Summer 6-1-1988

Aging and the Restructuring of Precued Movements

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Psychology and Aging
1988, Vol. 3, No. 2, 151–157

0882-7974/88/$00.75

Aging and the Restructuring of Precued Movements

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A precue paradigm was used to examine the time it takes to restructure a planned motor response. Two groups of subjects, a young group and an elderly group, performed an aiming task in which 75% of the trials involved no change of movement parameters. On remaining trials, subjects had to change one or more of the movement parameters. Elderly subjects had slower reaction times (RTs), movement times, and made more errors in both conditions. Elderly subjects had proportionally longer RTs overall, independent of restructuring a movement plan. Preparation of arm and direction also exhibited a proportional increase in RT. However, differential aging effects were found for preparation of extent. Elderly subjects were slower preparing short movements compared with long movements, whereas young subjects showed the opposite trend. These results suggest that with advancing age, operations concerned with movement-plan restructuring for arm and direction undergo change in processing rate, whereas operations for extent undergo more extensive alteration.

A consistent finding in the aging literature is that elderly individuals show cognitive and motor deficits when performing a speeded task. Increases in reaction time (RT) and movement time (MT) with increased age are found in a variety of tasks (Cerella, 1985; Jordan & Rabbitt, 1977; Rabbitt, 1968; Salthouse, 1985a, 1985b; Simon, 1967; Weiss, 1965). Rabbitt and Birren (1967) have found that older individuals do not use advance information in planning movements; Gottsdanker (1980) has shown that older subjects use advance preparation to aid them only if the preparation is easy. In addition, other studies (Brinley, 1965; Birren, Riegal, & Morrison, 1962; Jordan & Rabbit, 1977) manipulating response complexity have found that the elderly are disproportionately slower than the young. Studies have also shown that elderly individuals display deficits in motor processes (Mankovsky, Mints, & Lesenyuk, 1982; Weiss, 1965).

Recent studies by Larish and Stelmach (1982) and Stelmach, Goggin, and Garcia-Colera (1987) have sought to determine the central processes that are responsible for the slowing of RT and MT in simple movement tasks with advancing age. The results of these studies have indicated that the slowing observed may be localized in response selection processes. Larish and Stelmach found that elderly subjects were slower in their RTs, but that the processes responsible for preparing and restructuring remained intact with increasing age. The results obtained by Stelmach et al. indicated that the elderly were able to use advance precue information to plan an upcoming movement; the elderly, however, took increasingly more time to specify movement dimension(s) of arm, direction, and extent. In addition, when elderly subjects had less precue information and thus had to specify more movement dimensions, their RTs were proportionally slowed. It was concluded that the processes associated with determining dimensions of movement parameters in the elderly are less efficient than those in young subjects.

There were two purposes to this experiment. The first was to extend previous work (Stelmach et al., 1987), which has shown that movement slows with advancing age, by examining whether elderly individuals are similarly or differentially disadvantaged relative to young individuals when they are required to modify a planned movement with respect to specific parameters at the time of its initiation. A movement precue paradigm was used to study how elderly and young individuals restructure a planned motor response. Subjects were presented with valid precues, requiring no change of movement parameters on 75% of the trials. On the remaining 25% of the trials, parameter change was required, rendering the precue invalid on these trials. It was assumed that the 75% valid precue bias induces sufficient movement plan preparation to be either implemented or altered prior to its implementation (Rosenbaum & Kornblum, 1982). The parameters manipulated were arm, direction, and extent. On invalid precue trials, all possible combinations of parameters-to-change were varied such that on a given trial, one, two, or three movement parameters were restructured. This design was used because it permits inferences on how long it takes to restructure specific parameters and execute these modified plans with respect to age.

One pervasive account of cognitive aging effects is the general rate of processing deficit theory (Salthouse, 1985b). This theory states that with advancing age all processes remain intact but their rate of activity is slowed. This slowing is hypothesized to be proportional over a range of cognitive operations. The second purpose of the present experiment was, therefore, to test this hypothesis using data from a movement task. This involved determining whether the relative increases in elderly processing time across a range of movement dimensions and restructuring requirements are equivalent or systematically variant.

This research was supported by Grant AG 05154 from the U.S. Public Health Service.

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Method

Subjects

Subjects consisted of a young group (21–30 years) with a mean age of 23.6 years and an elderly group (65–75 years) with a mean age of 69.7 years. Each group had 7 men and 7 women who were closely matched in age, educational background, and health status. All of the subjects were right-handed. To determine if subjects were representative of their respective populations, they were given a subtest of the Weschler Adult Intelligence Scale, the Digit-Symbol Substitution Test (DSST). The purpose of the DSST was to determine if a subject's psychomotor speed corresponded to the norms for subjects in comparable age groups (Salthouse, 1985a). The young age-group mean was 67.2 and the elderly age-group mean was 43.1 (corresponding to 75% and 48% of maximal, respectively), which indicates that the psychomotor speed of the two age groups examined are representative of the population. These data are similar to those reported elsewhere (Salthouse, 1985a; Stelmach et al., 1987). Finally, these DSST test scores were negatively correlated with age, $r(12) = -.93$, $p < .01$, indicating that the scores declined with increasing subject age.

Apparatus

In a testing chamber, the subject sat in a chair in front of a table that was 80-cm high, and fixated on a visual display. The display consisted of eight red light-emitting diodes (LEDs) that were approximately 3 mm in diameter and were positioned on a black vertical board that was 70 cm from the subject. The LEDs were arranged in a 6.8-cm × 7.2-cm light array that subtended 5.6° of visual angle. The position of the LEDs on the board corresponded with the position of the keys on the response board. To obtain maximum compatibility, the LEDs and target keys were matched on color coding. In the middle of the eight red LEDs was a row of yellow LEDs that served as warning lights. Directly above and below the warning lights on both the left and the right were two red LEDs that served as stimulus lights (see Figure 1).

The response keys were mounted on a box, 10.5-cm high, that rested on the table. The keys were configured so that there were two columns of keys that were 21-cm apart and parallel to the sagittal axis. The column of keys on the left corresponded to the left hand and the column on the right to the right hand. In the middle of each of the columns was a yellow *home* key. The center of the near keys was situated 3.5 cm from the home keys, and the center of the far keys was 7.0 cm from the home keys. The home and near keys were 1.8-cm square, and the far keys were 2.6-cm square (the larger size was intended to compensate for increase movement difficulty associated with greater movement distance from the home keys). The keys were set into black styrofoam so that they were flush with the top surface of the board when not depressed. The keys were Cherry momentary contact switches with flat surfaces that required a force of 125 gm for closure. The experiment was controlled by a LSI-11/03 minicomputer.

Design and Procedure

After completing the DSST and prior to the actual data collection, each subject performed two blocks of 56 trials in which they practiced all possible movements. Starting with the index finger of each hand depressing the appropriate home key, the subject was required to move to each of the response keys in a quasi-random order as soon as each target light appeared. The response key that corresponded to the target light was to be pressed by the appropriate index finger, with the nonresponding index finger remaining on its home key. During the first movement practice block, the subject was able to look at the response panel so that he or she was able to use visual feedback and become accustomed to the position of the response keys and the home keys. During the remainder of the experiment, the subject was encouraged not to look at the keys during a trial and, consequently, wore eye goggles that only permitted them to see the stimulus lights and prevented them from seeing the response keys.

Subjects then received instructions for the precue tasks; two practice blocks of 56 precue trials of the experimental sequence followed. A typical trial began with three yellow warning lights illuminated to indicate that the subject should be ready for a trial to begin. One second later, concurrent with the warning lights, a single red LED was illuminated for one second. This light was the precue stimulus. Subjects were encouraged to use this light in preparing the motor response. After a subsequent one-second blank period (when no light was illuminated), a single red LED was illuminated; this was the target stimulus. Upon its presentation, subjects moved as quickly as possible to contact the corresponding target button.

On 75% of the trials, the stimulus signal was the same LED that was illuminated as a precue, and these trials constituted a programming condition. However, in 25% of the trials, any of the other seven LEDs could be illuminated and the subject would have to reprogram one, two, or three of the parameters that he or she had programmed during the precue. For example, if the far upper-*left* LED was illuminated as a precue, but the stimulus signal was the far upper-*right* LED, the subject would have to reprogram the parameter of arm; or if the far upper-*left* LED was illuminated as a precue, and then the stimulus signal was the near lower-*left* LED, the subject would have to reprogram the parameters of direction and extent.

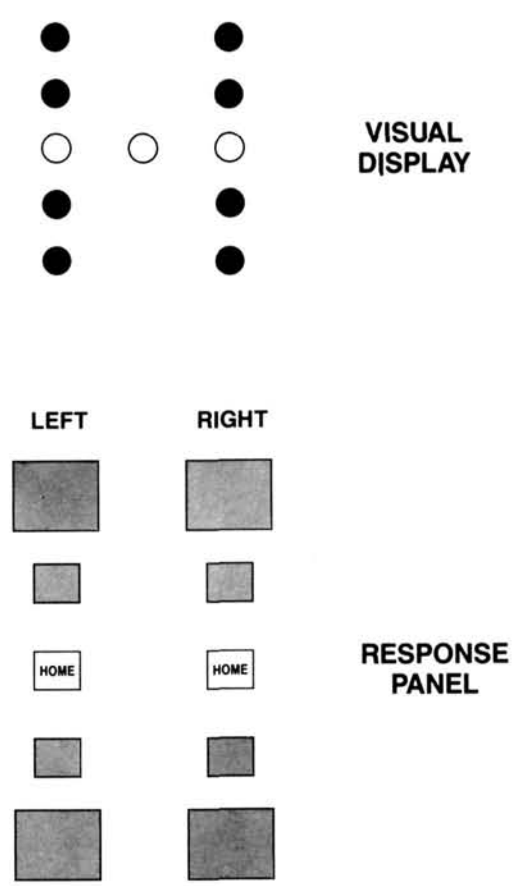

Figure 1. Schematic diagram of the visual display and the response panel. (Open circles are the warning lights and open squares the home keys.)

In each trial block of 56 trials, there were 42 valid precue and 14 invalid precue randomly intermixed trials. Valid precue trials were those in which the precue and the stimulus signal were the same (75% probability trials), and invalid precue trials were those in which the signals were different and some parameter(s) of the planned movement would have to be changed (remaining 25% of the trials). A total of 12 blocks of 56 trials were used in the analysis. All of the blocks were balanced so that both the valid and invalid precue responses occurred an equal number of times at all eight of the response keys.

The dependent measures in this experiment were RT and MT. Reaction time was defined as the time between target stimulus onset and subject initiation of movement (indicated by departure from one of the home keys). Movement time was defined as the time between departure from one of the home keys and arrival at the target response key.

At the end of the second practice block of 56 trials, in order to eliminate fast or slow RTs and MTs, a window was established for acceptable response latencies. Reaction times and movement times that were greater than 2 times a subject's mean RT and MT were considered errors. Additional errors were those in which the subject had an RT or MT that was too slow, contacting the wrong target, and moving prior to the actual signal to respond. Any trials on which errors were made were repeated randomly in the block so that each block contained 42 valid and 14 invalid precue error-free trials.

Subjects participated in two sessions on consecutive days. On the first day, each subject performed the DSST, two movement practice blocks, two practice blocks of the entire experimental sequence (56 precue trials), and four blocks of the experimental sequence for analysis. The second day began with a practice block of 15 precue trials, followed by the remaining eight blocks of the experimental trials.

Results

Errors

Overall error rates between the two groups according to error type are given in Table 1. The error rate data from all of the change of parameter conditions (invalid precue trials) are collapsed together because equivalent numbers of errors were committed across conditions. Elderly subjects made more errors than did the young subjects. As can be seen, the error data also indicate that subjects made more errors on the invalid precue trials than on the valid precue trials. The error rate for the young group was 7.2% on valid precue trials and 12.4% on invalid precue trials. In the elderly group, the error rate for valid and invalid trials was 11.2% and 17.8%, respectively. Note that elderly subjects had both greater errors and longer latencies. Thus, the latency data cannot be explained as a function of a simple speed–accuracy tradeoff.

Reaction Time

Preliminary analysis indicated a marked increase in the variance of elderly subject latencies when compared with young subject latencies. For this reason all analyses of variance were performed on log-transformed data. Furthermore, because of the scaling characteristics of the log transformation in these analyses, significant interactions represent disproportionate differences between groups and conditions, whereas nonsignificant Group × Condition interactions indicate proportional differences. Log RT and absolute RT data are given in Table 2 according to levels of the individual parameters and age groups.

Table 1
Error Percentages by Type for Valid and Invalid Precue Trials

Group	Responses: Slow	Responses: Incorrect	Both fingers left home keys	Wait for go	Total
Young					
Valid					
n	373	98	13	63	547
%	4.9	1.3	.17	.83	7.2
Invalid					
n	216	72	28	17	333
%	8.0	2.7	1.0	.63	12.4
Elderly					
Valid					
n	404	225	32	225	886
%	5.1	2.8	.40	2.8	11.2
Invalid					
n	266	156	12	74	508
%	9.3	5.4	.41	2.6	17.8

The log RT data and absolute RT data, according to parameter change condition for the two age groups, are given in Table 3.

Overall

Analysis of the valid and invalid precue data was carried out on latencies collapsed over trial block, specific types of parameters changed according to age group, validity of precue, and level of the three movement parameters involved in the preparation of the movement response to the target stimulus. Mean latencies are given in Tables 2 and 3 for valid and invalid precue trials, respectively. Overall, elderly subjects were much slower than the young subjects, $F(1, 26) = 37.4$, $p < .001$. Furthermore, the increase in RT for invalid compared with valid precue trials was highly significant, $F(1, 26) = 83.7$, $p < .001$. The increase for elderly subjects over young subjects was proportional; the Age × Precue validity interaction was nonsignificant, $F < 1$. Age group interacted with extent, $F(1, 26) = 12.1$, $p < .002$, such that elderly subjects were slower in preparing short movements compared with long movements, but the opposite occurred for young subjects. This effect can be seen in Tables 2 and 3 for both valid and invalid precue trials, respectively. It is interesting to note that, for both groups, direction and precue validity also interact, $F(1, 26) = 11.2$, $p < .003$, such that the difference between valid and invalid precue latency is greater for movements away from the body than for movements toward the body. This interaction also depends on age; this pattern is attenuated for the elderly subjects compared with the young subjects, $F(1, 26) = 5.1$, $p < .04$. Other interactions include Direction × Extent, $F(1, 26) = 8.5$, $p = .007$, and Precue Validity × Extent, $F(1, 26) = 41.2$, $p < .001$. The Direction × Extent interaction is such that latency to prepare a long movement away from the body was significantly faster than the other combinations of direction and extent levels. Finally, the Precue Validity × Extent interaction is such that the increase in latency for invalid over valid precue trials is greater for short movements than for long movements. Remaining effects and interactions were nonsignificant (all $ps > .05$). Because the two interactions concerning precue validity were so small, separate analyses of valid and invalid precue data with respect to levels of parameter deminsion were carried out.

Invalid Precue Trials and Parameter Restructuring

Analysis of restructuring levels for the invalid precue trials shown in Table 4 (excluding *none*) yielded latency differences for type of parameter change, $F(6, 156) = 22.5$, $p < .001$, in addition to an overall increase in latency for the elderly compared with the young subjects, $F(1, 26) = 35.6$, $p < .001$. The differences between age groups were proportional, the Age × Type of parameter change interaction was nonsignificant, $F < 1$. Two additional analyses were conducted, one to determine the effect of overall number of parameters changed (1, 2, or 3 parameters) and a second analysis to determine the cost to reprogram the specific parameters of arm, direction, and extent among the invalid precue trials.

Analysis of the effect of amount of parameter change was performed on latency collapsed over parameter change conditions yielding values for three levels of change: latencies in which one, two, or three parameters (i.e., A, D, E; AD, AE, DE; or ADE, respectively) were restructured. In addition to the overall decrement in elderly performance, $F(1, 26) = 35.1$, $p < .001$, elderly subjects showed an increase in response latency with an increase in the number of parameters changed proportional to that of the young subjects, $F(2, 52) = 22.4$, $p < .001$ (Age × Number of Parameters Changed, $F < 1$).

Analysis of the specific cost to change individual parameters was carried out on the invalid precue trials collapsed according to whether a given parameter was either altered or not altered for each of the three parameters. For example, cases in which the parameter of arm was altered included A, AD, AE, and ADE invalid precue trial conditions; cases in which arm was not altered included D, E, and DE invalid precue trial conditions. Analysis yielded an elderly performance decrement, $F(1, 26) = 35.6$, $p < .001$. In addition, there were main effects for the three parameters, $F(2, 52) = 28.9$, $p < .001$, and parameter change, $F(1, 26) = 30.9$, $p < .001$. It is interesting to note that

Table 2
Mean Response Latencies (in Milliseconds) for Valid Precue Trials

Measure	Left arm direction			Extent	Right arm direction		
	Toward	Away	*M*		Toward	Away	*M*
			Young subjects				
Reaction time (RT)	249	255	252	Short	248	260	254
SD	26	20			28	27	
LOG (RT)[a]	2.41	2.39			2.41	2.40	
RT	257	275	266	Long	257	283	270
SD	20	26			20	29	
LOG (RT)	2.45	2.41			2.44	2.41	
M	253	265	259		253	272	262
Movement time (MT)	115	120	118	Short	114	118	116
SD	46	28			39	31	
LOG (MT)[a]	2.06	2.03			2.07	2.20	
MT	164	163	164	Long	146	147	147
SD	46	31			33	29	
LOG (MT)	2.16	2.15			2.03	2.15	
M	140	142	141		130	133	132
			Elderly subjects				
RT	399	399	399	Short	398	396	397
SD	103	122			110	111	
LOG (RT)[a]	2.58	2.59			2.58	2.59	
RT	391	387	389	Long	384	394	389
SD	86	108			94	90	
LOG (RT)	2.59	2.57			2.58	2.58	
M	395	393	394		391	395	393
MT	390	412	401	Short	386	422	404
SD	194	216			208	260	
LOG (MT)[a]	2.53	2.51			2.54	2.51	
MT	516	488	502	Long	441	433	437
SD	246	230			220	220	
LOG (MT)	2.57	2.58			2.63	2.65	
M	453	450	452		414	428	421

[a] *M* LOG (latency) over individual subjects.

cost of parameter change was linear, with changing arm costing more time than changing direction, which in turn cost more time than changing extent, $F(2, 52) = 27.8, p < .001$. Compared with young subjects, elderly subjects were proportionally slower in all conditions. All Age × Condition interactions were nonsignificant (all $ps > .05$).

Movement Time

Log MT data and absolute MT for each group and parameter level for valid and invalid precue trials are given in Tables 2 and 3. These data are also given according to parameter change condition in Table 4. Again, a significant main effect was found for age, $F(1, 26) = 30.7, p < .001$, indicating that elderly subjects were much slower than young subjects overall. However, the absolute magnitude of this difference is positively skewed because of the extremely slower times of 4 elderly subjects. Further inspection of the data revealed that the performance of these 4 subjects did not deviate across experimental conditions from the performance of the other elderly subjects; they were simply slower by a constant in performing the required task. Overall, increase in extent resulted in an increase in MT; subjects took longer to move to contact far targets than to contact near ones, $F(1, 26) = 101, p < .001$. In addition, movements with the right arm were made faster than movements with the left arm for both groups, $F(1, 26) = 23.6, p < .001$.

There were two interactions concerning age group: Age × Extent, $F(1, 26) = 9.34$, $p = .005$, and Age × Parameter Change condition, $F(7, 182) = 2.12, p < .05$. The interaction of age with extent is such that the elderly subjects showed a smaller increase in latency when making long movements compared with short movements relative to the increase for young subjects; thus, elderly subjects were less affected by movement extent than were young subjects. The Age × Parameter Change interaction was such that the elderly were much less variant across change conditions than were the young in these movement latencies, al-

Table 3
Mean Response Latencies (in Milliseconds) for Invalid Precue Trials

Measure	Left arm direction: Toward	Left arm direction: Away	Left arm direction: *M*	Extent	Right arm direction: Toward	Right arm direction: Away	Right arm direction: *M*
			Young subjects				
Reaction time (RT)	404	400	402	Short	410	410	410
SD	44	41			41	46	
LOG (RT)[a]	2.60	2.60			2.61	2.61	
RT	391	391	391	Long	398	399	399
SD	40	49			45	47	
LOG (RT)	2.59	2.59			2.60	2.60	
M	398	396	397		404	405	405
Movement time (MT)	136	135	136	Short	132	124	128
SD	44	27			34	30	
LOG (MT)[a]	2.12	2.11			2.08	2.11	
MT	183	181	182	Long	170	160	165
SD	53	37			40	30	
LOG (MT)	2.25	2.24			2.20	2.22	
M	160	158	159		151	142	147
			Elderly subjects				
RT	633	626	630	Short	611	615	613
SD	133	155			135	164	
LOG (RT)[a]	2.78	2.79			2.78	2.78	
RT	574	566	570	Long	574	578	576
SD	108	128			138	147	
LOG (RT)	2.74	2.75			2.75	2.75	
M	604	596	600		593	597	595
MT	415	428	422	Short	413	433	423
SD	202	222			206	266	
LOG (MT)[a]	2.56	2.55			2.54	2.55	
MT	517	489	503	Long	459	422	441
SD	252	224			221	221	
LOG (MT)	2.64	2.65			2.56	2.60	
M	466	459	463		436	428	432

[a] *M* LOG (latency) over individual subjects.

Table 4
Mean Response Latencies (in milliseconds): Parameters to Change

Measure	N	E	D	A	DE	AE	AD	ADE
				Young subjects				
Reaction time (RT)	260	365	394	405	411	410	404	411
SD	21	36	41	46	43	47	47	44
LOG (RT)[a]	2.41	2.56	2.59	2.61	2.60	2.61	2.60	2.61
Movement time (MT)	136	168	154	143	142	146	153	150
SD	31	42	35	26	32	30	35	32
LOG (MT)[a]	2.11	2.20	2.16	2.16	2.14	2.14	2.16	2.15
Total	396	533	548	548	553	556	557	561
				Elderly subjects				
RT	394	562	584	595	601	618	608	621
SD	97	121	131	135	127	145	139	147
LOG (RT)[a]	2.58	2.73	2.75	2.77	2.76	2.77	2.77	2.78
MT	436	469	448	435	445	447	445	442
SD	218	236	227	220	218	217	217	220
LOG (MT)	2.56	2.60	2.57	2.57	2.56	2.58	2.58	2.57
Total	830	1031	1032	1030	1046	1065	1053	1063

Note. N = none (valid); E = extent; D = direction; and A = arm.
[a] *M* LOG (latency) over individual subjects.

though no specific pattern was evident. Remaining interactions include Arm × Extent, $F(1, 26) = 16.7$, $p < .001$, and Direction × Parameter Change condition, $F(7, 26) = 4.05$, $p < .001$. The interaction involving arm and extent is such that short movements were made equally fast for both arms, but long movements were made much faster with the right arm than with the left arm. The Direction × Parameter Change interaction was such that movements toward the body were less variant in latency than were movements away from the body across the different types of parameter change. A main effect was also found between movement parameters to change, $F(7, 182) = 9.61$, $p < .001$.

Two parameter change conditions account for 57% of the between-conditions variance of this effect. The parameter of extent, when changed, accounts for 42% of this variance. There was also a small advantage in MT for no-parameter-change valid precue trials compared with invalid precue trials, which accounts for the remaining 15% of the total variance. Any general interpretation of these effects is limited because, in the first case, MT for extent changed alone is greater than when it is changed with other parameters, and in the second case, MT for valid trials is very similar to that for some of the invalid precue trials. Thus, these differences do not provide comprehensive support for the argument that, in general, subjects were not fully prepared at 1,000 ms. In fact, with no parameter change and extent parameter change conditions removed, MT for the remaining six conditions is nonsignificant, $F(5, 26) = 1.74$, $p > .12$. Remaining effects and interactions were also nonsignificant (all *p*s > .05).

Discussion

Results reveal that not only were the elderly slower in their planned motor reactions but they also took considerably more time to restructure their planned motor responses. Evidence that a motor plan was initially planned to some extent before restructuring is given by the differences for both groups among the comparison of the various parameter change conditions. These effects argue against a simple cue validity effect accounting for the substantial difference between valid and invalid precue RT data. Although the effects are not large, we feel they are important, especially because they occur at the single subject level. However, because of their small size, further research is needed to fully validate their meaningfulness.

Elderly subjects were proportionally slower (50%) independent of parameter restructuring requirements, which suggests that movement restructuring processes remain intact with age but the rate of processing is generally slower (Salthouse, 1985a). Furthermore, the elderly are likewise proportional in their deficit in preparing arm and direction parameters. These findings support the proportional equality hypothesis. Other data provide evidence against this hypothesis, however. The age effect for preparing and restructuring extent represents fundamental differences within the processes for this parameter.

Overall MT is constant over parameter change conditions except for extent, in which MT latency appears to be related to RT. Furthermore, there is a slight increase (13 ms) for invalid precue MT over valid precue MT, although much less than is found in the RT results (172 ms). These results support our belief that a large portion of the observed slowing in RT in the elderly is due to a deficit in the cognitive–motor interaction associated with specifying movement parameters (see Stelmach et al., 1987).

The results suggest that, unlike parameters of arm and direction, extent is a parameter whose preparation and restructuring extends beyond response initiation. The general effect for restructuring of extent alone with respect to RT and MT can be seen in Table 4. When extent preparation is restructured, there is a decrease in RT relative to other parameter change conditions. However, a concurrent increase in MT is observed as well. These RT/MT effects suggest that restructuring occurs during the execution stage of the response, unlike the other parameters.

The second finding is of greater interest because it concerns the differential age effects and extent. Here, elderly subjects exhibit an *increase* in RT for short movements over long movements with a *minimal increase* in MT for long movements over short movements. However, young subjects exhibit a slight *decrease* in RT for short movements relative to long movements but a substantial *increase* in MT for long movements compared to short movements. Because it is expected that MT should be much larger for long compared with short movements, because of the physical characteristics of the task, the attenuation in this difference for the elderly subjects suggests that execution of short movements by elderly subjects concerns a fundamentally different process than such execution by young subjects. One reason why execution of short movements is slower in elderly subjects may be due to a deficit in the response dynamics of the task, specifically force production and control. It is likely that of the three parameters tested here, extent is the most susceptible to deficits in aspects of force control because it involves changes in the magnitude of muscular activity (or degree of force production), whereas the other parameters require a change in phased order of that activity. If elderly subjects indeed have a slower or more variant rate of force production (some evidence has been found; see Stelmach & Worringham, 1988), this would in turn explain the slower RT for short movements as well. It has been argued (Carlton, Carlton, & Newell, 1987) that certain dynamics of movement such as rate of force production bear a direct relation to preparation latency. Thus, changes in the parameter of extent due to aging may in fact be due to a deficit in the more dynamic aspects of motor control rather than in the strictly cognitive aspects.

In summary, it is apparent from the results of the present experiment that another aspect of response selection processes, restructuring an existing movement plan, is adversely affected by age. Beyond finding an overall deficit due to age, these data allow a more specific look at how age *differentially* affects certain movement processes at the level of individual parameters. These include a greater proportional cost overall to restructure an existing movement plan for the elderly subjects compared with the young subjects. Furthermore, it also appears that preparation of arm and direction also costs the elderly proportionally more time than it costs the young. This finding suggests that movement plan restructuring and certain parameter preparation processes are similar for both age groups. Differential effects found for the parameter of extent suggest that the two groups differ in how they program at least one component of movement. Thus, differential changes found across the three parameters studied here suggest that movement preparation and restructuring are not generalized processes, per se, but are dependent on the structure of the specific parameters involved.

Both differences and similarities among young and elderly individuals are important to ascertain if we are to fully understand the affect of aging on movement organization processes. Some processes such as those involved in movement plan restructuring, preparation, and execution of arm and direction parameter dimensions remain intact, but exhibit a slower rate of processing (see Salthouse, 1985a). However, extent preparation, restructuring, and execution processes appear to undergo some functional alteration (see Rabbitt & Birren, 1967), possibly because of change in the dynamic aspect of movement execution. Given the present results, strict global processing rate deficit or global change of process structure (see Salthouse, 1985a) accounts of aging appear inadequate.

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Received August 27, 1986
Revision received August 3, 1987
Accepted August 4, 1987 ■