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Old Adults Exhibit Greater Motor Output Variability Than Young Adults Only During Rapid Discrete Isometric Contractions

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The purpose of this study was to examine the ability of young and elderly individuals to control submaximum levels of force (5–90%) during continuous and rapid discrete isometric contractions of the quadriceps femoris. Participants were 24 young (25.3 ± 2.8 years) and 24 elderly individuals (73.3 ± 5.5 years) that were healthy and active. The strength of elderly participants was approximately 40% lower than young participants. The standard deviation and coefficient of variation (CV) of force were greater during discrete contractions than during continuous isometric contractions. During continuous isometric contractions, young and elderly participants exhibited similar CVs of force. During discrete contractions, however, elderly participants exhibited greater CVs for peak force and impulse and greater standard deviations and CVs for temporal characteristics than young participants. Results suggest that the control of force in active elderly people declines only during rapid discrete contractions and that this decline may be associated with declines in temporal characteristics of the force production.

ONE factor that can influence the quality of voluntary movements is motor output variability. The appropriate application of force, including the magnitude, direction, and the timing of force, is required to minimize motor output variability and consequently spatial error (kinematic error; 1,2). Several studies have shown that old adults exhibit increased kinematic variability compared with young adults during functional movements (3,4) and that they prefer to slow down to eliminate errors and loss of balance (3,5). From these and other observations, it has been suggested that the elderly population's increased tendency to fall could also be related to a reduced ability to control muscle force (5–7).

Force control appears to be reduced in elderly adults compared with young adults, particularly at low levels of force (7–12). These age-related differences, however, are not consistent across limbs (13) and become smaller when old adults participate in strength training (9) or physical activities such as T'ai Chi (14,15). One of the factors that might be associated with the decreased ability of the elderly population to control force is the reorganization of small motor units (16,17), which can alter the strategies used by the nervous system to control muscle force (18,19).

Traditionally, motor output variability has been measured by using continuous (7) and discrete isometric tasks (2). In continuous tasks the participant attempts to match a constant force level for an extended period of time, whereas in discrete tasks the participant attempts to match a force–time parabola with a short duration by controlling force output. The standard deviation (SD) and coefficient of variation (CV) have been used frequently to measure the within-subject variability in motor output characteristics such as the level of force, time to peak force, impulse, and impulse duration. It is generally accepted that for both continuous and discrete isometric contractions, the SD of force increases as the level of force increases, and the CV of force decreases as the level of force increases (2,7,8,11,20). In addition, it appears that the most appropriate way to compare individuals from different strength groups is to compare the normalized variability (i.e., CV) as a function of the normalized muscle activation level (percentage of maximum voluntary contraction [%MVC]) (21).

Studies that examine age-related differences in motor output variability have focused on slow- and low-force continuous isometric and anisometric contractions (7–12). To our knowledge, there are no studies that have examined age-related differences by using a rapid discrete task. Rapid discrete contractions differ from continuous contractions in many respects. The rate of force production is higher, the motor command must be repeated over trials, and the use of kinesthetic feedback is minimized. From the existing literature and the above observations, we hypothesized that age will impair control of both continuous and discrete isometric contractions; however, this impairment will be greater during discrete isometric contractions. A secondary hypothesis was that the control of force would be significantly worse during discrete contractions than during continuous isometric contractions.

Methods

Participants

Twenty-four active young (25.3 ± 2.8 years old) and 24 active older adults (73.3 ± 5.5 years old) volunteered for this experiment (Table 1). A medical history questionnaire

Table 1. Age and MVC of the Subjects for Continuous and Rapid Discrete Isometric Contractions

Subjects	Age (y)	Continuous Isometric (*n*)	Discrete Isometric (*n*)
Young			
All subjects (*N* = 24)	25.3 ± 2.8	804.4 ± 235.9	724.3 ± 218.7
Males (*n* = 12)	26.0 ± 2.9	1003.1 ± 142.5	913.5 ± 107.2
Females (*n* = 12)	24.7 ± 2.6	605.7 ± 99.8	535.1 ± 102.1
Old			
All subjects (*N* = 24)	73.3 ± 5.5	493.1 ± 188.1	393.8 ± 148.1
Males (*n* = 12)	72.6 ± 4.8	585.8 ± 194.3	450.4 ± 153.4
Females (*n* = 12)	74.0 ± 6.3	400.3 ± 132.3	337.2 ± 123.8

Notes: Values are group means ± standard deviation for age and each type of contraction. MVC = maximum voluntary contraction.

given to each individual prior to the study indicated that all participants were healthy and had no history of knee pathology nor neurological disorders. Based on a physical activity questionnaire (22) that was previously validated (23) all subjects engaged in moderate to intense regular physical activity. None of the older participants had cognitive deficits as assessed by the Pfieffer mental status scale (24). Testing protocols were approved by the institutional review board for research with human subjects, and each participant gave his or her informed consent.

Apparatus

To assess force production and motor output variability for a leg-extension task during continuous and discrete isometric contractions, a KIN-COM 500H isokinetic dynamometer (Chattecx, Chattanooga, TN) was used. The KIN-COM 500H has been shown to be a reliable way to assess force isometrically (25,26). Prior to this experiment we contacted two pilot studies (one for discrete and one for continuous contractions) to test the reliability of our equipment. We found that our equipment and protocol were reliable. Furthermore, the CV from our continuous data is comparable with that from data from other labs. We couldn't, however, compare data for discrete contractions because no previous data exist on the quadriceps femoris with a similar protocol to ours.

Procedures

Strength and motor output variability were assessed by using continuous and discrete isometric contractions of the quadriceps femoris muscle group. Participants attended two separate sessions: one for continuous and one for discrete isometric contractions. For each type of contraction the level of maximum voluntary contraction was determined. Based on the MVC produced, target forces, expressed as %MVC, were determined.

The participants were seated on the isokinetic dynamometer chair for testing with the backrest angle at 90°. The axis of rotation of the right knee (lateral epicondyle of the femur) was aligned with the axis of rotation of the dynamometer armature. The ankle cuff (load cell assembly) was positioned so that the lowest part of the cuff was 2.5 cm above the talus bone. To eliminate postural instability, stabilization straps were placed over the pelvis and chest. In addition, are participants positioned their arms across their chests during each trial to eliminate other variables that could have influenced MVC and variability of force (e.g., arm strength). The knee angle was set to 90° for all trials, and a soccer shin guard was placed over the right shin to protect the participants from any potential discomfort caused by the large number of leg extensions performed during each session.

The order of contraction types was counterbalanced. The MVC trials and the trials at the various %MVCs were blocked. The order of the %MVC levels within a contraction type were randomly determined. Prior to each session, participants warmed up by walking for 5 minutes and stretching their quadriceps femoris, hip flexors, and gastrocnemius muscles. The MVC of each participant for each type of contraction was measured at the completion of the warm-up. Specific warm-up (three submaximal trials) was given to the participants before testing their MVCs to familiarize them with the apparatus and task.

Maximum Voluntary Continuous Contractions

As a way to identify the maximum voluntary isometric force production for continuous tasks, young and elderly participants were asked to produce maximal leg-extension force for 5 seconds. This procedure was repeated twice with a 30-second rest between trials. Trials were accepted only if the highest recorded forces between trials were within 5% of each other (the highest number of trials performed by a participant was five). Participants monitored the force produced on the monitor of the isokinetic dynamometer. Similar to other investigations, the average of the 10 highest force values produced over all three trials was considered the maximum voluntary continuous isometric contraction level for the participant (27). Following each contraction session, each subject performed another MVC to identify whether fatigue had taken place.

Maximum Voluntary Discrete Contractions

For discrete isometric contractions, participants were asked to produce maximal effort force pulses with brief durations. The criterion of time to peak force for each trial was 200 milliseconds. Because longer times to peak force can increase maximum force (28,29), the 200 millisecond time to peak force was used to identify the MVC. A rapid time to peak force also eliminates any potential changes to the force produced by the participant that are due to feedback. Participants were able to monitor the gradation of force on the monitor of the isokinetic dynamometer. Maximum effort trials were repeated with a 30-second rest between the trials until three trials with a time to peak force of 200 milliseconds (±10%) were produced (the highest number of attempts required by a participant was 10 trials). The highest of the three force values produced from the three accepted trials was considered the maximum voluntary contraction. Similar to the continuous contractions, at the end of the contraction session each subject performed another MVC to identify whether fatigue had taken place.

Continuous and Discrete Isometric Contraction Tasks

The positioning of the participant was the same as that used for the MVCs. For the whole range of muscle activation to be examined, eight target-force levels were determined based on the maximum isometric force produced by each participant. These forces were 5%, 10%, 20%, 35%, 50%, 65%, 80%, and 90% of MVC, and they were selected because they represent a wide range of muscle activation levels. The order of target forces was determined randomly for each participant.

Continuous task.—For the continuous isometric task the target force for a %MVC level was displayed as a horizontal line on the computer monitor located 50 cm in front of the participant (Figure 1A). The force exerted by the participant was also displayed on the monitor as a function of time (a different colored line was used for target and force produced). Participants were instructed to match the leg-extension force with the target force. Trials lasted 15 seconds for levels of force below 50% MVC and 10 seconds for all higher levels of force. Visual feedback was provided for the first 5 seconds for guidance. At the end of the fourth second, the monitor was covered and the participant was asked to maintain the same leg-extension force for the remainder of the trial. One practice trial was given to each participant so that he or she would feel comfortable in completing the task and matching the target force for that %MVC level. The same procedure was used for each target force for two experimental trials. A brief rest period of 30 seconds was given between data-collection trials, and 120 seconds of rest was given between target forces.

Rapid discrete task.—For the discrete isometric task each participant attempted to match a force–time parabola (Figure 1B). The target force–time parabola was drawn on a transparency sheet and attached to the monitor. The time to the highest or peak force of the parabola was 200 milliseconds and the impulse duration was 400 milliseconds. Each participant was instructed to match the target parabola by controlling leg-extension force, and each trial lasted approximately 0.5 seconds with 4.5 seconds of rest given between consecutive trials. Each participant received 30 practice trials followed by 40 experimental trials at each force level. Both the force–time parabola and the force produced by the participant were displayed on the monitor during the trial for the first 10 practice trials. During the last 20 practice trials and all experimental trials, the force–time parabola was hidden during the leg-extension force production. Immediately following the trial, visual feedback of the force–time curve produced and the force–time target parabola was provided. In addition, participants received verbal feedback regarding the amount of force and temporal characteristics they produced in order to enhance their learning of the target parabola. A brief rest period of 120 seconds was given to each participant between levels of target force.

Experimental Design and Data Reduction

Means, SD, and CV of several force and time parameters were computed from the experimental trials. For continuous isometric contractions, a preliminary analysis indicated that mean force significantly decreased and SD and CV significantly increased at times over 7.5 seconds. This trend was greater at levels of force over 50% MVC. As a way to eliminate shifts in mean force values caused by fatigue within each trial, only force values from 5 to 7.5 seconds were used in the calculations for the continuous isometric task. For the discrete isometric task, a number of trial characteristics were analyzed from the 40 experimental trials. These included peak force, impulse (the integral of force/time), time to peak force, and impulse duration.

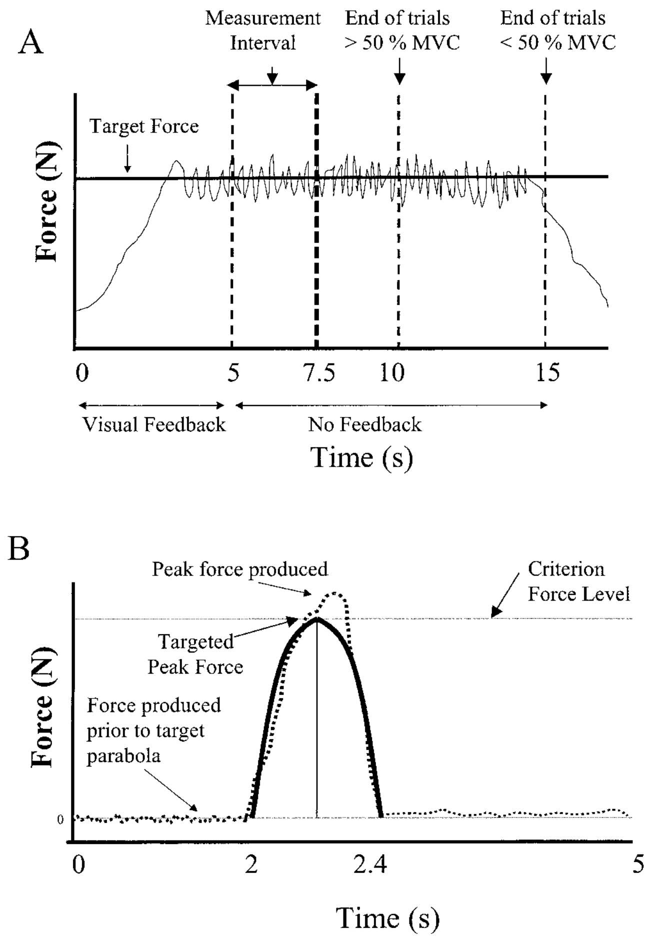

Figure 1. Tasks: **A**, the continuous isometric task; **B**, the rapid discrete isometric task. MVC = maximum voluntary contraction.

An initial examination of force variability (SDF) indicated that males were more variable than females. This was expected because males had greater MVCs; therefore, the criterion force level at any %MVC was greater compared with that of the female participants. Normalizing the variability of force to the level of force produced by each participant (CV) resulted in a nonsignificant effect for gender, for continuous isometric contractions, and peak force, impulse, time to peak force, or impulse duration for discrete isometric contractions (all $p > .05$). Therefore, the two gender groups were combined for further analyses.

Statistical Analysis

Maximum force produced (MVC) was examined by using a three-factor complete factorial analysis of variance (ANOVA; 2 Age groups × 2 Genders × 2 Contraction types), with repeated measures on contraction type. As a way to identify whether fatigue occurred during each contraction session, the MVC was examined by using a paired *t* test between the MVC before and the MVC recorded after the contraction session. A three-factor complete factorial ANOVA (2 Age groups × 2 Contraction types × 8% MVC), with repeated measures on contraction type and %MVC, was used to examine the variability of force (SDF) and the coefficient of variation of force (CVF). For the continuous isometric contractions, mean force, SDF, and CVF were based on two-trial averages. For discrete isometric contractions, mean, SD, and CV of peak force (based on the last 40 trials) were analyzed. A two-factor complete factorial ANOVA (2 Age groups × 8% MVC), with repeated measures on %MVC, was used to examine the SD and CV of impulse, time to peak force, and impulse duration for discrete contractions. The alpha level for all statistical tests was set at 0.05 and paired contrasts (*t* tests) were used to locate differences between age groups and contractions when ANOVAs yielded significant interactions. A summary of the ANOVAs used and their results are in Table 2.

Results

Strength

Young participants produced greater maximum isometric force than elderly participants, and participants produced greater force during continuous than during discrete isometric contractions (Table 1). The interaction between gender and age group indicated that gender differences were smaller for elderly participants than for young participants in both types of isometric contractions. Furthermore, the MVCs (for all participants) before and after each contraction session were not significantly different ($p > .05$), indicating that quadriceps fatigue did not occur.

Matching of Targets

Mean peak force and impulse increased systematically with increases in level of force. The mean peak force and impulse error indicated that, on average, young and old subjects produced higher peak forces and impulses than the goal force at low percentages of MVC and lower peak forces than the goal at high percentages of MVC. The temporal error indicated that, on average, both age groups performed slightly shorter-duration contractions than the goal time at low forces and longer-duration contractions than the goal time at high forces.

Motor Output Variability for Age and Contraction Type

SD of force.—Young participants exhibited greater variability than elderly participants, and discrete isometric contractions were more variable than continuous isometric contractions. As expected, the SDF increased as the level of force increased. The interactions between age group and contraction type, and age group and level of force, indicated that young adults were more variable than elderly adults for both continuous and discrete contractions at all levels of force; however, age differences were greater for discrete isometric contractions and at lower levels of force (Table 3). Variability during discrete isometric contractions was sig-

Table 2. Summary of the ANOVA Results

Parameter	Strength During Continuous and Discrete Isometric Contractions	Value
Age		$p < 0.01$
Gender		$p < 0.01$
Contraction type		$p < 0.01$
Age × Gender		$p < 0.01$
Age × Contraction		$p > 0.10$
Gender × Contraction		$p > 0.10$
Age × Gender × Contraction		$p > 0.10$

Variability of Force During Continuous and Discrete Isometric Contractions

	SDF	*CVF*
Age	$p < 0.01$	$p < 0.01$
Contraction	$p < 0.01$	$p < 0.01$
Force level	$p < 0.01$	$p < 0.01$
Age × Contraction	$p < 0.01$	$p < 0.01$
Age × Force level	$p < 0.01$	$p < 0.01$
Contraction × Force level	$p < 0.01$	$p < 0.01$
Age × Contraction × Force level	$p > 0.10$	$p < 0.01$

Motor Output Variability During Discrete Isometric Contractions

	SDI	*CVI*	*SDTPF*	*CVTPF*	*SDID*	*CVID*
Age	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p = 0.05$	$p < 0.01$
Force level	$p < 0.01$	$p < 0.01$	$p > 0.10$	$p < 0.01$	$p < 0.01$	$p < 0.01$
Age × Force level	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p > 0.10$	$p < 0.01$

Note: ANOVA = analysis of variance; SD = standard deviation; CV = coefficient of variation; SDF and CVF = SD and CV of force; SDI and CVI = SD and CV of impulse; SDTPF and CVTPF = SD and CV of time to peak force; SDID and CVID = SD and CV of impulse duration.

Table 3. Group Mean, SDF, and Peak Force for Continuous and Rapid Discrete Isometric Contractions at Each Force Level

	Continuous Isometric		Discrete Isometric	
%MVC	Old Adults	Young Adults	Old Adults	Young Adults
Mean Force (*N*)				
5	31.5 ± 10.6	44.8 ± 12.1	29.6 ± 10.7	44.7 ± 11.9
10	54.0 ± 17.5	81.4 ± 21.1	51.8 ± 17.7	85.1 ± 28.1
20	101.4 ± 37.6	159.6 ± 47.6	90.3 ± 33.2	163.8 ± 58.3
35	170.8 ± 63.6	274.2 ± 87.8	147.4 ± 58.2	270.1 ± 86.5
50	237.8 ± 91.8	386.1 ± 117.8	210.5 ± 72.6	374.3 ± 118.5
65	300.6 ± 115.6	493.1 ± 151.0	257.7 ± 103.3	469.4 ± 148.1
80	364.6 ± 142.9	583.6 ± 183.9	301.7 ± 120.6	554.0 ± 171.5
90	401.0 ± 159.7	642.3 ± 199.9	329.1 ± 133.5	606.7 ± 188.9
SDF (*N*)				
5	1.2 ± 0.5	1.6 ± 0.5	9.5 ± 3.7	11.9 ± 3.9
10	1.5 ± 0.6	2.5 ± 1.1	14.0 ± 4.5	18.0 ± 6.1
20	2.4 ± 1.2	4.0 ± 1.4	18.4 ± 7.0	23.3 ± 6.8
35	3.4 ± 1.2	6.5 ± 2.7	23.5 ± 9.5	31.4 ± 11.7
50	5.2 ± 2.5	11.7 ± 5.9	26.7 ± 13.0	37.4 ± 15.3
65	8.1 ± 5.0	13.4 ± 4.7	24.7 ± 8.6	39.2 ± 14.0
80	10.0 ± 6.3	17.4 ± 7.5	28.9 ± 13.8	39.7 ± 15.1
90	12.8 ± 7.5	18.0 ± 6.1	24.4 ± 9.6	38.3 ± 14.3

Notes: Values are group means ± SD for age and each type of contraction. SD = standard deviation; SDF = SD of force; %MVC = percentage of maximum voluntary contraction.

nificantly higher across all eight levels of force compared with continuous isometric contractions; nevertheless, differences were greater in the middle range of target-force levels (Figure 2).

CV of force.—Elderly participants exhibited greater relative variability (CV) than young participants, and discrete isometric contractions exhibited greater CVs compared with continuous isometric contractions. As expected, the CV decreased as the level of force increased. The three-way interaction, among age group, contraction type, and level of force (Figure 3), indicated that young and elderly participants exhibited similar CVs across levels of force during continuous isometric contractions, whereas during discrete isometric contractions the elderly participants exhibited significantly greater CVs compared with young participants, particularly at levels of force up to 50% MVC. Furthermore, variability during discrete isometric contractions was significantly higher across all eight levels of force compared with continuous isometric contractions; there were greater differences in the lower range of target-force levels.

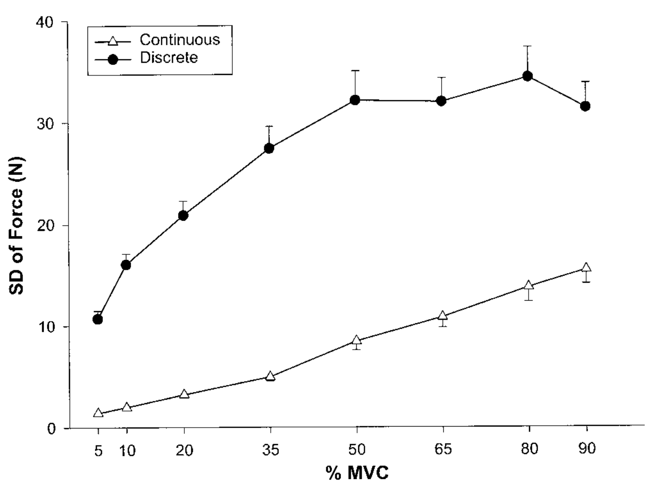

Figure 2. The interaction between contraction type and level of force on the standard deviation (SD) of force during isometric contractions (%MVC = percentage of maximum voluntary contraction).

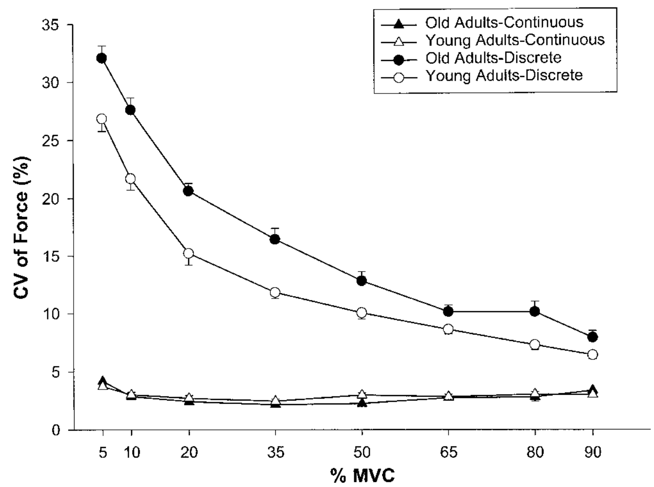

Figure 3. The interaction among age group, contraction type, and level of force on the coefficient of variation (CV) of force during isometric contractions (%MVC = percentage of maximum voluntary contraction).

Discrete Isometric Parameters

SD of impulse.—Young participants exhibited greater impulse variability (SD) than elderly participants, and the SD of impulse increased as the level of force increased. The interaction between age group and level of force indicated that impulse variability was not significantly different between the two age groups up to 35% MVC; however, at levels of force of 50% MVC and beyond, young participants exhibited significantly greater impulse variability than elderly participants (Table 4).

CV of impulse.—Elderly participants exhibited greater CVs than young participants, and the CV decreased as the level of force increased. The interaction between age group and level of force (Figure 4) indicated that elderly participants exhibited significantly greater CVs at all levels of force, except at 65% and 90% MVC.

SD of time to peak force.—Elderly participants exhibited greater variability than young participants (Table 5). The interaction between age group and level of force indicated that elderly participants produced significantly greater variability at levels of force up to 35% MVC; however, at levels of force of 50% MVC and beyond, the SD for time to peak force was not significantly different between the two groups.

CV of time to peak force.—Elderly participants exhibited greater relative variability (CV) than young partici-

Table 4. Group Mean and SDI for Rapid Discrete Isometric Contractions at Each Force Level

	Discrete Isometric	
%MVC	Old Adults	Young Adults
Mean Force (*N*)		
5	6.1 ± 2.8	7.7 ± 2.6
10	11.5 ± 5.6	16.5 ± 5.9
20	20.5 ± 8.7	36.3 ± 16.7
35	35.1 ± 15.7	61.4 ± 23.0
50	50.5 ± 18.5	91.8 ± 34.8
65	62.6 ± 25.9	117.0 ± 41.5
80	79.2 ± 32.6	147.7 ± 48.6
90	88.1 ± 37.2	166.3 ± 57.4
SDF (*N*)		
5	2.5 ± 1.1	2.5 ± 0.6
10	3.9 ± 1.5	4.1 ± 1.2
20	5.4 ± 2.4	6.6 ± 2.6
35	7.7 ± 3.9	9.7 ± 4.4
50	9.6 ± 4.1	13.0 ± 5.3
65	9.7 ± 3.7	17.3 ± 7.8
80	14.1 ± 6.8	19.8 ± 7.8
90	13.2 ± 5.3	23.6 ± 11.6

Notes: Values are group means ± SD for age and each type of contraction. SD = standard deviation; SDI and SDF = SD of impulse and force, respectively; %MVC = percentage of maximum voluntary contraction.

Table 5. Group Mean and SD of Time to Peak Force and Impulse Duration for Rapid Discrete Isometric Contractions at Each Force Level

	Time to Peak Force		Impulse Duration	
%MVC	Young Adults	Old Adults	Young Adults	Old Adults
Mean (s)				
5	0.103 ± 0.025	0.106 ± 0.023	0.241 ± 0.049	0.287 ± 0.081
10	0.125 ± 0.029	0.128 ± 0.045	0.315 ± 0.055	0.342 ± 0.109
20	0.152 ± 0.047	0.146 ± 0.043	0.393 ± 0.085	0.399 ± 0.084
35	0.170 ± 0.047	0.158 ± 0.051	0.439 ± 0.082	0.445 ± 0.092
50	0.189 ± 0.056	0.159 ± 0.056	0.481 ± 0.087	0.469 ± 0.097
65	0.198 ± 0.052	0.176 ± 0.052	0.493 ± 0.095	0.481 ± 0.084
80	0.225 ± 0.047	0.190 ± 0.058	0.528 ± 0.071	0.522 ± 0.102
90	0.231 ± 0.045	0.189 ± 0.055	0.535 ± 0.083	0.518 ± 0.107
SD (s)				
5	0.023 ± 0.011	0.040 ± 0.016	0.046 ± 0.014	0.066 ± 0.021
10	0.023 ± 0.011	0.043 ± 0.021	0.041 ± 0.013	0.068 ± 0.025
20	0.023 ± 0.012	0.042 ± 0.020	0.048 ± 0.037	0.070 ± 0.038
35	0.028 ± 0.013	0.040 ± 0.022	0.051 ± 0.020	0.086 ± 0.104
50	0.025 ± 0.011	0.031 ± 0.017	0.062 ± 0.030	0.072 ± 0.056
65	0.029 ± 0.010	0.031 ± 0.019	0.074 ± 0.037	0.080 ± 0.069
80	0.031 ± 0.008	0.033 ± 0.020	0.093 ± 0.061	0.096 ± 0.055
90	0.028 ± 0.009	0.032 ± 0.017	0.092 ± 0.034	0.086 ± 0.050

Notes: Values are group means ± SD for age and each temporal characteristic. SD = standard deviation; %MVC = percentage of maximum voluntary contraction.

pants, and the CV for time to peak force decreased as the level of force increased. The interaction between age group and level of force (Figure 5) indicated that elderly participants had significantly greater CVs than young participants across all levels of force ($p < .05$), except at 65% and 80% MVC ($p > .1$).

SD of impulse duration.—Elderly participants exhibited greater variability than young participants ($p = .051$), and the SD of impulse duration increased as the level of force increased (Table 5).

CV of impulse duration.—Elderly participants exhibited greater CVs than young participants, and the CV for impulse duration decreased as the level of force increased. The interaction between age group and level of force (Figure 6) indicated that elderly participants exhibited significantly greater CVs at levels of force up to 35% MVC; however, at levels of force of 50% MVC and beyond, no significant differences were found between the two groups.

Discussion

Age-Related Differences in Motor Output Variability

The present experiment demonstrated that relative variability (CV) in motor output during continuous isometric

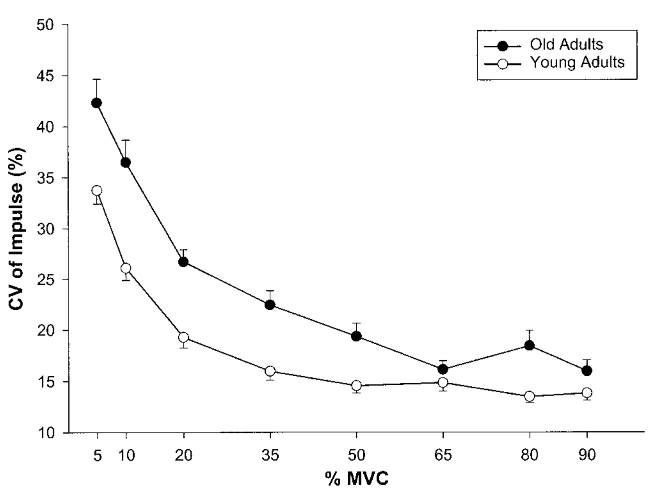

Figure 4. The interaction between age and level of force on the coefficient of variation (CV) of impulse during discrete isometric contractions (%MVC = percentage of maximum voluntary contraction).

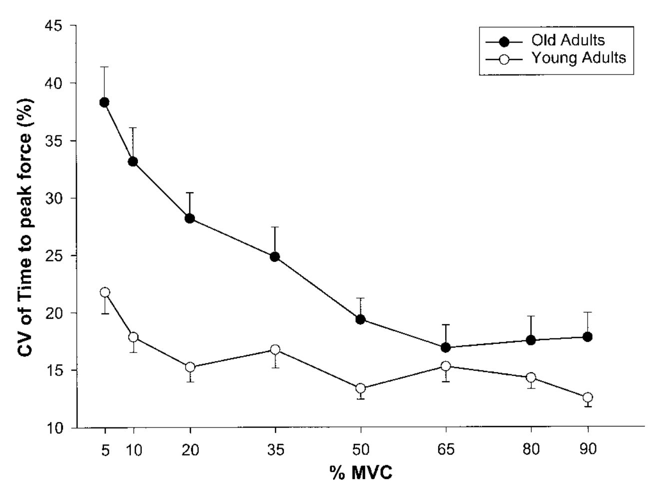

Figure 5. The interaction between age and level of force on the coefficient of variation (CV) of time to peak force during discrete isometric contractions (%MVC = percentage of maximum voluntary contraction).

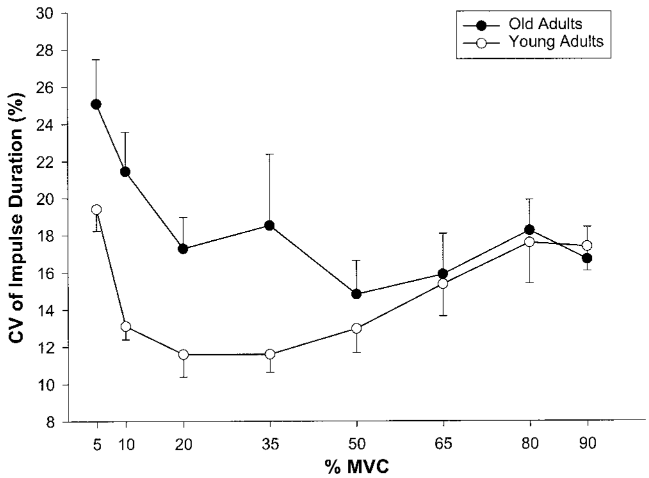

Figure 6. The interaction between age and level of force on the coefficient of variation (CV) of impulse duration during discrete isometric contractions (%MVC = percentage of maximum voluntary contraction).

contractions was not affected by age. These findings are in agreement with a previous experiment performed on elbow flexors (13) and differ from other experiments performed on a hand muscle (7,11,30) and knee extensors (12). These differences may be due to two different factors. One factor may relate to the levels of force examined. Studies that have found significant differences between young and elderly participants have typically found these differences at low levels of force production. For example, Galganski and colleagues (7) found that elderly individuals exhibited greater relative variability than young individuals but only at 2% MVC, whereas other studies (11,12,30) reported age-related differences up to 10% MVC. In the present study there were no significant differences in relative variability with the %MVC ranging from 5% to 90%. Another factor that may have influenced these findings is the nature of the participants studied in this and previous studies. The elderly participants tested in previous studies were healthy sedentary individuals, whereas the elderly participants in this study were very active and healthy. It has been shown that age-related differences at low %MVCs can be eliminated following strength training (9,10). It is possible, therefore, that age-related differences in variability reported by other studies might be due to the activity profile of the two age groups.

Compared with the young participants in this study, the elderly participants consistently produced higher relative variability (CV) during rapid discrete isometric contractions when the level of force was expressed as %MVC. This finding was robust for peak force, impulse, time to peak force, and impulse duration. The inability of the elderly participants to control force (CV) and timing (SD and CV) only during rapid contractions supports previous results suggesting that elderly people perform as accurately as young people during slow-speed continuous movements (31); however, movement control is reduced with increases in speed and complexity of movement (32,33).

There is accumulating evidence that discharge-rate variability is primarily responsible for greater motor output variability in the elderly population (11,34,35). One physiological mechanism that could increase the variability in the discharge rate of motor units in the elderly population is decreases in the transmission velocity from corticospinal and reflex pathways to the motor neurons (36,37). This transmission impairment can be caused by the 25–35% reduction in the total number of cortical motor neurons (38), the lumbosacral (spinal cord) motor neurons (20), and particularly the loss of the largest alpha motor neurons and their myelinated axons (19). Other mechanisms, such as increased average force produced by motor units (39), the pattern of coactivation by the agonist and antagonist muscles (40), and synchronization of motor units (30), have been refuted as the explanations for the increased variability exhibited by elderly individuals.

The differences between young and older adults did not appear to be due to differences in the speed of learning a new motor skill. Older adults, compared with young adults, have reduced motor learning abilities only when the task requires a strategy (41,42). In addition, young and old adults appear to use knowledge of results similarly to learn a new motor task (43). The discrete isometric task used in this study was nonstrategic (matching a line or parabola with a single joint movement), and the same knowledge of results was given to both young and old participants. A preliminary examination of our discrete isometric data suggests that both age groups improved accuracy of the motor output at a similar rate. We believe, therefore, that age-related learning impairments did not influence the results of this study.

Contraction Differences

The present experiment demonstrated that variability in force production (SD and CV) is significantly greater during discrete isometric contractions than it is during continuous isometric contractions. This finding was consistent across levels of force ranging from 5% to 90% MVC. Greater variability for discrete isometric contractions may be related to several factors.

One difference between the two tasks is feedback utilization caused by the temporal requirements. Continuous isometric contractions are slow and have no temporal constraints; therefore, kinesthetic feedback is a potential factor that can provide additional information, enhance corrections, and reduce variability of force (closed-loop control system). The discrete isometric contractions used in the present experiment were fast and had very short temporal constraints (time to peak force was 200 milliseconds), and this minimized the ability of the neuromuscular system to use kinesthetic feedback and allow corrections within the contraction time (open-loop control system) (44).

A second factor that may account for the greater variability for discrete isometric contractions is the influence of rate of force production. The rate of force production has a significant effect on motor output variability, and experiments that have manipulated the rate of force production have demonstrated systematic changes in variability of force impulse, especially for higher levels of force (1,2,28,29,45,46). Longer contraction times have been associated with decreases in variability of force and impulse (2,45,46).

Other possible factors that may account for the greater variability found during rapid discrete isometric contractions are the type and discharge-rate variability of motor units. The orderly recruitment of motor units is preserved during both slow continuous and rapid discrete isometric contractions; however, during rapid contractions, motor units are recruited at an earlier %MVC (47,48) and with more variable discharge rates (49). Large motor units (50) and higher discharge-rate variabilities of motor units (51) have been associated with greater variability in force.

Another potential factor that can increase variability of force during discrete isometric contractions is the change in the neuromuscular system that is due to repetition of the motor command. During continuous isometric contractions, each level of force was maintained for approximately 10 seconds and was repeated only once by each participant. During discrete isometric contractions, however, the repetition of the motor command (40 trials) can slightly alter the number, size, and discharge rate of motor neurons recruited for each trial.

Several possible explanations have been suggested for the differences in variability between continuous and discrete isometric contractions. Although a single factor may account for these differences, it is also possible that a combination of differences in feedback availability, recruitment, and task characteristics may account for the up to sixfold increase in variability for discrete isometric contractions.

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