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The effects of age and feedback on isometric knee extensor force control abilities

Jeff M. Schiffman [a], Carl W. Luchies [b,*], Lorie G. Richards [c], Carole J. Zebas [d]

[a] *U.S. Army Soldier Systems Center, Natick MA 01760-5020, USA*
[b] *Department of Mechanical Engineering, University of Kansas, 3013 Learned Hall, Lawrence KS 66045-2234, USA*
[c] *Department of Occupational Therapy Education, University of Kansas Medical Center, Kansas City KS 66160, USA*
[d] *Department of Health, Sport and Exercise Science, University of Kansas, Lawrence 66045-2378, USA*

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Abstract

Objective. To investigate the effects of age and feedback on submaximal isometric force control abilities in the knee extensors.

Design. Analysis of a force control task in a quasi-experimental design.

Background. The ability to control submaximal strength is important to accomplish activities of daily living. The purpose of this study was to investigate the effects of age, feedback, and force level on force control ability in knee extension, which is often used to accomplish daily activities.

Methods. The performance of an isometric force control task was measured in young (mean age 26, SD 2.7 yrs) and older (mean age 72, SD 2.0 yrs) adult healthy male participants. Each participant maintained a steady force in knee extension at two levels of force (20% and 60% MVC) with and without visual bandwidth feedback. Age, force level, and feedback effects were examined on the dependent variables of force variability, bias, and time in bandwidth.

Results. Both groups were fairly accurate at accomplishing the task, particularly at the lower force level. The higher force was harder to control, particularly when feedback was absent. The absence of feedback did not affect variability during force control. Older adults performed with less variability and a higher safety margin. Both groups performed better in time spent in bandwidth and safety margin with visual feedback, compared to the no-feedback condition.

Conclusions. Healthy older and younger adults performed quite similarly regardless of feedback being provided or not. The intermittent feedback condition may have been more closely aligned with a no feedback condition rather than a continuous feedback condition.

Relevance

Clinical evaluation of submaximal force control ability may be useful for delineating impairments in motor skill and measuring outcomes of intervention programs. To be useful in the clinic, force control assessments must be both sensitive and specific to underlying impairments. The current study investigated the normal range of force control variability to allow the detection of true impairments.

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Keywords: Aging; Feedback; Isometric; Force control; Knee extensor

1. Introduction

In several conditions causing disability, such as stroke, Parkinson's disease, and Huntington's disease, impairments in force control have been implicated in the causes of disability [1–3]. However, most of what is known about force control comes from studies that have investigated maximal force control. Since maximal strength is seldom recruited in daily activities, other components of strength must be important in the completion of activities of daily living [4,5]. The ability to regulate submaximal strength may significantly affect activities of daily living. Increasing our understanding of how submaximal forces are regulated may provide insight into better assessment tools that will more clearly define areas of impairment in conditions that impair motor skill. More definitive pic-

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tures of impairment should lead to more precise interventions for such conditions.

The elderly form a group in which the study of submaximal force control could lead to important understandings about force control. This is because the elderly experience sarcopenia, the loss of skeletal muscle mass (and therefore maximal strength) with age [6]. An interesting topic is the quality of submaximal force control in the elderly despite maximal force decrements. One aspect of submaximal force control is the steadiness in maintaining a given amount of force. The aim of this experiment was to compare the steadiness of force production in young and older adults.

Force steadiness can be measured in terms of variability of force production. Force variability primarily results from the unfused contractions of the most recently recruited motor units [7]. The order of motor unit recruitment is smallest to largest [8]. Because aging reduces the number of motor units, the remaining motor neurons sprout to innervate abandoned motor fibers, resulting in an increased number of larger motor units [9,10]. Thus, even at lower force levels, elders recruit larger motor units than the young. As differences in forces produced by different-sized motor units result in different force fluctuations [11], and the elderly have larger motor units, it is logical to assume that the elderly would show larger force variability than young adults—especially at lower force levels when young adults should be recruiting relatively small motor units.

There are mixed results regarding the effects of age on force variability. For submaximal forces produced primarily by a single muscle at the index finger, elderly were more variable than young adults, especially at low force levels [12,13]. For submaximal force produced by a group of larger muscles (e.g. elbow flexors), variability was similar between elderly and young adults, although, in some cases, the elderly were less variable [12,14–16].

One explanation for these mixed results is a difference in the number of large motor units recruited. Larger muscles consist of larger motor units than small muscles. Hence, larger motor units would have been recruited even at lower levels of force [17]. Thus, the relative number of large motor units recruited may have been more similar between the elderly and young adults, resulting in similar force variability between the two groups when larger muscles produced the force.

A second explanation is that force variability is related to the number of force-producing muscles. When multiple muscles are used, performance steadiness is less affected by variations in individual muscle activation [18,19]. Therefore, the variability in a force produced by multiple muscles may be similar between young and older adults.

Whether the mixed results are due to the number of large motor units recruited or the number of muscles activated, the effect should be larger at the knee, which can produce the force using muscles larger in number and size. As age has been shown to increase force variability at the index finger (single small muscle), have no effect at the elbow (muscles larger in number and size compared to index finger), we would expect older adults, compared to young adults, to be less variable at maintaining submaximal forces at the knee (muscles larger in number and size compared to elbow) [20]. However, it has also been demonstrated that older adults, compared to young adults, had a greater coefficient of variation at low forces (less than 10% maximum voluntary contraction (MVC) but not at high forces (50% MVC) during knee extensor force control [21].

A second important aspect of force control is the role of feedback. Most activities of daily living require the monitoring of internal feedback regarding submaximal forces. Yet, many force control investigations have used continuous external feedback. Motor learning research reveals that continuous feedback increases force variability as participants make corrections on every trial [22]. Bandwidth feedback decreases variability because it reduces the number of corrections [22]. However, older adults may be more variable when they rely on their tactile and proprioceptive feedback systems than on external feedback due to age-related changes in sensation [23]. Consistent with this idea, individuals with neurological pathology impairing intrinsic feedback loops were more variable using bandwidth feedback than continuous feedback [24]. However, young and older adults have performed similarly when continuous feedback was removed, both drifting away from the target more as force level increased [14].

How age and feedback affects force control is not well understood. This study investigated the effects of age (young versus older adults), force level (20% versus 60% MVC), and feedback condition (with visual bandwidth feedback versus feedback removed) on submaximal force control in knee extension.

2. Methods

2.1. Participants

Twenty young and 20 older healthy adult males participated after written informed consent (IRB

Table 1
Group demographics (means (SD))

	Young adults	Older adults
Age (yrs)	25.8 (2.7)	71.8 (2.0)
Education (scale)[a]	4.8 (0.9)	4.6 (1.1)
Height (cm)	181.0 (6.4)	177.9 (7.0)
Weight (kg)	82.7 (13.2)	84.9 (11.3)
Knee MVC (Nm)	161.3 (31.3)	104.3 (25.1)

[a] Education was assessed through a self-report using a scale based answer: four represented completion of college and six represented completion of graduate degree.

approved) (Table 1). Older adults were randomly selected from a database of over 500 older adults (Center on Aging, University of Kansas Medical Center). The young adults were recruited from local staff and students. Exclusion criteria included inability to differentiate green and yellow or read fine print, history of musculoskeletal problems in the legs, cardiovascular illness, neuromuscular deficits, or arthritis in the joints of the tested leg. The groups had comparable height, weight, and education (Table 1). Eighteen young adults and 19 older adults reported being right leg dominant, identified by asking which leg was used to kick a ball. Participants wore shorts and were instructed to relax their arms at their sides and to keep breathing during testing.

2.2. Tasks

Two tasks were used: maximal voluntary contraction and submaximal force control in isometric knee extension (knee joint set at 60° flexion). For the MVC task, participants produced a maximal isometric knee extension in one practice followed by three maximal effort trials, each lasting 5 s with a 15 s rest period between trials. The peak strengths from the three trials were averaged (the coefficient of variation across the three trials averaged 6.2% for the volunteers). For the force control task, participants were instructed to quickly produce and maintain a submaximal force (20% and 60% MVC) within a bandwidth for 8 s. The two force levels corresponded to averages of 32.3 and 96.7 Nm for young adults and 20.9 and 62.5 Nm for older adults. The upper and lower bandwidth limits were defined as the force level ±6.1 Nm. Similar research has previously used discrete bandwidth feedback and employed a fixed tolerance range [24]. Pilot testing indicated that this fixed value allowed participants to accomplish the task with minimal feedback. If the bandwidth is set too narrow, resulting in excessive feedback, performance declines and variability increases [22].

The force control tasks were conducted under two conditions: visual feedback presented throughout the trial or visual feedback presented for the initial 2 s and then removed (Fig. 1). One practice and three trials were completed for each of the four force control tasks (two force levels, two feedback conditions), for a total of 12 analyzed trials, with task order randomized across participants.

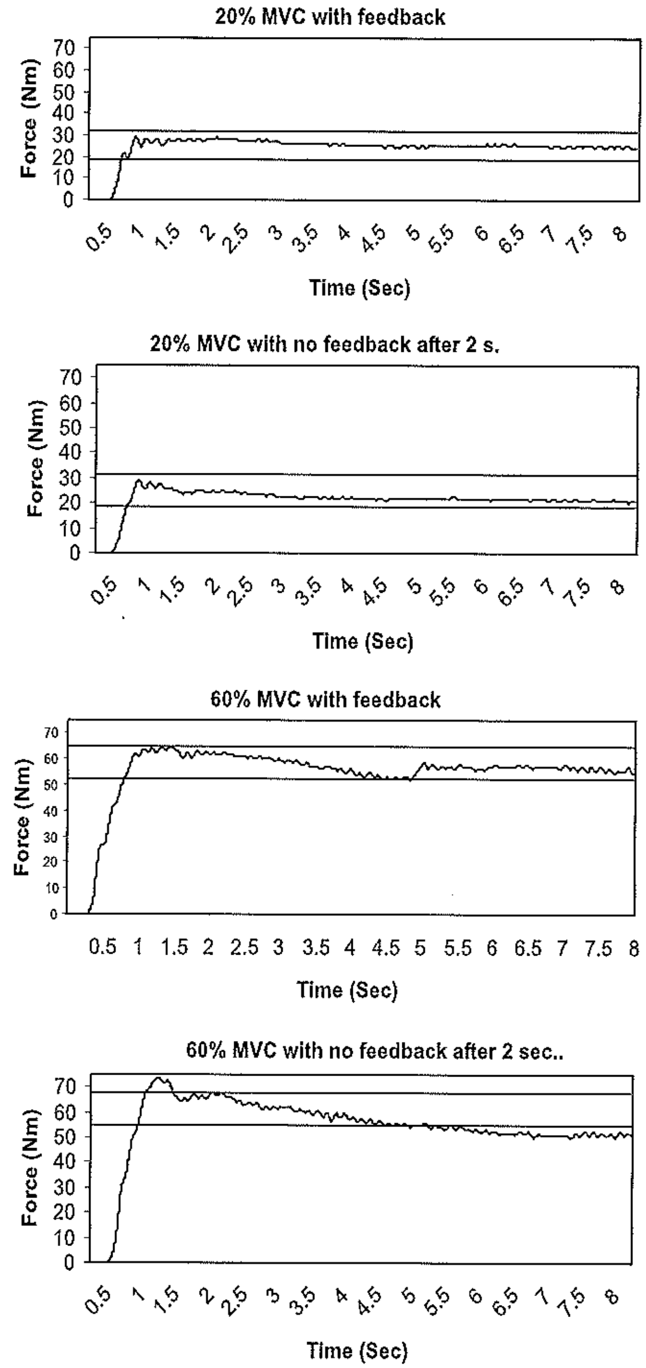

Fig. 1. These plots represent one adult's data across tasks. They serve as examples that illustrate the change in performance across force level and feedback conditions. These sample data do not necessarily reflect typical or average data.

2.3. Data recording and analysis

Strength was measured using the Cybex 6000 isokinetic dynamometer system (Lumex, Inc., Ronkonkoma, New York, USA) interfaced with a computer based data acquisition system as described previously [20]. The data were collected with a microcomputer running LabVIEW 5.0 with a data acquisition board (National Instruments, Austin, TX, USA). The voltage output from the Cybex dynamometer was sampled at 200 Hz, filtered with a low-pass Butterworth filter (cut-off frequency of 10 Hz) and converted to physical units (Nm), eliminating phase shift using forward and backward passes [8].

For all force control tasks, LabVIEW provided visual discrete feedback using a 17-inch computer monitor placed approximately 80 cm in front of the participant at eye level. The on-screen feedback consisted of a green light with "Push more" and a red light with "Push less" above it illuminating whenever force production fell below or rose above the bandwidth limits.

Force variability, bias, and time in bandwidth were computed from the final 6 s of data, representing the steady state portion of the force control task. Force variability was calculated as the force signal standard deviation. Bias was the average difference between the force produced and the midline of the bandwidth. Time in bandwidth was calculated by summing the time spent successfully in the bandwidth.

2.4. Statistical analysis

Using SPSS 9.0 (SPSS Inc., Chicago, Illinois, USA), the effect of age (young adults and older adults), force level (20% and 60% MVC), and feedback condition (with feedback and no feedback) on force control abilities was determined using a three-way multivariate analysis of variance (MANOVA) (age × force × feedback) on the three-trial average of the dependent variables of force variability, bias, and time in bandwidth. A p value of less than 0.05 was considered significant. Reliability on the force control variables has been previously reported [20].

3. Results

For the MANOVA, significant main effects were found for age, force, and feedback and significant interactions for age × force and feedback × force (Table 2). Therefore, follow-up ANOVAS (Table 3) were conducted with type I error controlled with the Holm's sequential Bonferroni method. Observed power is also reported [25].

Table 2
Multivariate analyses evaluating the effects of age, force (20% versus 60%), and feedback on force variability, bias, and time in bandwidth

Effect	p value	F^a	Wilks' Λ	Multivariate η^2	Observed power
Age × force × feedback	0.914	0.174	0.997	0.003	0.082
Age × feedback	0.076	2.34	0.955	0.045	0.579
Age × force	0.001*	6.08	0.892	0.108	0.957
Feedback × force	0.000*	24.09	0.675	0.325	1.000
Age	0.000*	8.06	0.861	0.169	0.990
Force	0.000*	61.50	0.448	0.552	1.000
Feedback	0.000*	63.28	0.441	0.559	1.000

*Significant at $p < 0.05$.
[a] df = (3, 150).

Table 3
ANOVA evaluating the effects of age, force (20% MVC vs. 60% MVC) and feedback on force variability, bias, and time in bandwidth

Variable	Effect	p value	F^a	η^2	Observed power
Force variability					
	Age × force	0.002*	9.74	0.060	0.873
	Feedback × force	0.170	1.90	0.012	0.278
	Age	0.000*	16.69	0.099	0.982
	Force	0.000*	163.22	0.518	1.000
	Feedback	0.038	4.38	0.028	0.548
Bias					
	Age × force	0.110	2.58	0.017	0.358
	Feedback × force	0.000*	46.70	0.235	1.000
	Age	0.000*	13.77	0.083	0.958
	Force	0.000*	75.68	0.332	1.000
	Feedback	0.000*	65.18	0.300	1.000
Time in Bandwidth					
	Age × force	0.748	0.103	0.001	0.062
	Feedback × force	0.000*	46.95	0.236	1.000
	Age	0.055	3.74	0.024	0.485
	Force	0.000*	99.13	0.395	1.000
	Feedback	0.000*	153.5	0.502	1.000

*Significant at $p < 0.05$ and after correction for Type I error using Holm's sequential Bonferroni method.
[a] df = (1, 152) for interaction effects and df = (1, 78) for main effects.

3.1. Force variability

As force increased, variability increased for both groups, with young adults having greater increases in variability. The interaction of age × force was significant (Fig. 2). Follow-up ANOVAS indicated force variability significantly increased with increases in force for young adults ($F(1,78) = 115.7$, $P < 0.05$, observed power = 0.10) and for older adults ($F(1,78) = 49.5$, $P < 0.05$, observed power = 1.00). Variability was significantly higher for the young adults, compared to older adults at the 60% MVC ($F(1,78) = 14.3$, $P < 0.05$, observed power = 0.96), but not at 20% MVC ($F(1,78) = 2.1$, $P = 0.147$, observed power = 0.30). The main effect of feedback on variability was not significant after correcting for type I error and the mean values for the feedback and feedback-removed condition were 1.55 (1.18) and 1.85 (1.46) Nm, respectively.

3.2. Bias

Increase in age, decrease in force level, and presence of feedback resulted in significantly less bias away from bandwidth midline (Fig. 3). The feedback × force interaction was significant (Fig. 4). Bias was larger with an increase in force for the feedback condition ($F(1,78) = 7.771$, $P < 0.05$, observed power = 0.78) and for the feedback removed condition ($F(1,78) = 59.6$, $P < 0.05$, observed power = 0.43). Bias was equivalent across feedback conditions at 20% MVC ($F(1,78) = 0.8$, $P > 0.36$, observed power = 0.01). However, at 60% MVC, bias was significantly larger for the feedback removed condition ($F(1,78) = 84.9$, $P < 0.05$, observed power = 0.5).

3.3. Time in BW

Both older adults and young adults spent more time within the bandwidth at 20% compared to 60% MVC and with feedback than without. The follow-up ANOVA

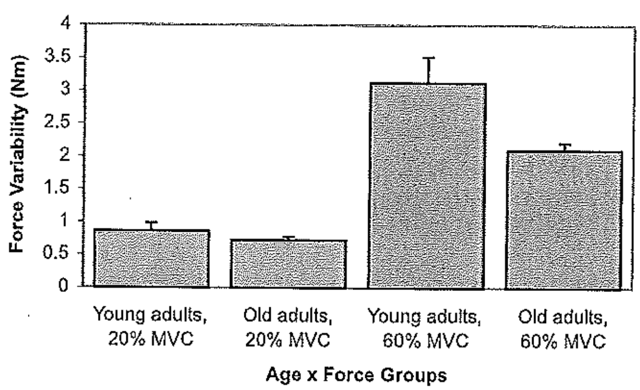

Fig. 2. Age × force effects on force variability, means and standard deviations.

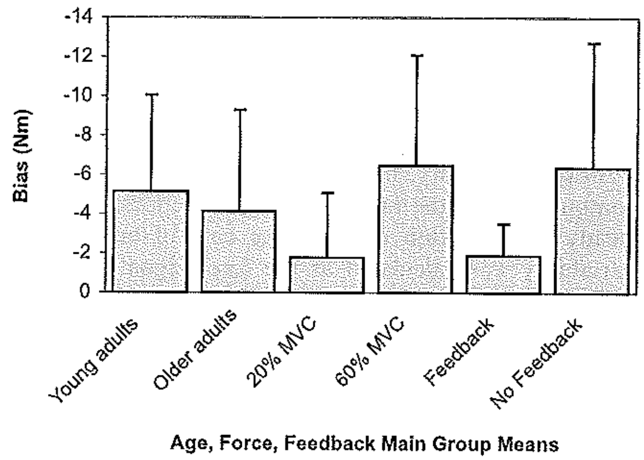

Fig. 3. Age, force, feedback condition main effect means and standard deviations for bias.

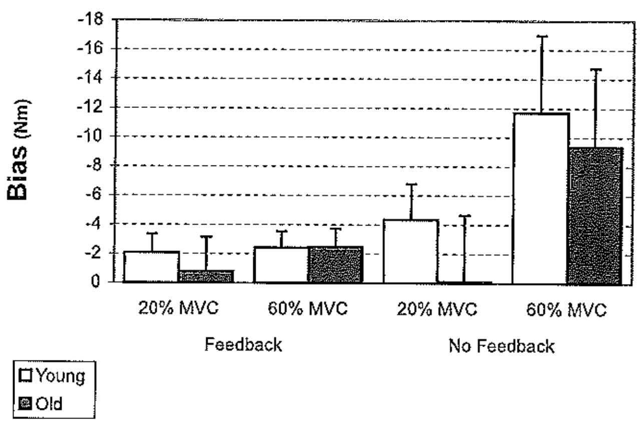

Fig. 4. Feedback × force interaction effect means and standard deviations of bias.

indicated that the feedback × force interaction was significant (Fig. 5). Time in bandwidth decreased as force increased with feedback ($F(1,78) = 49.6$, $P < 0.05$, observed power = 1.00) and without ($F(1,78) = 73.6$, $P < 0.05$, observed power = 1.0). Time in bandwidth decreased in the feedback removed condition at 20% MVC ($F(1,78) = 17.9$, $P < 0.05$, observed power = 1.00) and at 60% MVC ($F(1,78) = 159.6$, $P < 0.05$, observed power = 1.00).

4. Discussion

This study examined the young adults' and older adults' control of submaximal knee extension forces with and without visual feedback. We found that both groups were fairly accurate, particularly at the lower force level. Variability of force output increased with increasing force. While the two groups were equally variable at the low force, the young adults were more

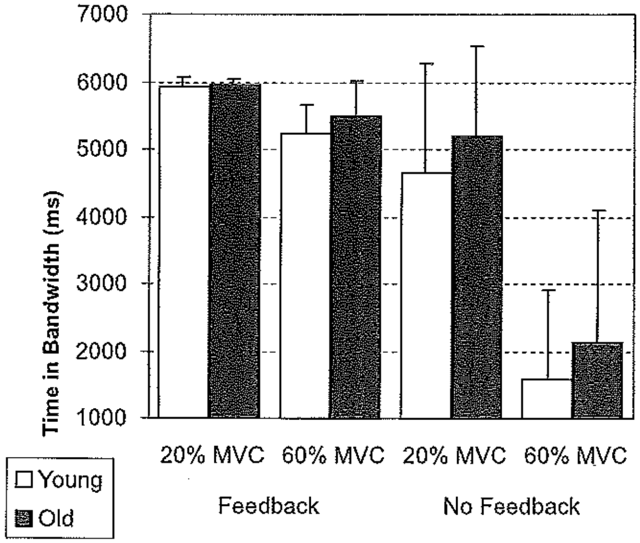

Fig. 5. Feedback × force interaction effect means and standard deviations for time in bandwidth.

variable at the higher force. We had predicted the opposite, that the groups would differ at lower forces where young adults might have recruited relatively smaller motor units than older adults. It may be that the young adults had and subsequently recruited more motor units with larger cell bodies (fast motor units) as compared to the older adults resulting in greater force fluctuations. Aging has been associated with a reduction in fast motor units and as type II motor units denervate, they reinnervate from innervated type I fibers [26]. While larger muscle groups may promote a smoother net force output compared to smaller muscles [14], Graves et al. [15] suggested that the mechanisms of force control in large groups as compared to small groups might be quite different. These mechanisms may be related to the fiber type, the fiber per motor unit ratio, and the muscles being specifically designed to meet requirements for fine motor control [26]. Identification of the recruitment of motor units, the frequency of unit activation, and the type and number of motor units being use during a force control task may help explain age effects seen with large knee extensor muscles.

It is important to note that, although we found statistically different variability between groups at the 60% MVC level, the actual difference was small (1 Nm), suggesting that the two groups actually performed quite similarly. Such a small difference in variability probably has little clinical significance. This is consistent with other research considering the effect of age on submaximal force control by multiple large muscles. For example, no age differences were found in elbow submaximal force control [12,15] or at the knee at 50% MVC [21].

While older adults may have more within muscle force variability [13], young adults may use strategies for the activation of multiple muscles that lead to increased variability. To verify this suggestion, EMG studies of muscle activation are needed, such as Graves, et al. [15] who did find differences in muscle activation between young adults and older adults. Adaptable patterns of muscle activation might be beneficial. For example, movement fluctuations allow systems to change with changes in dynamics [27], and performance variability may provide additional information regarding the interaction of dynamics with the environment [28]. Variability in accomplishing a task might provide information necessary to make performance changes as the internal and external dynamics change. Older adults may be at a disadvantage due age-related decreases in brain dopamine activity which have been correlated with decreases in motor task performance and mental flexibility [29].

The presence of feedback had little effect on variability. Once corrected for type I error, the main effect of feedback on variability (a 0.30 Nm difference between conditions) became statistically non-significant. Previous studies have used continuous visual feedback, consisting of a target force and the produced force continuously displayed. Our feedback was intermittent. The only time our participants received feedback was when they produced forces outside the bandwidth. Therefore, our participants did not observe a target for which to aim nor could they observe their produced force in relation to a target force. Our feedback condition may have been more similar to the "no feedback" than the "continuous feedback" conditions of other studies. Intermittent feedback allows undetected force variations when those forces remain within the bandwidth.

Both groups produced forces that were close to the lower limit of the bandwidth, particularly at the 60% MVC. This might reflect an economy of effort as producing just enough force to accomplish a task saves energy. Producing larger forces than necessary would result in faster energy depletion. The difference between needed force and that produced has been termed the safety margin [23].

The creation of a safety margin also appears to depend on the presence of feedback. It relies on an accurate target force representation in working memory. When feedback is removed, it is probable that the target's mental representation in working memory either decays or, more likely given our task's short duration, is interfered with by incoming proprioceptive and tactile sensations as the participant continues to produce force [30]. The fact that bias became larger without feedback suggests that the force target representation may have become less than the actual target, resulting in lower produced force.

What constitutes "just enough" force differs in the two groups. In other studies of submaximal force control, such as lifting and moving a small box, older adults typically exert more force than necessary to maintain grip on the box [23,31]. It has been suggested that older adults have a larger safety margin because of age-related impairments in tactile and proprioceptive sensation. Therefore we expected, consistent with the results, that the older adults would use more force in our task than the young adults. The young adults produced just enough force to be within the bandwidth, while the older adults produced more force than required. Interestingly, the older adults produced more force than required even when feedback was removed. This suggests that the changes to their target force representations were similar to those of the young adults [32].

At 20% MVC, both groups remained in the bandwidth approximately 99% and 89% of the time, with and without feedback, respectively. For both groups, the higher force (60% MVC) was harder to control, particularly when feedback was absent, as participants remained in the bandwidth about 82% with and 31% without feedback. Interestingly, with feedback at 60% MVC, the young adults, although spending equivalent time in the bandwidth as the older adults, had more variability. Older adults, compared to the young, may have taken longer to respond to the feedback, which may be attributed to the age-related slowing in information processing [33].

Clinical evaluation of force control may be useful for delineating impairments in motor skill and measuring outcomes of intervention programs [2,34]. Providing force control assessments sensitive enough to detect difference is critical to this process. A second step is understanding the normal range of variability under different conditions to allow the detection of true impairments [34]. In addition, the development of efficacious intervention programs is dependent upon an accurate description of the motor impairment. Thus, knowledge of how submaximal force is controlled could lead to modifications to intervention programs that are designed to target problem areas. This study, in conjunction with others in the literature, suggests that many factors, such as the joint tested, age of the person, or feedback condition may affect force variability, one aspect of submaximal force control [11–15,21–24]. Future research should, like Enoka and colleagues [12], compare force variability across several joints, under a variety of feedback conditions, and in a variety of populations. In addition, the relationship of force variability to functional skills, such as fine and gross coordination activities is warranted.

5. Conclusions

In summary, both groups were fairly accurate at accomplishing the task, the higher force was harder to control, and the visual feedback improved performance in terms of time spent in bandwidth and safety margin but had little affect on force variability. Additional study is needed to investigate the appropriate external feedback condition (e.g. no feedback, intermittent feedback, continuous feedback) for assessing submaximal force control ability. Older adults performed with a higher safety margin and less variability. Whether the age group differences are the result of motor unit size and/or muscle recruitment patterns requires further study. Also, further study is needed to determine if and how age-related changes in force control abilities relate to functional abilities.

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