. J., & Corkin, S. (1985). Effectiveness of attentional cueing in older and younger adults. *Journal of Gerontology, 40,* 185–191.

Posner, M. I. (1978). *Chronometric explorations of mind.* Hillsdale, NJ: Erlbaum.

Rosenbaum, D., & Kornblum, S. (1982). A priming method for investigating the selection of motor responses. *Acta Psychologica, 51,* 223–243.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 400–426). New York: Van Nostrand Reinhold.

Stelmach, G. E., Goggin, N. L., & Amrhein, P. C. (1988). Aging and the restructuring of precued movements. *Psychology and Aging, 3,* 151–157.

Stelmach, G. E., Goggin, N. L., & Garcia-Colera, A. (1987). Movement specification time with age. *Experimental Aging Research, 13,* 39–46.

Welford, A. T. (1977). Motor performance. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 450–456). New York: Van Nostrand Reinhold.

(*Appendix A follows on next page*)

Appendix A

Mean Response Latencies (in Milliseconds) for Experiment 1

Direction of arm	Valid precue: Left arm	Valid precue: Right arm	Valid precue: *M*	Arm change: Left arm	Arm change: Right arm	Arm change: *M*	Direction change: Left arm	Direction change: Right arm	Direction change: *M*	Both change: Left arm	Both change: Right arm	Both change: *M*	SRT task: Left arm	SRT task: Right arm	SRT task: *M*	CRT task: Left arm	CRT task: Right arm	CRT task: *M*	Total *M*
Elderly subjects: PI = 250 ms																			
Toward																			
RT	398	397	398	494	515	504	553	530	542	562	580	571	370	367	368	436	462	449	472
SD	112	102		121	135		163	175		251	237		104	105		106	144		
MT	291	320	306	333	367	350	340	357	349	375	292	334	252	280	266	302	287	294	316
SD	147	191		200	229		174	132		175	166		129	165		125	124		
Total	689	717	704	827	882	854	893	887	891	937	872	905	622	647	634	738	749	743	788
Away																			
RT	448	422	435	524	525	524	516	504	510	527	553	540	382	374	378	432	446	439	471
SD	121	119		138	150		216	155		186	133		96	95		110	125		
MT	306	351	328	388	301	344	340	300	320	310	250	280	290	336	313	282	273	278	310
SD	172	165		192	204		185	146		171	132		168	161		110	124		
Total	754	773	763	912	826	868	856	804	830	837	803	820	672	710	691	714	719	717	781
Mean RT	423	410	416	509	520	514	534	517	526	544	566	556	376	370	373	434	454	444	472
Mean MT	298	336	317	360	334	347	340	328	334	342	271	307	271	308	290	292	280	286	313
Mean total	721	746	733	869	854	861	874	845	860	886	837	863	647	678	663	726	734	730	785
Elderly subjects: PI = 500 ms																			
Toward																			
RT	364	363	364	497	511	504	528	511	520	506	536	521	339	332	336	408	439	424	445
SD	106	116		152	134		194	126		121	235		122	109		106	155		
MT	298	327	312	333	286	310	306	356	330	365	296	331	263	293	278	311	321	316	313
SD	152	192		185	184		138	163		162	153		128	165		128	138		
Total	662	690	676	830	797	814	834	867	851	871	832	851	602	625	614	719	760	740	758
Away																			
RT	413	393	403	516	534	525	505	490	498	482	492	487	351	343	347	426	409	418	446
SD	130	117		202	168		160	174		102	134		127	111		188	113		
MT	315	350	332	363	314	338	364	357	360	310	315	312	295	328	312	308	257	282	323
SD	169	159		194	158		225	223		182	174		154	152		140	104		
Total	728	743	735	879	848	863	869	847	858	792	807	799	646	671	659	734	666	700	769
Mean RT	388	378	384	506	522	514	516	500	509	494	514	504	345	338	342	417	424	421	446
Mean MT	306	338	322	348	300	324	335	356	346	338	306	321	279	310	295	310	289	299	318
Mean total	694	716	706	854	822	838	851	856	855	832	820	825	624	648	637	727	713	720	764

Elderly subjects: PI = 750 ms

Toward																			
RT	390	388	389	522	485	504	505	482	494	469	504	486	345	339	342	413	429	421	439
SD	153	140		196	114		133	115		125	126		115	110		144	141		
MT	315	355	335	325	309	317	321	364	343	350	355	352	265	279	272	329	313	321	323
SD	156	179		168	151		168	166		160	217		128	141		139	145		
Total	705	743	724	847	794	821	826	846	837	819	859	838	610	618	614	742	742	742	762
Away																			
RT	414	396	405	488	500	494	484	479	482	512	469	490	364	332	348	410	446	428	441
SD	146	130		144	126		116	123		190	125		121	102		133	153		
MT	315	364	340	344	289	316	323	329	326	334	323	328	287	336	312	313	299	306	321
SD	163	164		157	134		163	183		216	168		154	142		141	140		
Total	729	760	745	832	789	810	807	602	808	846	792	818	651	668	660	723	745	734	762
Mean RT	402	392	397	505	492	499	494	480	487	490	486	488	354	336	345	412	438	424	440
Mean MT	315	360	338	334	299	316	322	346	334	342	339	340	276	308	292	321	306	314	322
Mean total	717	752	735	839	791	815	816	826	821	832	825	828	630	644	637	733	744	738	762

Elderly subjects: PI = 1,000 ms

Toward																			
RT	424	418	421	506	520	513	487	475	481	508	558	533	374	382	378	468	470	469	466
SD	130	131		144	141		138	128		128	185		127	115		182	143		
MT	308	337	322	352	290	321	309	326	318	345	314	330	281	283	282	317	299	308	314
SD	149	177		161	143		136	122		158	171		152	154		119	131		
Total	732	755	743	858	810	834	796	801	799	853	872	863	655	665	660	785	769	777	780
Away																			
RT	460	433	446	503	514	508	473	453	463	480	512	496	397	368	382	439	453	446	457
SD	155	122		150	139		136	151		104	130		120	107		123	146		
MT	310	354	332	348	327	338	302	350	326	333	294	314	286	359	322	314	293	304	323
SD	160	147		165	174		158	198		180	134		140	186		160	138		
Total	770	787	778	851	841	846	775	803	789	813	806	810	683	727	704	753	746	750	780
Mean RT	442	426	434	504	517	511	480	464	472	494	535	514	386	375	380	454	462	458	462
Mean MT	309	346	327	350	308	330	306	338	322	339	304	322	284	321	302	316	296	306	318
Mean total	751	772	761	854	825	841	786	802	794	833	839	836	670	696	682	770	758	764	780

Elderly subjects: Across PI

Toward																			
RT	394	392	393	505	508	506	518	500	509	511	544	528	357	355	356	431	450	440	455
MT	303	335	319	336	313	324	319	351	335	358	314	336	265	284	274	315	305	310	316
Total	697	727	712	841	821	830	837	851	844	869	858	864	622	639	630	746	755	750	771
Away																			
RT	434	411	422	508	518	513	494	482	488	500	507	504	374	354	364	427	438	432	454
MT	312	355	334	361	308	335	332	334	333	322	296	309	290	340	315	304	280	292	320
Total	746	766	756	869	826	847	826	816	821	822	803	813	664	694	679	731	718	724	774
Mean RT	414	402	408	506	513	510	506	491	498	506	526	516	366	354	360	429	444	436	455
Mean MT	308	345	326	348	310	329	326	342	334	340	305	323	278	312	294	310	292	301	318
Mean total	722	747	734	854	823	839	832	833	832	846	831	839	644	666	654	739	736	737	773

(*Appendix A continues on next page*)

Appendix A (*continued*)

Direction of arm	Trial type: Valid precue Left arm	Valid precue Right arm	Valid precue *M*	Arm change Left arm	Arm change Right arm	Arm change *M*	Direction change Left arm	Direction change Right arm	Direction change *M*	Both change Left arm	Both change Right arm	Both change *M*	SRT task Left arm	SRT task Right arm	SRT task *M*	CRT task Left arm	CRT task Right arm	CRT task *M*	Total *M*
Young subjects: PI = 250 ms																			
Toward																			
RT	268	280	274	381	359	370	423	378	400	372	400	386	266	278	272	339	343	341	340
SD	25	37		80	56		79	84		36	70		29	42		49	78		
MT	142	153	148	154	161	158	182	197	190	175	160	168	132	143	138	184	170	177	163
SD	34	43		38	81		70	69		40	32		27	46		70	35		
Total	410	433	422	535	520	528	605	575	590	547	560	554	398	421	410	523	513	518	503
Away																			
RT	302	291	296	392	379	386	380	399	390	379	345	362	288	288	288	319	321	320	340
SD	42	36		124	59		58	80		62	37		41	47		44	40		
MT	163	174	168	176	186	181	174	143	158	151	141	146	159	177	168	173	167	170	165
SD	40	40		38	77		101	36		36	37		44	43		50	47		
Total	465	465	464	568	565	567	554	542	548	530	486	508	447	465	456	492	488	490	505
Mean RT	285	286	285	386	369	378	402	388	395	376	372	374	277	283	280	329	332	331	340
Mean MT	152	164	158	165	174	170	178	170	174	163	150	157	146	160	153	178	168	174	164
Mean total	437	450	443	551	543	548	580	558	569	539	522	531	423	443	433	507	500	503	504
Young subjects: PI = 500 ms																			
Toward																			
RT	259	266	262	337	329	333	399	396	398	359	359	359	243	240	242	314	298	306	317
SD	23	40		31	41		67	80		65	55		27	35		48	33		
MT	148	153	150	153	145	149	190	188	189	210	172	191	134	140	137	187	174	180	166
SD	30	43		31	28		64	56		60	53		30	32		40	38		
Total	407	419	412	490	474	482	589	584	587	569	531	550	377	380	379	501	472	486	483
Away																			
RT	288	277	282	350	346	348	354	371	362	368	350	359	271	255	263	294	301	298	319
SD	46	42		43	44		64	65		57	64		38	32		43	52		
MT	168	188	178	188	177	182	155	167	161	145	157	151	151	169	160	177	167	172	167
SD	47	50		71	63		51	50		50	59		31	38		43	34		
Total	456	465	460	538	523	530	509	538	523	513	507	510	422	424	423	471	468	470	486
Mean RT	274	272	273	344	338	341	376	384	380	364	354	359	257	248	252	304	300	302	318
Mean MT	158	170	164	170	161	166	172	178	175	178	164	171	142	154	148	182	170	176	166
Mean total	432	442	437	514	499	507	548	562	555	542	518	530	399	402	400	486	470	478	484
Young subjects: PI = 750 ms																			
Toward																			
RT	266	270	268	354	345	350	396	372	384	364	377	370	239	242	240	311	295	303	319
SD	36	35		57	60		77	66		58	89		30	31		48	37		
MT	150	159	154	169	144	157	184	196	190	192	169	180	140	147	144	195	187	191	169

Young subjects: PI = 750 ms (*continued*)

SD	41	41		87	34		54	43		47	32		32	36		85	43		
Total	416	429	422	523	489	507	580	568	574	556	546	550	379	389	384	506	482	494	488
Away																			
RT	291	282	286	353	346	350	333	370	352	337	313	325	261	250	256	302	290	296	311
SD	43	36		52	45		64	49		58	42		41	42		41	41		
MT	174	185	180	200	198	199	158	175	166	173	152	162	153	174	164	175	186	180	175
SD	50	45		79	70		31	109		77	41		35	37		47	46		
Total	465	467	466	553	544	518	491	545	519	510	465	487	414	424	420	478	476	476	486
Mean RT	278	276	277	354	346	350	364	371	368	350	345	348	250	246	248	307	292	299	315
Mean MT	162	172	168	184	171	178	171	186	178	182	160	171	146	160	154	185	186	186	172
Mean total	440	448	445	538	517	528	535	557	546	532	505	519	396	406	402	492	478	485	487

Young subjects: PI = 1,000 ms

Toward																			
RT	286	289	288	347	363	355	374	369	372	356	370	363	264	260	262	329	318	324	327
SD	36	49		59	38		88	73		62	60		41	41		55	51		
MT	154	155	154	175	157	166	219	225	222	219	181	200	145	148	146	198	180	189	180
SD	39	41		64	38		101	65		71	69		51	40		54	42		
Total	440	444	442	522	520	521	593	594	594	575	551	563	409	408	408	527	498	513	507
Away																			
RT	314	292	303	363	361	362	356	351	354	328	337	332	287	272	280	303	308	306	323
SD	56	48		49	43		61	68		41	42		52	48		57	43		
MT	175	181	178	205	179	192	148	179	164	195	155	175	152	176	164	195	186	190	177
SD	40	40		84	52		38	66		105	34		32	47		60	56		
Total	489	473	481	568	540	554	504	530	518	523	492	507	439	448	444	498	494	496	500
Mean RT	300	290	295	355	362	358	365	360	362	342	354	348	276	266	271	316	313	315	325
Mean MT	165	168	166	190	168	179	184	202	193	207	168	188	148	162	155	196	183	190	178
Mean total	465	458	461	545	530	537	549	562	555	549	522	536	424	428	426	512	496	505	503

Young subjects: Across PI

Toward																			
RT	270	276	273	355	349	352	398	379	388	363	376	370	253	255	254	323	314	318	326
MT	148	155	152	163	152	158	198	202	194	199	170	184	138	144	141	191	178	184	170
Total	418	431	425	518	518	501	592	581	586	562	546	554	391	399	395	514	492	502	496
Away																			
RT	299	286	292	364	358	361	356	373	364	353	336	344	277	266	272	304	305	304	323
MT	170	182	176	192	185	188	159	166	162	166	151	158	154	174	164	180	177	178	171
Total	469	468	468	556	543	549	515	539	526	519	487	502	431	440	436	484	482	482	494
Mean RT	284	281	282	360	354	357	377	376	376	358	356	357	265	260	263	314	310	311	324
Mean MT	159	168	164	178	168	173	176	184	180	183	160	171	146	160	152	186	178	181	170
Mean total	443	449	446	538	522	530	553	560	556	540	516	528	411	420	415	500	488	492	494

Note. PI = preparation interval; SRT = simple reaction time; CRT = choice reaction time; RT = reaction time; and MT = movement time.

(*Appendix B follows on next page*)

Appendix B

Mean Response Latencies (in Milliseconds) for Experiment 2

	Trial type																		
	Valid precue			Arm change			Direction change			Both change			SRT task			CRT task			
Direction of arm	Left arm	Right arm	*M*	Left arm	Right arm	*M*	Left arm	Right arm	*M*	Left arm	Right arm	*M*	Left arm	Right arm	*M*	Left arm	Right arm	*M*	Total *M*
Elderly subjects																			
Toward																			
RT	293	322	308	462	474	468	355	348	352	453	454	454	261	262	262	375	365	370	369
SD	66	77		113	117		87	71		149	115		75	70		95	91		
MT	394	370	382	395	343	369	432	375	404	425	365	395	411	386	398	369	358	364	385
SD	105	112		127	90		93	104		183	114		119	103		107	100		
Total	687	692	690	857	817	837	787	723	756	878	819	849	672	648	659	744	723	734	754
Away																			
RT	322	335	328	465	464	464	357	368	362	473	467	470	259	297	278	408	400	404	384
SD	108	97		167	126		106	89		157	115		50	67		124	111		
MT	411	421	416	407	432	420	468	472	470	389	439	414	454	413	434	400	391	396	425
SD	160	133		171	154		146	135		140	156		197	152		179	136		
Total	733	756	744	872	896	884	825	840	832	862	906	884	713	710	712	808	791	800	809
Mean RT	308	328	318	464	469	466	356	358	357	463	460	462	260	280	270	392	382	387	377
Mean MT	402	396	399	401	388	394	450	424	437	407	402	399	432	400	416	384	374	380	405
Mean total	710	724	717	865	857	860	806	782	794	870	862	861	692	680	686	769	756	767	782
Young subjects																			
Toward																			
RT	215	228	222	324	354	339	325	327	326	337	344	340	171	180	176	265	271	268	279
SD	23	29		47	64		45	48		46	50		39	38		34	45		
MT	180	177	178	190	179	184	207	200	204	177	184	181	195	181	188	201	189	195	188
SD	45	47		42	61		69	42		46	71		45	41		49	35		
Total	395	405	400	514	533	523	532	527	530	514	528	521	366	361	364	466	460	463	467
Away																			
RT	244	250	247	330	342	336	290	314	302	344	351	348	200	202	201	283	285	284	286
SD	15	22		40	36		65	56		50	48		41	39		38	45		
MT	198	190	194	204	198	201	272	240	256	224	189	206	194	195	194	208	225	216	211
SD	41	50		54	47		80	66		100	66		42	43		42	58		
Total	442	440	441	534	540	537	562	554	558	568	540	554	394	397	395	491	510	500	497
Mean RT	230	239	234	327	348	338	308	320	314	340	348	344	186	191	188	274	278	276	282
Mean MT	189	184	186	197	188	192	240	220	230	200	186	194	195	188	191	204	209	206	200
Mean total	419	423	420	524	536	530	548	540	544	540	534	538	380	379	379	478	487	482	482

Note. SRT = simple reaction time; CRT = choice reaction time; RT = reaction time; and MT = movement time.

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