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Age Differences in Bimanual Coordination

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A bimanual coordination experiment was conducted in which two groups of 10 male and female participants, elderly (67 to 75 years of age) and young (21 to 25 years of age), produced unimanual, bimanual symmetrical (equal extent amplitude), and bimanual asymmetrical (unequal extent amplitude) movements. In addition to an overall increase in performance latency, the elderly group exhibited a linear increase in response initiation (RT) with increases in task complexity similar to that of the young group. However, the elderly participants showed a proportional increase over the young participants in response execution latency (MT). Further, the elderly group had a slower RT for short movements than long movements, an effect not found in the young group. Compared with the young participants, the elderly participants showed greater asynchrony in response initiation of bimanual movements; increased inability to subsequently compensate during response execution also resulted in a greater asynchrony in response termination. These results suggest specific aging deficits in bimanual coordination processes.

IN this experiment, unimanual and bimanual movement tasks were used to determine whether or not elderly individuals have difficulty in coordinating two hands in simple motor acts. Complexity of the task was manipulated using a unimanual task, a symmetric (same extent amplitude) bimanual task, and an asymmetric (different extent amplitude) bimanual task. Although many researchers have studied bimanual movements, few have investigated the age differences in these movements.

A procedure similar to that reported by Kelso et al. (1979a, 1979b), Marteniuk and MacKenzie (1980a), and Marteniuk et al. (1984) was used in the present research. In those experiments the task involved simple lateral movements in the frontal plane. Kelso et al. found that individuals who performed bimanual movements to targets of differing amplitude or size initiated the movements simultaneously. Kinematic analysis indicated that the hand moving toward an easy target had a slower relative velocity compared to the hand moving toward a difficult target, although the hands reached peak velocity and acceleration together. Kelso et al. concluded that the brain produces simultaneous action of the hands by grouping muscles to act as a single unit. However, Marteniuk and MacKenzie and Marteniuk et al. varied movement amplitude and the mass of the stylus in their experiments and found marked asynchrony in two-handed movements, concluding that there is neurological ''cross-talk'' between limbs that acts to influence bimanual coordination.

In other studies, Norrie (1964, 1967) found that when individuals performed movements of differing amplitudes with two hands, the starting time and contact time differences were greater than when the movement amplitudes of the hands were the same. In addition, she found that the hand that moved the greatest distance initiated the movement first and completed the movement last. Finally, Heuer (1986) found mixed results of asynchrony when responses differ in duration, but not when movements differ in amplitude.

The purpose of this experiment was to determine what changes in response organization and execution might occur with age when these processes are compared in relation to unimanual and bimanual tasks with varying extents of movement. Consistent with earlier research on task complexity, elderly individuals should show increased deficits when performing movements with two hands as compared to one. Further, although it was expected that bimanual compensation (matching response termination by adjusting execution latency) would be more difficult in the asymmetric bimanual than the symmetric bimanual task for both groups, it was also predicted that the elderly participants would be especially poor in the asymmetric task because unequal movement extent should induce another type of complexity in a bimanual task.

METHODS

Participants

There were two groups of 10 participants, a young group (21 to 25 years of age; $M = 22.4$ years) and an elderly group (67 to 75 years of age; $M = 69.8$). Each group contained five males and five females who were closely matched in age, educational background and health status. Everyone with the exception of one young participant was right handed. To determine whether or not they were representative of their respective populations, their scores on the Digit Symbol Substitution Test (DSST), a subtest of the Weschler Adult Intelligence Scale, was compared. According to Salthouse (1985a, 1985b), DSST scores are indicative of overall psychomotor speed. The young group's mean was 70.5, and the elderly group's mean was 44.2 (which corresponds to 78 and 49% of their respective maximums). These data are similar to those reported previously (e.g., Salthouse, 1985a). DSST test scores were negatively correlated with age, $r(18) = -.84, p < .01$.

Apparatus

Testing took place in a soundproof testing chamber. Each individual sat in a chair in front of a table 80 cm high and fixated on a visual display consisting of a row of six light-emitting diodes (LEDs) approximately 3 mm in diameter. LEDs were positioned on a black vertical board 70 cm from the participant. In the middle of the row of LEDs were two yellow LEDs that served as warning lights. On each side of these warning lights were two red LEDs that served as stimulus lights. The spatial configuration of the LEDs on the board corresponded with the arrangement of the keys on the response board. To maximize compatibility, LEDs and response keys were color matched.

Response keys were mounted on a 10.5 cm high box placed on the table. The row of six keys was approximately 30 cm from the participant parallel to the frontal plane. In the middle of the six keys were two circular yellow "home" keys 1.5 cm in diameter, one for the index finger of each hand. To the left and right of the home keys were two circular, red response keys. The center of the near keys (for performing short movements) was situated 10.5 cm from the home keys; the center of the far keys (for performing long movements) was 21.0 cm from the home keys. Near and far keys were 5.0 cm and 7.0 cm in diameter, respectively. The Index of Difficulty (Fitt's Law) for short movements to near targets was 2.07 and 2.58 for long movements to far targets. These keys were Snap-Action momentary contact switches, which required an approximate force of 40 gm for closure. The experimental events were controlled by an LSI-11/03 minicomputer. For the second set of practice trials and experimental trials, the participants wore eye goggles that occluded vision of their hands and response keys but that allowed vision of the stimulus display.

Design and Procedure

Testing took place during two consecutive sessions, each 1.5 hr in length. On the first day, the participants were given the DSST. After completing the DSST, and prior to the experiment, they performed an initial set of 64 *movement* practice trials consisting of eight replications of the eight possible unimanual and bimanual movements. Trials were randomly presented in each block. In the unimanual movement condition, the individual began with the index finger of each hand depressing the appropriate home key; the participant moved to one of the corresponding four response keys as soon as the stimulus light appeared. When the response key was pressed, the stimulus light was turned off. The response key was pressed by the left or right index finger (corresponding to the lateral position of the stimulus), while the other index finger remained on the home key. One of four responses (right or left arm and long or short extent) occurred on a given trial.

In the bimanual movement conditions, the individual moved both hands to the appropriate response keys when the stimulus lights appeared. This response again turned off the stimulus lights. The participants were told not to attempt to leave the home keys simultaneously but merely to avoid completing a response with one hand before initiating a response with the other. One of four possible sets of responses occurred on these trials: two pairs of symmetric movements (short extent–both arms, long extent–both arms) and two pairs of asymmetric movements (short extent–left arm, long extent–right arm and vice versa).

Participants then performed a second set of practice trials and the experimental trials for each of the unimanual and bimanual tasks. In these trials, a 1-sec warning light flashed on followed by a 1-sec blank period (no lights illuminated) preceding onset of the target stimulus. Participants received these trials in blocks of 34, 32 valid trials (four replications of the four possible movements for the unimanual and bimanual tasks) and two catch trials (no target stimulus light following warning light). Trials were randomly presented for each block.

In each experimental session, the participants received one block of the 32-movement practice trials and two practice blocks each of the unimanual and bimanual trials in an alternating order. Following the practice trials, on the first day, participants subsequently received three blocks of experimental trials for each task (unimanual or bimanual, with symmetric and asymmetric trials intermixed) in an alternating block order; on the second day, they received 10 practice trials for each task in an alternating order followed by five blocks of experimental trials for each task (again in alternating block order).

The dependent measures were response initiation (RT) and response execution latency (MT). RT was defined as the time between stimulus onset and the participant's initiation of movement — indicated by departure from one or both of the home keys (dependent on task). MT was defined as the time between departure from one or both of the home keys (dependent on task) and arrival at the response key(s).

At the end of the second practice block of both the unimanual and bimanual tasks, a window was established for responses in order to eliminate fast or slow RTs or MTs based on latency data from the practice blocks for each type of task. RTs and MTs greater than two times an individual's mean RT and MT in both unimanual and bimanual tasks were considered errors. (Separate windows were created for the two different tasks.) In addition, trials in which the participant has an RT of less than 120 ms or an MT of less than 80 ms were excluded. These extremely slow and fast latencies were considered collectively as outliers. Other errors included trials in which an individual contacted the wrong target, prematurely responded to the target signal onset, or released both home keys in the unimanual task. Any trials in which errors occurred were repeated randomly in the remaining trials of the block. This error substitution procedure produced an error-free set of data for each participant.

RESULTS

Errors

The overall error rates for the elderly and young groups for unimanual, bimanual symmetric, and bimanual asymmetric movement tasks are shown in Table 1. Overall, the elderly group made slightly more errors (8.2%) than the young group (7.7%), with errors increasing with task demands for both groups: unimanual, 4.7%; bimanual symmetric, 6.0%; and bimanual asymmetric, 13.4%. For both groups, over all conditions, the highest percentage of errors was for slow movement time errors, followed by incorrect responses.

Table 1. Error Rate Percentages

Error types	Age groups (in years) Young group (21 to 25)	Elderly group (65 to 75)
Unimanual		
RT outliers	.05	.03
MT outliers	1.8	2.5
Bimanual release (unimanual tasks)	.23	.15
Incorrect target contact	1.4	1.4
Premature response	1.1	.6
Total	4.6	4.7
Bimanual symmetric		
RT outliers	—	.28
MT outliers	2.9	3.3
Bimanual release (unimanual tasks)	—	—
Incorrect target contact	.7	.35
Premature response	2.6	1.8
Total	6.2	5.7
Bimanual asymmetric		
RT outliers	.28	1.2
MT outliers	7.2	8.6
Bimanual release (unimanual tasks)	—	—
Incorrect target contact	2.2	3.0
Premature response	2.7	1.5
Total	12.4	14.3

Table 2. Mean Response Initiation (RT)

Extent	Young group (21 to 25 years old) Left arm	Right arm	*M*	Elderly group (65 to 75 years old) Left arm	Right arm	*M*
Unimanual						
Short	316	307	312	412	395	404
Long	322	313	318	383	373	378
M	319	310	320	398	384	391
Bimanual symmetric						
Short	337	334	336	450	438	444
Long	347	344	346	436	423	430
M	342	339	341	443	431	437
Bimanual asymmetric						
Short	373	372	373	486	488	487
Long	367	365	366	486	456	471
M	370	369	370	486	472	479

Note. RT measured in milliseconds.

Table 3. Mean Response Execution Latency (MT)

Extent	Young group (21 to 25 years old) Left arm	Right arm	*M*	Elderly group (65 to 75 years old) Left arm	Right arm	*M*
Unimanual						
Short	129	128	129	237	245	241
Long	186	200	193	300	309	305
M	158	164	161	269	277	273
Bimanual symmetric						
Short	144	147	146	290	303	297
Long	204	209	207	349	358	354
M	174	178	177	320	331	326
Bimanual asymmetric						
Short	194	193	194	344	367	356
Long	215	217	216	386	386	386
M	205	205	205	365	377	371

Note. MT measured in milliseconds.

Reaction Time

Overall. — The RT data for unimanual, bimanual symmetric, and bimanual asymmetric movement conditions were analyzed together. In Table 2, mean RT latencies over individuals and trial blocks for each level of task, extent, and arm are given.

There was a significant main effect obtained for age, $F(1,18) = 12.8, p < .01$, with the elderly group being much slower (436 ms) than the young group (344 ms). There also were main effects for: arm, $F(1,18) = 12.9, p < .01$, with movements with the right arm being slightly faster (384 ms) than movements with the left arm (393 ms); extent, $F(1,18) = 11.7$, $p < .01$, with long movements (385 ms) being initiated faster than short movements (393 ms); and task, $F(2,36) = 41.3$, $p < .001$, with unimanual movements being fastest (356 ms), followed by bimanual symmetric movements (389 ms) and bimanual asymmetric movements (425 ms). There also was a significant Extent × Age interaction, $F(1,18) = 22.4, p < .001$, in which the young group initiated short movements (340 ms) as fast as long movements (343 ms) but in which the elderly group initiated long movements (426 ms) faster than short movements (445 ms).

Bimanual movement initiation. — To determine the degree of simultaneity of movement onset in both limbs for the bimanual tasks, average absolute RT differences between the arms for each trial were computed for type of bimanual task and extent. These values represent the average difference ($M = 23$ ms), $F(1,18) = 184, p < .001$, between the slower and faster of the two hands (left or right) on a given trial. Differences were found only for age, $F(1,18) = 16.4$, $p < .001$, where the elderly group exhibited almost twice the asynchrony in initiation time (30 ms) as compared to the young group (16 ms) and task, $F(1,18) = 6.6, p < .025$, where asynchrony was slightly greater for the asymmetric (26 ms) than for the symmetric task (20 ms).

Movement Time

Overall. — Mean MT latencies for unimanual, bimanual symmetric, and bimanual asymmetric movement conditions for both groups are given in Table 3, collapsed over participants and trial blocks for task, extent, and arm variables. As with the RT data, there was a significant effect for age, $F(1,18) = 10.3$, $p < .01$, with the young participants moving much faster (181 ms) than the elderly participants (323 ms). An effect was found for task, $F(2,36) = 32.8$, $p < .001$, with MT for unimanual movements being fastest (217 ms), followed by bimanual symmetric movements (252 ms), and bimanual asymmetric movements (288 ms). However, there was a significant Age × Task interaction, $F(2,36) = 5.02$, $p < .01$. MT increased proportionally more for the elderly group compared to the young group, with increases in task complexity. This interaction was due primarily to differences between unimanual and bimanual symmetric conditions (increase of 37 ms for the elderly group), $F(1,18) = 10.7$, $p < .005$; differences between bimanual symmetric and asymmetric conditions (increase of 17 ms for the elderly group) were nonsignificant, $F(1,18) = 1.23$, $p < .28$. There also was a significant difference for extent, $F(1,18) = 125$, $p < .001$, with short movements (227 ms) being completed faster than long movements (277 ms) as seen in Table 3. Finally, there was an Extent × Task interaction, $F(2,36) = 18.6$, $p < .001$, such that the MT advantage for short over long extent decreased from 62 ms for unimanual and bimanual symmetric tasks to 26 ms for the bimanual asymmetric task. Neither the main effect nor the interaction concerning extent interacted with age group (both $Fs < 1$).

Bimanual Movement Termination

To determine the degree of simultaneity of movement completion in both limbs for the bimanual tasks, average absolute total time (RT + MT) differences between the arms for each trial were computed according to type of bimanual task and movement extent. These values represent the average movement termination difference ($M = 32$ ms), $F(1,18) = 110$, $p < .001$, between the slower and the faster of the two hands (left or right) on a given trial. Overall, the elderly participants showed double the asynchrony in movement termination (44 ms) relative to the young participants (21 ms), $F(1,18) = 14.6$, $p < .002$. Further, greater asynchrony was found for terminating asymmetric (41 ms) than symmetric (24 ms) movements, $F(1,18) = 32.3$, $p < .001$. This difference was equivalent for both age groups, $F(1,18) = 3.4$, $p > .08$.

Bimanual RT and MT Intercorrelations

As an index of bimanual movement compensation for the two groups, intercorrelations between RT and MT of both hands were computed separately for each individual over trials according to the levels of the task, extent, and arm variables. These intercorrelations were based on the differences between RT of the left and right hands versus the differences between MT of the left and right hands. A significant negative correlation indicates that movement preparation and execution are compensatory, such that faster preparation latency in one hand is compensated by longer execution latency in that hand so that arrival at the target buttons is the same for both hands. Failure to find a significant negative correlation indicates that preparation and execution are noncompensatory. Average intercorrelations over participants for each age group and experimental condition are given in Table 4. As can be seen, significant negative correlations were found for all conditions for the young group. However, only for long-extent conditions were there significant negative correlations for the elderly group, although all correlations were in the same direction.

An analysis of variance (ANOVA) was performed on Fischer's r to z-transformed intercorrelations for the variables of task, extent, and arm. Overall, the elderly participants had poorer bimanual compensation as compared to the young participants, $F(1,18) = 7.1$, $p < .02$. Further, compensation was more difficult to achieve for asymmetric than for symmetric bimanual movements, $F(1,18) = 10.5$, $p < .005$. Finally, degree of compensation was influenced by the combination of task and extent levels such that for symmetric movements, compensation was easier to achieve for long than for short movements, but for asymmetric movements, it was achieved equally well for both levels of extent, $F(1,18) = 5.15$, $p < .04$. However, this interaction between task and extent did not interact with age, $F < 1$.

DISCUSSION

The results from the present bimanual coordination experiment clearly corroborate the overall elderly performance deficit found in several aging studies (e.g., Birren et al., 1979; Cerella, 1985; Gottsdanker, 1980; Welford, 1984), including studies of the aging motor system (e.g., Larish & Stelmach, 1982). With respect to task complexity, elderly participants, on average were 94 ms slower than young participants in RT across unimanual, bimanual symmetric, and bimanual asymmetric movements combined. Further, both age groups showed similar increases ($M = 36$ ms) across levels of task complexity in movement preparation. This finding replicates the increase in RT found between unimanual and bimanual movement tasks reported by Marteniuk and MacKenzie (1980a) and Marteniuk et al. (1984). This finding is also interesting because it suggests that, regardless of age, the cost of preparing two hands for symmetric movements compared to preparing one hand is the same as that between preparing two hands to make symmetric movements and two hands to make asymmetric movements.

Table 4. Bimanual Condition Correlations[a]

	Age groups (in years)	
Extent	Young group (21 to 25)	Elderly group (65 to 75)
	Symmetric	
Short	−.61***[b]	−.24
Long	−.71***	−.50**
	Asymmetric	
Short	−.51**	−.26
Long	−.52**	−.37*

[a] Based on mean intercorrelations ($RT_L - RT_R$ vs. $MT_L - MT_R$) computed for each participant over individual condition trials.

[b] $df = 30$ (32 condition trials − 2).

*$p < .05$, **$p < .01$, ***$p < .001$.

One explanation for this additive effect for task complexity is the presence of a higher level parameter concerned with the number of lower level parameter values that need to be prepared or programmed. For example, in the unimanual task, only a single value need be programmed for parameters of arm and extent. However, in the bimanual symmetric task, although only one extent value need be programmed, two arm values need to be programmed. Finally, in the bimanual asymmetric task, two extent values and two arm values need to be programmed. As task demands increase, there is an increase in the number of parameter values that need to be programmed, which, in turn, increases RT.

Unlike RT, MT did interact with age group. Elderly individuals demonstrated differentially greater performance deficit as task complexity increased. This deficit was found when the task required two hands as compared to a single hand. Thus, the RT and MT results taken together suggest that the locus of differential aging effects in bimanual coordination at the task level, beyond simple overall latency increase, is in the control of movement execution rather than in movement preparation.

The interaction of age with extent for RT — that for the elderly group a short movement took more time to prepare than a long movement but that for the young group the same amount of time was required — suggests that changes in the programming of the magnitude of an externally defined (Kerr, 1978; Martenuik & MacKenzie, 1980b) phased order of muscular activity occurs with advancing age, whereas such changes do not occur for preparation of different internally defined phased orders of muscular activity (i.e., arm). Further, this effect for the elderly group was inversely related to execution time where increases in extent resulted in longer MT, consistent with the pattern of MT data for the young group. Thus, the locus of change in parameter processes for extent, beyond a simple overall latency increase, appears to be in movement preparation rather than in control of movement execution.

The relationship between movement preparation and execution latency between arms in a bimanual task provides a measure of limb compensation. This compensation is characterized as an increase in MT of movements with quicker RT for one arm and vice versa for the other arm such that resultant arrival at the response keys is (nearly) simultaneous. In the present study, there was evidence that, overall, compensation in varying degrees occurs in the two age groups for both tasks when each limb is performing the identical (equal movement extent) or related but different (unequal movement extent) task. This compensation is incidental in nature because the participants were never explicitly instructed to yoke limb activity.

In addition, compensation was poorer for asymmetric than for symmetric tasks, replicating the findings of Norrie (1964, 1967). However, compensation also varies differentially as a function of task and extent such that for symmetric movements, it is poorer for short than for long movements, whereas for asymmetric movements, it is equivalent for both levels of extent but poorer overall than that for symmetric movements. Thus, even when limbs are moving in the same manner, movement control processes are less successful in monitoring and yoking activity when amplitude of movement extent is short than when it is long. However, the demands of coordinating movements of different amplitudes of extent mitigate any advantage for long movements and more fully tax control processes, although some compensation is still evident. This mitigating effect is underscored by the Task × Extent interaction for MT. The advantage for executing short over long movements is greatly reduced when bimanual coordination concerns unequal movement extent relative to equal movement extent. Thus, although the overall findings support the notion forwarded by Kelso et al. (1979a, 1979b), that motor control processes attempt to prepare and execute movements of the two limbs as a single unit of muscle linkage, extent processes appear to interact with these operations reducing their control of the bimanual movement activity.

Two of our findings are particularly interesting for the study of aging motor processes. One, elderly individuals were much poorer in compensating bimanual movements compared to the young individuals. Second, the elderly group was not as sensitive to the influence of task complexity on compensation as was the young group; the young group accounted for 80% of this effect, whereas the elderly group showed little change, as they seemed to be near floor performance (the Age × Task interaction approached significance, $F(1,18) = 3.77, p = .068$). More specifically, the poorer compensation for the elderly group explains their greater absolute differences in movement termination latency; differences in response initiation cannot be as successfully compensated by movement execution. Thus, higher level processes involved in bimanual limb compensation (Marteniuk & MacKenzie, 1980a) seem to undergo a decrement in performance such that the effect of complexity is greatly attenuated relative to young individuals. To our knowledge, this is the first demonstration of this type of deficit in the aging literature.

These studies suggest specific aging deficits for movement processes in unimanual and bimanual tasks. These include poorer preparation of short movements relative to long movements, regardless of task complexity; lessened ability to yoke initiation of bimanual activity; and, at a more complex level of motor control, poorer ability to compensate for movement initiation asynchrony so as to terminate movement in a near simultaneous manner, reportedly found in young individuals (Kelso et al., 1979a, 1979b).

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