The Motor-Learning Process of Older Adults in Eccentric Bicycle Ergometer Training

Jarno Purtsi, Veikko Vihko, Anna Kankaanpää, and Eino Havas

This study describes the motor-learning process of older individuals during the course of a training intervention on a motor-driven eccentric bicycle ergometer. Seventeen women and 16 men (64 ± 6 yr) took part in a 10-wk training program. Uniformity of force production and consistency of timing were used to describe their motor performance. The results suggested that participants improved the coefficient of variation of peak force during the intervention (measured at the 2nd, 4th, 6th, 8th, 10th, 12th, and the 18th training sessions). They reached a fairly constant level of motor performance around the 12th training session (5 wk). Age and sex affected improvements in the early phases of the learning process to an extent, but the differences diminished by the end of the intervention. These results suggest that the force control of continuous eccentric muscle contractions improves as a result of training in older adults.

Keywords: motor control, force production, improved performance

Strength training has been found to be essential in preventing and delaying sarcopenia—a key component associated with functional impairment and physical inability in older adults (Janssen, Heymsfield, & Ross, 2002)—and may, therefore, enhance quality of life (Barry & Carson, 2004; Hess & Woollacott, 2005; Roth, Ferrell, & Hurley, 2000). However, there is a great demand to find adequate strength-training methods to fulfill the needs of the elderly population (Barry & Carson, 2004).

Eccentric exercise has recently been proposed as a feasible and effective strength training-method for older adults (see Gerber, Marcus, Dibble, Greis, & LaStayo, 2006; LaStayo, Ewy, Pierotti, Johns, Lindstedt, 2003; LaStayo, Reich, Urquhart, Hoppeler, & Lindstedt, 1999; Meyer et al., 2003). It is known to impose a low cost on the cardiovascular system (Bonde-Petersen, Knuttgen, & Henriksson, 1972; Knuttgen & Klausen, 1971; LaStayo et al., 2003; LaStayo et al., 1999; Perrey, Betik, Candau, Rouillon, & Hughson, 2001) and, due to its minimal oxygen demands, may be beneficial and safe for people with cardiovascular problems (LaStayo et al., 2003).
Older people face numerous challenges in learning new motor tasks and acquiring the skills to benefit fully from the technological innovations of rehabilitation and physical exercise methods. An increased knowledge of older adults’ motor learning may contribute valuable information to the promotion of a lifelong active lifestyle.

Learning new motor skills requires cognitive and musculoskeletal adaptations in accordance with the task at hand. Cognitive and musculoskeletal adaptations have been found to diminish with age (see Hess & Woollacott, 2005; Raz, Williamson, Gunning-Dixon, Head, & Acker, 2000; Silsupadol, Siu, Shumway-Cook, & Woollacott, 2006; Walker, Philbin, & Fisk, 1997; Wishart & Lee, 1997). When acquiring new motor skills, older people tend to require more trials and practice than younger participants do (Etnier & Landers, 1998; Smith et al., 2005; Tunney et al., 2003). Information and knowledge about the motor learning and performance of older adults is important in optimizing rehabilitation strategies and exercise programs (Orrell, Eves, & Masters, 2006; van Hedel & Dietz, 2004).

Eccentric-ergometer training is a relatively uncommon, seldom-used training modality; therefore, we have no previous knowledge of its motor-learning processes. Despite some promising results of the benefits of eccentric-ergometer training in everyday life (LaStayo et al., 2003), data are scarce on the process of learning motor skills in the older population. Our goal was to describe the motor-learning processes of older people in eccentric-bicycle-ergometer training and expand the knowledge on motor learning of older adults.

**Methods**

**Participants**

The study was carried out in the LIKES Research Center, Finland. The protocol, approved by the Ethics Committee of the Central Finland Health Care District, adhered to the principles of the Declaration of Helsinki. All the participants completed an informed-consent form, and individuals with restrictive musculoskeletal dysfunction were excluded from the study. From 80 volunteers, 39 participants were drawn randomly for the eccentric-ergometer training group. Three participants were excluded after a medical examination. One participant, experiencing previously diagnosed back pain that increased during training, resigned from the study, and 2 did not complete a sufficient number (18) of training sessions to be included in the data. Altogether, 17 women and 16 men 55–78 years of age completed a minimum of 18 training sessions and were included in the data (see Table 1). Participants

<table>
<thead>
<tr>
<th></th>
<th>Total, N = 33</th>
<th>Women, n = 17</th>
<th>Men, n = 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>63.7 (5.9)</td>
<td>62.8 (5.3)</td>
<td>64.7 (6.5)</td>
</tr>
<tr>
<td>Habitual physical activity, hr/week</td>
<td>5.1 (4.2)</td>
<td>6.3 (5.3)</td>
<td>3.8 (3.8)</td>
</tr>
<tr>
<td>Maximal voluntary isometric knee extension, kg</td>
<td>63.7 (5.9)</td>
<td>62.8 (5.3)</td>
<td>64.7 (6.5)</td>
</tr>
</tbody>
</table>
reported their physical activity—including gardening and household activities—via a questionnaire at the beginning of the study. According to the reports, the participants participated in some kind of physical activity for $5.1 \pm 4.2$ hr/week and represented fairly common and active Finnish older people.

**Eccentric Ergometer**

The frame of the eccentric ergometer was made from the ergometer of a regular recumbent bicycle (see Figure 1). Its pedals rotated in a backward direction, driven by a direct-current (DC) motor and, for safety reasons, only when the participant pressed an on button with his or her right hand. If the on button was released, the ergometer stopped. An instructor supervised the training at all times and could control and adjust the workload and the rotation speed of the pedals. For safety reasons, the eccentric ergometer was set to stop if the expressed torque exceeded the target level by 40%. The seat was adjusted so that the participants were not able to completely straighten their legs, to avoid injury.

**Motor Task**

The task was to resist the movement of the pedals at a preset target load in a constant and precise manner and at a constant preset rhythm measured in revolutions per minute (rpm). The participants received concurrent visual feedback on force production relative to the target peak-force values from simple signal lights. The aim was to maintain a bright-green light-emitting diode (LED). If the produced peak force matched the target level, a green LED lit up and remained bright. The

---

*Figure 1* — Eccentric bicycle ergometer.
cut-off point for the green light was 20% of the target force: If the force was insufficient or the participant’s rhythm was off, the green LED flickered, indicating a need for higher force production. A red LED lit up if the produced force exceeded the target level. The online signal of the produced force on the computer was also visible to the participants to help in accurate timing of peak forces.

Intervention

The exercise intervention consisted of 20 ± 2.5 individually administered, 10- to 20-min training sessions over a 10-week period. The level of performance was analyzed using the coefficient of variation of peak force (CVF) and time (CVt) measured in the 2nd, 4th, 6th, 8th, 10th, 12th, and 18th training sessions. Motor learning occurred as a decreasing value of CV: The lower the CV, the better the performance.

To avoid and minimize muscle soreness, the training began with a very light workload intended to familiarize participants with the eccentric-training modality, after which the training intensity was increased incrementally throughout the intervention. During the first 4 weeks, the participants completed two training sessions per week and thereafter three sessions per week. Training sessions never occurred on consecutive days, and each session consisted of 3-min warm-up sessions and cooldown sessions in which there was no or very little resistance. The workload was adjusted to match each participant’s capabilities using the 6–20 Borg rating-of-perceived-exertion (RPE) scale (Borg, 1998) with a target RPE of 14–15. During the initial phase, which comprised the first six training sessions, three pedal speeds were used, and the focus and instructions were directed mainly at learning skills. After the initial phase, a speed of 60 rpm was added to the training regimen. Three exercise programs aimed at strength gain were varied throughout the remainder of the intervention.

A Servo controller at a 1,000-Hz frequency monitored and maintained a constant pedal speed in rpm by supplying additional power to the motor—which had a 2-ms response time—if the rpm slowed. The relation between the power signal and the force applied to the pedal was confirmed by a calibration measurement (Tolonen, 2005), in which the peak-force value and peak-power signal value were correlated linearly ($r^2 = .99$). The Servo control collected data through voltage and amperage outputs to the computer when force was applied to the pedal. During the training session, the computer collected a parameter describing the force production and drew a real-time image of the force production on a 50-Hz screen. The image was made available to the participants also and operated as a form of concurrent feedback. An AD converter and the Goodstrength program (Metitur Ltd., Palokka, Finland) were used in collecting the data, which were then processed in Microsoft Excel using a sliding average of three consecutive signals (20 ms) to smooth signal variation.

Measures of Motor Performance

Each resistive peak-force value and peak-force time was used for uniformity of force-production analysis, and two indicators of successful performance were applied. The coefficients of variation ($CV = [SD/M] \times 100$) of peak force (CVF) and the accurate timing of peak forces (CVt) were calculated from a 30-s period
of force production at the beginning of the 2nd, 4th, 6th, 8th, 10th, 12th, and 18th training sessions (Figure 2). In each training session, the data were analyzed at speeds of 30, 40, and 50 rpm.

**Calculating the Coefficient of the Variation of Peak Force**

The standard deviation of force \( s_{\text{force}} \) is a statistic that tells how closely the force values are clustered around the mean force \( F_{\text{mean}} \) in a set of data.

CVF is defined as the ratio of the standard deviation to the mean: \( CVF = \frac{s_{\text{force}}}{F_{\text{mean}}} \). This is defined for a nonzero mean only. We report the CVF as a percentage (%) by multiplying it by 100: \( V_{\text{force}} = CVF \times 100 = \left(\frac{s_{\text{force}}}{F_{\text{mean}}}\right) \times 100 \).

In Figure 2, the mean peak force is \( F_{\text{pmean}} = 549 \) N and the standard deviation of peak forces is \( s_{\text{force}} = 34.3 \) N, so \( V_{\text{force}} = \frac{s_{\text{force}}}{F_{\text{pmean}}} \times 100 = \left(\frac{34.3}{549}\right) \times 100 = 6.24 \).

**The Coefficient of Variation of Accurate Timing of Peak Forces (CVt)**

The CV of time is defined as \( CVt = \frac{s_{\text{time}}}{t_{\text{mean}}} \), in which CVt is the coefficient of variation of time, \( s_{\text{time}} \) is the standard deviation of time, and \( t_{\text{mean}} \) is the average time value.

Figure 3 illustrates the same force curve as Figure 2. The average time value, \( t_{\text{mean}} \), is the average time frame between the peak forces of each leg (every other peak is for the left leg and every other for the right leg).

Here, for example, \( t_1 \) might be the time between the first peaks of the left leg and \( t_2 \) the time between the first peaks of the right leg. In this example, \( t_{\text{mean}} = 1.53 \) s and \( s_{\text{time}} = 0.045 \), so \( V_{\text{time}} = CVt \times 100 = \left(\frac{0.045}{1.53}\right) \times 100 = 3.0 \).
Reliability of CVF and CVt

The reliability of the CVF and CVt was confirmed using the test–retest method and analyzing data in two separate 30-s periods at 40 rpm from the final training session. The Pearson correlation coefficient for the two periods of CVF was .951 and for CVt it was .72.

Statistical Analysis

The results are presented using CV as $M \pm SD$. Mean percentage change in CV compared with baseline (Trial 2) was calculated for each trial (Table 2). Motor learning was investigated by comparing the CVs in the 2nd, 4th, 6th, 8th, 10th, 12th, and 18th training sessions. The CVF was adjusted for the operational force level using curvilinear-regression analysis, before we tested the statistical significance of change over trial (the training session) to subtract the effect of increasing operational force levels. The coefficient of determination $R^2$ was calculated to evaluate the goodness of fit.

Separate analyses of the adjusted CVF and the CVt were performed using repeated-measures analysis of covariance, with trial and pedaling rate as the within-participant factors and gender as the between-subjects factor. The age range of the participants, 55–78 years, was taken into account. The age was centered when used as a covariate for the analysis. Similarly, the isometric maximal-force spread (245.5–811 N) was taken into account, and this variable was centered when used as a covariate. The analysis of the adjusted CVF was controlled for centered age, and the analysis of the CVt was controlled for centered age and for the centered isometric maximal force. If the assumption of sphericity was violated strongly (the coefficient of correction $\varepsilon < .75$), $p$ values for Greenhouse–Geisser-corrected
<table>
<thead>
<tr>
<th>Trial</th>
<th>30 Revolutions/Min</th>
<th>40 Revolutions/Min</th>
<th>50 Revolutions/Min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women, n = 17</td>
<td>Men, n = 16</td>
<td>Women</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28.32 ± 7.79</td>
<td>32.88 ± 12.74</td>
<td>26.41 ± 8.00</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>4</td>
<td>22.71 ± 11.75</td>
<td>25.29 ± 7.92</td>
<td>23.09 ± 13.21</td>
</tr>
<tr>
<td></td>
<td>(–19.81)</td>
<td>(–23.08)</td>
<td>(–12.57)</td>
</tr>
<tr>
<td>6</td>
<td>21.38 ± 12.21</td>
<td>19.48 ± 6.71</td>
<td>19.97 ± 8.59</td>
</tr>
<tr>
<td></td>
<td>(–24.50)</td>
<td>(–40.76)</td>
<td>(–24.38)</td>
</tr>
<tr>
<td>8</td>
<td>20.25 ± 8.42</td>
<td>14.64 ± 5.48</td>
<td>16.32 ± 5.94</td>
</tr>
<tr>
<td></td>
<td>(–28.51)</td>
<td>(–55.49)</td>
<td>(–38.21)</td>
</tr>
<tr>
<td></td>
<td>(–39.70)</td>
<td>(–56.02)</td>
<td>(–37.27)</td>
</tr>
<tr>
<td></td>
<td>(–49.19)</td>
<td>(–56.33)</td>
<td>(–50.09)</td>
</tr>
<tr>
<td>18</td>
<td>12.57 ± 4.00</td>
<td>10.85 ± 3.26</td>
<td>10.41 ± 2.12</td>
</tr>
<tr>
<td></td>
<td>(–55.61)</td>
<td>(–66.99)</td>
<td>(–60.60)</td>
</tr>
<tr>
<td>Trial</td>
<td>30 Revolutions/Min</td>
<td>40 Revolutions/Min</td>
<td>50 Revolutions/Min</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------</td>
<td>--------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td></td>
<td>Women, n = 17</td>
<td>Women, n = 16</td>
<td>Women, n = 16</td>
</tr>
<tr>
<td>2</td>
<td>8.32 ± 7.04 (0.00)</td>
<td>8.20 ± 4.79 (0.00)</td>
<td>6.50 ± 3.84 (0.00)</td>
</tr>
<tr>
<td>4</td>
<td>5.50 ± 2.12 (–33.85)</td>
<td>5.34 ± 1.92 (–34.93)</td>
<td>6.19 ± 5.65 (–4.78)</td>
</tr>
<tr>
<td>6</td>
<td>4.22 ± 1.44 (–49.28)</td>
<td>3.99 ± 1.23 (–51.38)</td>
<td>4.23 ± 2.12 (–34.93)</td>
</tr>
<tr>
<td>8</td>
<td>3.44 ± 1.23 (–58.63)</td>
<td>3.35 ± 0.75 (–59.20)</td>
<td>3.29 ± 0.76 (–49.31)</td>
</tr>
<tr>
<td>10</td>
<td>3.29 ± 1.45 (–60.49)</td>
<td>3.47 ± 1.25 (–57.69)</td>
<td>2.95 ± 0.97 (–54.59)</td>
</tr>
<tr>
<td>12</td>
<td>2.76 ± 1.05 (–66.89)</td>
<td>3.21 ± 1.15 (–60.93)</td>
<td>2.49 ± 0.79 (–61.75)</td>
</tr>
<tr>
<td>18</td>
<td>2.25 ± 0.83 (–72.97)</td>
<td>2.60 ± 0.72 (–68.37)</td>
<td>1.89 ± 0.66 (–70.90)</td>
</tr>
</tbody>
</table>
degrees of freedom are reported; otherwise the Huynh–Feldt method was used. When a significant interaction among trial, pedaling rate, and covariate was found, the change over trial was analyzed using repeated-measures analysis of covariance separately with each pedaling rate. The $\alpha$ level of significance was set at .05. Eta squared ($\eta^2$) was used to estimate the effect size for each of the effects, $\eta^2 = SS_{effect}/SS_{total}$. All the statistical analyses were performed with IBM SPSS Statistics 19.

**Adjustment of Relative Intensity of Force**

In a steady-contraction (Enoka et al., 2003) and in an eccentric-contraction task (Christou & Carlton, 2002), the force fluctuation and coefficient of variation of force have been found to decrease with contraction intensity. Therefore, we needed to establish that the increasing operational force level was not the reason for the low CVF. To examine whether the increasing force level was associated with the motor-learning process, the coefficient of variation was calculated from three trials (Trials 4, 12, and 18) at low and high force levels.

The data were combined and new data were created. A variable of all the operational-force data and a variable of the corresponding CVF were formed. Curvilinear-regression analysis was used to evaluate the association between these variables. A cubic equation was used to fit the curve, and analysis resulted in the model $y = 36.36688461 - 0.06902620x + 0.00005648x^2 - 0.00000002x^3$, where $x =$ operational force level and $y =$ the CVF (See Figure 4).

The cubic curve expressed better fit to the data than the linear one did. The coefficient of determination $R^2$ equals .47 for the cubic equation and .32 for the 

![Figure 4](image)

**Figure 4** — Curvilinear regression for the combined operational force level data and the coefficient of variation (CV) of force data of Trials 4, 12, and 18.
linear equation. The effect of the force level on the CVF was evaluated with this model (except the constant term), and new variables were calculated for each of seven trials, for example, $\text{CVF}^2 = \text{CVF}^2 - (-0.06902620 \times \text{MeanF}^2 + 0.00005648 \times \text{MeanF}^2 - 0.00000002 \times \text{MeanF}^2^3)$. These residual variables represent the relative variability of force, from which the effect of the force level is eliminated.

A repeated-measures analysis of covariance—with gender as a between-subjects factor, trial and rate as within-subject factors, and centered age as a covariate—was performed on the residual variables. A separate analysis was performed for the CVt: This analysis was similar except that a centered isometric maximal force was used as a covariate in addition to centered age. The age range of the participants (55–78 years) and the isometric maximal-force spread (245.5–811 N) were taken into account in the analysis by centering the covariates.

**Results**

**Variability of Force**

The motor-learning process did not differ under different pedaling rates. The interaction between pedaling rate and trial was not significant, Greenhouse–Geisser corrected $F(5.6, 169.1) = 1.2, p = .38, \eta^2 = .03$. The analysis revealed a significant change in the CVF with trial, Greenhouse–Geisser corrected $F(3.0, 90.3) = 10.7, p < .001, \eta^2 = .22$. There was a significant interaction between centered age and trial, Greenhouse–Geisser corrected $F(3.0, 90.3) = 3.6, p = .02, \eta^2 = .07$. Moreover, a three-way interaction between trial, pedaling rate, and centered age was significant, Greenhouse–Geisser corrected $F(5.6, 169.1) = 3.3, p = .005, \eta^2 = .09$. In other words, the interaction between centered age and trial was not similar under different rates.

Separate analyses under each pedaling rate revealed that the interaction between centered age and trial was significant under the pedaling rate of 30 rpm, Greenhouse–Geisser corrected $F(3.3, 98.2) = 5.6, p = .001, \eta^2 = .11$, and under the rate of 40 rpm, Greenhouse–Geisser corrected $F(3.3, 99.4) = 3.0, p = .03, \eta^2 = .07$. In both cases, participants under the age of 70 improved their results in a more stable way at an earlier stage of training than older participants did (see Figure 5). Their CVF had a decreasing direction after the second or the fourth trial, while participants at the age of 70 or older indicated stable improvement after the fourth or the sixth trial. The CVF stabilized at the end of the intervention, regardless of participant age.

The motor-learning process differed between genders. The interaction between gender and trial was significant, Greenhouse-Geisser corrected $F(3.0, 90.3) = 4.0, p = .01, \eta^2 = .08$. Male participants indicated a stronger decrease in the CVF than female participants until Trial 8 (see Figure 6). The difference between genders diminished at the end of the intervention. Tests of repeated contrasts revealed that the interaction was significant between Trials 4 and 6.

**Variability of Accurate Timing of Peak Forces**

The analysis did not indicate significant interaction between pedaling rate and trial, Greenhouse–Geisser corrected $F(2.7, 78.7), p = .4, \eta^2 = .03$ (Figure 7 and Table 2). The motor-learning process was similar at different pedaling rates.
Figure 5 — Three-way interaction among trial, rate, and centered age on the coefficient of variation of force (CVF). Values are estimated marginal means at the chosen values of covariate.
Analysis revealed significant change in the CVt with trial, Greenhouse–Geisser corrected $F(1.6, 47.4) = 50.0, p < .001, \eta^2 =0.61$. There were no significant interactions among trial, pedaling rate, gender, centered age, and centered isometric maximal force. The CVt was similar at different pedaling rates, Huynh–Feldt corrected $F(2.0, 58.0) = 1.5, p = .2, \eta^2 = .05$ (Figure 7).

Tests of the between-subjects effects revealed that the main effect of age was nearly significant, $F(1, 29) = 4.1, p = .05, \eta^2 = .12$. Older participants exhibited a greater variability of accurate timing of peak forces (see Figure 8).
Figure 8 — The main effect of age under the rates of 30, 40, and 50 revolutions/min (rpm). Values are estimated marginal means at the chosen values of covariate.
Self-reported physical activity did not seem to be connected to the motor-learning process. The assessed time a participant spent on physical activity in hours per week did not correlate systematically with change in the CVF or CVt between adjacent trials.

The results indicated that the participants progressed throughout the intervention and reached a fairly constant level of motor performance before the 12th training session. The entire group improved their CVF and CVt continuously during the course of training. All the participants learned to operate the eccentric ergometer safely in the initial phase of the intervention. However, substantial individual variation in motor-learning processes occurred throughout the intervention.

**Discussion**

In the current study, we characterized the long-term motor-learning processes of older participants in a continuous motor skill using an objective method of measurement. Results showed that the force control of continuous eccentric muscle contractions improves as a result of training in older individuals. The control of force variability and accurate timing of peak forces improved with training. The strong curvilinear relationship of the operational force level and the corresponding CVF indicated that a higher operational force level may in part explain the lower variation in force control. This observation is consistent with the results of Enoka et al. (2003) and Christou and Carlton (2002), who state that force fluctuation decreases with contraction intensity. However, by itself, the operative force level did not explain the uniformity of force production in this study; the more evident explanation was the motor learning that occurred throughout the intervention. The participants reached a fairly constant level of motor performance around the 12th training session. There were some differences in the motor-learning process. Age and gender appeared to explain some of the differences in motor-learning processes in the early phases of the intervention.

None of the participants had any previous experience of eccentric-bicycle-ergometer exercise, which they found very different from their usual physical activities. Physiologically, eccentric-ergometer training resembles stair descent. When descending stairs, one resists gravity at the level of one’s body weight, producing force while the muscles lengthen; eccentric work controls the momentum. In eccentric-ergometer training, the participant resists the movement of the pedals by producing force, resulting in an eccentric lengthening of the quadriceps muscles (LaStayo et al., 2003). In eccentric-ergometer training, the two measures of motor control were adjusted to individual capabilities, offering an objective measure of motor learning.

Although concentric and eccentric contractions are produced by the same muscles, their force production differs in many ways. According to Enoka (1996), eccentric contractions require unique activation and control strategies from the nervous system. Recent studies have shown that eccentric movements are more difficult to control than concentric movements (see Christou & Carlton, 2002; Fang, Siemionow, Sahgal, Xiong, & Yue, 2001, 2004). Greater force fluctuations and movement variability have been found in eccentric contractions (Hortobagyi, Tunnel, Moody, Beam, & DeVita, 2001; Tracy, Byrnes, & Enoka, 2004; Tracy & Enoka, 2002). These findings also imply that motor skills that require eccentric muscle contractions may be more challenging to learn.
Christou and Carlton (2002) discovered that force control declines in older people in rapid discrete contractions but not in slow continuous movements. In addition, it has been found that movement control is reduced with increases in speed and complexity of movement. We did not see any difference in performance between different pedaling rates in rpm, and movement speed did not have an effect on performance level. The results suggest that during a 10-week intervention older people can improve force control of the lower limbs and thus prevent and slow the normal effects of aging in muscle control.

One main component of eccentric-ergometer training is force control and adjustment. While that is not the only aspect of successful performance, force-fluctuation studies may provide some perspective on the current results. Three studies on force-fluctuation improvements in the quadriceps femoris (Hortobagyi et al., 2001; Tracy et al., 2004; Tracy & Enoka, 2002) concluded that older individuals can decrease force fluctuations in eccentric and concentric muscle contractions but not in isometric contractions. Bellew (2002) found that a high-intensity strength-training program improved the maximal knee-extension strength of older people but was ineffective in improving submaximal isometric force control. In addition, Hortobagyi et al. found that eccentric contractions were considerably more difficult for older participants to control than concentric contractions. The current results are consistent with studies on force-fluctuation improvements of older participants in eccentric contractions (Kornatz, Christou, & Enoka, 2005; Laidlaw, Kornatz, Keen, Suzuki, & Enoka, 1999; Tracy et al., 2004). In the current study, the participants were 55–78 years of age. A higher age appeared to predict slower learning, especially in the control of force variability.

Tracy et al. (2004) reported improvements of older adults in force fluctuations of anisometric contractions in a knee-extension task during 8 weeks of training; participants completed 24 training sessions with no further improvement at the end of a 16-week study. In our study, improvement of skill levels appeared to plateau for most participants around the 12th training session. Training with the eccentric bicycle ergometer demands task-specific elements other than force control. The other main component is the accurate timing of peak forces, which, in this study, seemed unaffected by age. The relative variability seemed to get slightly lower as pedaling rate was raised, but the effect of pedaling rate was not significant. The sample size may have limited the statistical power of our study, and the possibility of Type II error cannot be excluded.

Progression in motor learning occurred at different phases of the intervention for women and men. Men progressed slightly more in the early phases of the study and reached their best performance level earlier than women. Similar gender differences were found in learning a juggling task, in which men improved their performance to a higher degree than women did in the early phase of the study, and women improved their performance to a higher degree than men did in the latter phase (Voelcker-Rehage & Willimczik, 2006). Regardless of the different motor-learning processes in the current study, both groups achieved the same skill level by the final training session.

In this study, women appeared more hesitant than men to produce high forces and more cautious to monitor their performance early in the study. This observation is supported by the lower force level of women in the second training session and by the higher force level and increased variability in the sixth training session.
Kauranen and Vanharanta (1996) made a similar observation, stating that women were more cautious and performed slower hand and foot movements than men of all age groups.

Several studies have compared the motor learning of older and younger participants or examined age-related differences in the motor-learning process. Most studies have reported motor learning to be slower for older adults, accompanied with a poorer performance level in various tasks (see Etnier & Landers, 1998; Raz et al., 2000; Shea, Park, & Braden, 2006; Smith et al., 2005; Tunney et al., 2003; van Hedel & Dietz, 2004; Voelcker-Rehage & Willimczik, 2006; Wishart & Lee, 1997). Motor-learning abilities seem to diminish with age (Raz et al., 2000; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002). In this study, we examined motor learning in older participants to see if the age-related difference was evident in older age groups. The younger participants improved their performance in earlier phases of the study, whereas the older participants did so in the latter phases. At the end of the study, the skill level was similar for all the ages. This suggests that motor learning might take longer and require more training sessions for older adults but that they seem capable of improving their performance with training and of achieving a constant skill level in a demanding motor task. The age effect was more evident in the control of force variability than in accurate timing of peak forces.

In this study, self-reported physical activity (hours per week) was not connected to the motor-learning process and did not explain differences in motor learning. Etnier, Romero, and Traustadottir (2001) noted that good physical fitness has a positive relation to motor learning. While this study did not assess actual physical fitness in relation to motor learning, the results did not show that physical activity positively affected the motor-learning process. Self-reported habitual physical activity may also be compromised by social-desirability bias and therefore not the best indicator for this study.

The results of this study provide new information on motor learning of older adults and a detailed description of the learning process with an eccentric bicycle ergometer with two objective measures of motor performance. The information gained from this may be important when conducting motor-skill-acquisition and physical activity programs for older people.

**References**


Tracy, B.L., & Enoka, R.M. (2002). Older adults are less steady during submaximal isometric contractions with the knee extensor muscles. *Journal of Applied Physiology*, 92, 1004–1012. PubMed


