Effect of Arm Cranking Direction on EMG, Kinematic, and Oxygen Consumption Responses

Eadric Bressel¹ and Gary D. Heise²
¹Utah State University; ²University of Northern Colorado

The purpose of this study was to compare muscle activity, kinematic, and oxygen consumption characteristics between forward and reverse arm cranking. Twenty able-bodied men performed 5-min exercise bouts of forward and reverse arm cranking while electromyographic (EMG), kinematic, and oxygen consumption data were collected. EMG activity of biceps brachii, triceps brachii, deltoid, and infraspinatus muscles were recorded and analyzed to reflect on-time durations and amplitudes for each half-cycle (first 180° and second 180° of crank cycle). Kinematic data were quantified from digitization of video images, and oxygen consumption was calculated from expired gases. Dependent measures were analyzed with a MANOVA and follow-up univariate procedures; alpha was set at .01. The biceps brachii, deltoid, and infraspinatus muscles displayed greater on-time durations and amplitudes for select half-cycles of reverse arm cranking compared to forward arm cranking (p < 0.01). Peak wrist flexion was 9% less in reverse arm cranking (p < 0.01), and oxygen consumption values did not differ between conditions (p = 0.25). Although there were no differences in oxygen consumption and only minor differences kinematically, reverse arm cranking requires greater muscle activity from the biceps brachii, deltoid, and infraspinatus muscles. These results may allow clinicians to more effectively choose an arm cranking direction that either minimizes or maximizes upper extremity muscle activity depending on the treatment objectives.

Key Words: upper body exercise, shoulder rehabilitation, biomechanics, hand cycling, electromyography

Arm cranking exercise is often prescribed to patients for the rehabilitation of shoulder injuries and to wheelchair users for propulsion. In the rehabilitation setting, arm cranking helps develop muscular strength, muscular endurance, joint

¹Biomechanics Lab, HPER Department, 7000 Old Main Hill, Utah State University, Logan, UT 84322; ²School of Kinesiology and Physical Education, University of Northern Colorado, Greeley, CO 80631.
range of motion, and cardiovascular endurance (Pollock, Miller, Linnerud, et al., 1974; Sawka, 1986; Walker, Nawag, Wilkinson, et al., 2000). With respect to wheelchair propulsion, researchers have reported that conventional hand-rim propulsion requires more oxygen consumption than arm cranking at comparable work rates (Price & Campbell, 1999; Sedlock, Knowlton, & Fitzgerald, 1990; Tropp, Samuelsson, & Jorfeldt, 1997). Consequently, arm cranking devices have been attached to wheelchairs to increase the mobility and independence of people who lack the use of their lower limbs for locomotion.

In an effort to optimize the usefulness of arm cranking exercise, researchers have examined variations in forearm position (Bressel, Bressel, Marquez, & Heise, 2001), shoulder position relative to the crank axis (Cummins & Gladden, 1983), and cranking patterns such as asynchronous versus synchronous arm motions (Hopman, van Teeffelen, Brouwer, Houtman, & Binkhorst, 1995; Mossberg, Willman, Topor, Crook, & Patak, 1999). A cranking pattern that has received less attention is reverse arm cranking.

Fujii and Nagasaki (1995) examined angular kinematics about the elbow joint during reverse arm cranking to determine whether the pattern of motion was more proficient than forward arm cranking. Using an electrogoniometer attached to the elbow joint, they found that peak joint angular velocities were greater and that accelerations during transitions from pushing to pulling were greater for reverse arm cranking. Based on intrasubject variability of select kinematic descriptors, Fujii and Nagasaki concluded that reverse arm cranking was less proficient than forward arm cranking. They suggested that differences in kinematics may have been related to a decreased coordination of the neuromuscular system in response to the reverse arm cranking pattern.

Researchers comparing the economy (i.e., oxygen consumption at a given submaximal work rate) of reverse arm cranking to forward arm cranking have indirectly supported the results of Fujii and Nagasaki (1995). For example, Danielsson, Grambo, and Wennberg (1980) reported that reverse arm cranking required more oxygen consumption than forward arm cranking at comparable work rates. Their findings were not statistically tested and in fact contradict the data reported by Langbein and Maki (1995), who examined oxygen consumption during reverse arm cranking in a group of wheelchair users. Langbein and Maki’s results indicated that reverse arm cranking may impose a lower oxygen uptake than forward arm cranking during an incremental exercise bout. They explained that reverse arm cranking relies more heavily on the elbow flexors, and thus high-level spinal-cord-injured patients (C5-C6) have an advantage in reverse arm cranking due to a greater capacity for elbow flexion.

Together, these studies imply that during reverse arm cranking either a different coordination pattern was used, or certain upper extremity muscles were activated to a greater extent than in forward arm cranking. However, these studies relied on few participants (Fujii & Nagasaki, 1995, \( n = 8 \); Danielsson et al., 1980, \( n = 4 \)), did not consider the kinematics about the shoulder or wrist joints, and did not record muscle activity responses during the tasks. These limitations prevent a basic understanding of the interrelationships between neuromuscular, kinematic, and oxygen consumption responses from being established.

An understanding of these interrelationships may provide clinicians, and others who use arm cranking exercise, insight into the potential advantages and disadvantages of reverse arm cranking. Therefore, the purpose of this study was to
compare muscle activity, kinematic, and oxygen consumption characteristics between forward and reverse arm cranking exercises. We hypothesized that upper extremity muscles such as the biceps brachii, triceps brachii, deltoid, and infraspinatus would display different activity patterns and amplitudes between forward and reverse arm cranking. These changes in muscle activity would be consistent with observations made for the lower extremity during reverse pedaling (Bressel, Heise, & Bachman, 1998; Neptune, Kautz, & Zajac, 2000; Ting, Kautz, Brown, & Zajac, 1999). We also hypothesized that the unfamiliar motion pattern of reverse arm cranking would lead to kinematic differences without a significant change in oxygen consumption between conditions.

**Methods**

Twenty physically active able-bodied men from a university volunteered to take part in this study. They were free of pain, had no impairments to the active segments, and had minimal experience at forward and reverse arm cranking. All participants signed an informed consent form approved by the institution’s ethics committee. Their physical characteristics were as follows (mean ± SD): age 30 ± 7 years; mass 77 ± 13 kg; height 2.0 ± 0.1 m.

During a single test session the participants engaged in one continuous 5-min exercise bout for each direction of arm cranking (forward and reverse) using the experimental setup shown in Figure 1. For each exercise bout they arm-cranked a Monark ergometer (881E; Monark-Crescent AB, Varberg, Sweden) using a bilateral reciprocal motion at an external work rate of 25 W and maintained a cadence of 60 rev/min with feedback from a metronome. The work rate was chosen for comparative purposes (Bressel et al., 2001) and to reflect the loads typically encountered during rehabilitation (Langbein & Maki, 1995). The two exercise bouts were separated by a 10-min rest period and were performed in random order. All participants warmed up prior to testing by arm cranking at their own chosen intensity. During the warm-up, verbal encouragement was given to help them maintain smooth arm cranking while they cranked for 3 min in both the forward and reverse directions.

The participants’ seating position in relation to the ergometer was the same for each condition. Crank axis height was positioned at shoulder level and each participant’s distance from the ergometer was set according his own preference. Participants used a pronated handgrip position with standard horizontal pegs. The Monark ergometer was calibrated prior to each test session.

Electromyographic (EMG) signals were recorded using Ag-AgCl bipolar surface electrodes, which contained preamplifiers (35 x) potted in plastic enclosures (Therapeutics Unlimited, Iowa City, IA). The electrode configuration included an inter-electrode distance of 22 mm and an electrode diameter of 8 mm. The surface electrodes were positioned on the skin over the midline of the muscle belly. The following muscles of the left upper extremity were monitored: biceps brachii, long head of triceps brachii, middle deltoid, and infraspinatus. These muscles were selected so as to allow comparisons with previous work (Bressel et al., 2001). Electrode sites were determined using a systematic approach described by Cram and Kasman (1998). To ensure high fidelity of the EMG signal, standard procedures were used to affix the electrodes to the skin (Cram & Kasman, 1998). A common reference electrode was placed on the lateral malleolus of the right leg.
To assure that the affixed electrodes were not detecting cross talk, we conducted muscle function tests on all participants using standardized manual muscle testing techniques as described by Kendall, McCreary, and Provance (1993).

Sagittal plane motion of the left upper extremity was recorded for each 5-min exercise bout with a video camcorder (Panasonic AG-188U; 60 Hz with a shutter speed of .002 s) placed at a distance of 5.8 m from the object points and at a height of 0.8 m from the floor. The video camera was zoomed in so that the image of the left upper extremity was as large as possible. Reflective markers were applied to the following locations to aid in subsequent digitizing: distal head of fifth metacarpal bone, styloid process of ulna, lateral epicondyle of humerus, and lateral aspect of acromion process. We tested the sagittal plane assumption during pilot testing by conducting 2-D sagittal, frontal, and transverse plane assessments of the shoulder joint during forward and reverse arm cranking. The analysis included two participants and indicated that nonsagittal plane ranges of motion were
usually less than 20°. Note that this would result in possible errors of less than 3% in our kinematic measurements.

The crank arm position with respect to the ergometer was monitored with a photocell-based event marker system. As the left crank arm passed through top dead center of the crank cycle, a light-emitting diode was illuminated in the field of view of the video camcorder and a 30-ms voltage pulse was transmitted to a computer that allowed for synchronization of EMG data, crank arm position, and motion analysis data. A 0° crank arm position was defined as horizontal and away from the participant (Figure 1). Crank angles were positive in the direction of motion regardless of cranking direction. This coordinate system was used so that crank angles between 0° and 180° corresponded to elbow flexion while crank angles between 180° and 360° corresponded to elbow extension for both forward and reverse arm cranking.

During the last minute of each exercise bout, 5 sec of EMG and event marker data were collected using a microcomputer. The analog signals were amplified using an EMG-67 processor (Therapeutics Unlimited) with adjustable gains in steps between 1k–50k with a bandwidth of 20–4000 Hz. The common mode rejection was 87 dB at 60 Hz and the input impedance was greater than 15 MΩ at 100 Hz. The amplified signals were sampled at 1,000 Hz with an analog-to-digital expansion board (MetraByte DAS-1400, Keithley Instruments, Inc., Taunton, MA) and subsequently used for analytical procedures.

A computerized on-line metabolic measurement system (SensorMedics) calculated oxygen consumption (VO₂ L·min⁻¹ STPD) every 30 sec via open-circuit spirometry. Calculations were made from expired gases taken from participants breathing through a two-way valve mouthpiece (Hans Rudolph, Kansas City, MO). Before each testing session, O₂ and CO₂ analyzers were calibrated with known gas mixtures and the pneumotach was calibrated with a 3-L syringe. The VO₂ measures were averaged over the last 2 min of each 5-min exercise bout.

EMG data were full-wave rectified and low-pass filtered (cutoff frequency = 15 Hz). Muscle onset and cessation were identified using an interactive computer graphics program that plotted the linear envelopes of the EMG signals for each participant. Muscle onset and cessation were identified from prominent bursts of activity within a cycle of data (0 to 360°). Researchers have suggested that this visual determination method allows the experimenter to utilize the pattern recognition capabilities of the human brain and may be more desirable than automated analyses based on absolute thresholds (Hodges & Bui, 1996; Walter, 1984). On-time durations and EMG amplitudes were quantified from the temporally analyzed EMG data for each half-cycle (i.e., 0–180° = first half-cycle and 180–360° = second half-cycle; Figure 1). Muscle on-time duration was calculated as a percentage of the half-cycle while the mean amplitude (or activity) was calculated by integrating the linear envelope of each half-cycle and dividing the value (mV·s) by the on-time duration for that half-cycle (mV). Mean amplitudes were not normalized, given the within-subject design of this study. On-time durations and amplitudes were averaged over three complete cycles.

Kinematic data were based on a 2-D, three-segment model of the left arm (see Figure 1). To fully describe the motion differences between arm cranking directions, we calculated angular displacements, velocities, and accelerations. The motion descriptors were calculated from coordinate data taken from the digitization of reflective markers using a motion analysis system (Peak Performance Tech-
The digitization process included one cycle of arm cranking (0–360°) for each EMG cycle analyzed for all participants. Coordinate data were smoothed using a 4th-order, zero lag Butterworth low-pass filter. Cutoff frequencies were chosen using the Jackson knee method (Jackson, 1979).

A within-subjects design was employed in which arm-cranking direction (forward and reverse) was the independent variable and EMG, kinematic, and VO₂ measures were the dependent variables. A multivariate analysis of variance (Wilks’ lambda) was initially employed, given the number of dependent variables. If the multivariate test was significant, follow-up multiple paired t-tests (36 total) were then conducted on the individual dependent variables. Mean EMG values were statistically compared between half-cycles of forward and reverse arm cranking and peak angular kinematics (i.e., for flexion and extension about three joints), and VO₂ responses were compared between complete cycles (0° to 360°) of forward and reverse arm cranking. An alpha level of .05 was used to determine significance in the multivariate analysis, whereas an alpha level of .01 was used for the univariate analyses.

**Results**

The multivariate Wilks’ lambda indicated there were differences between arm cranking directions ($p = 0.01$). Follow-up univariate statistics showed that there were significant differences in EMG and kinematic variables.

Muscle activity patterns (linear envelopes) for one cycle of forward and reverse arm cranking are shown in Figure 2. It was observed that by displaying the linear envelopes with representative data of one participant, rather than as the mean of all participants, features of the actual data were not compromised. The muscle activity patterns shown in Figure 2 illustrate some of the amplitude and on-time duration differences reported in Tables 1 and 2, respectively.

The EMG signal of the biceps brachii displayed a similar burst of activity (amplitude) during the first half-cycle of forward and reverse arm cranking, whereas for the second half-cycle a 63% greater amplitude was observed for reverse arm cranking (Table 1). Percent on-time durations for the biceps brachii muscle were significantly greater for both half-cycles of reverse arm cranking compared to forward arm cranking ($p < 0.01$; Table 2).

The triceps brachii muscle exhibited a prominent burst of activity during the second half-cycle of forward and reverse arm cranking (Figure 2). Amplitudes and percent on-time durations for the triceps brachii muscle did not differ between conditions ($p > 0.05$).

The deltoid and infraspinatus muscles displayed distinct phase shifts in response to reverse arm cranking (Figure 2). The deltoid muscle exhibited 53% and 15% greater amplitude for the first and second half-cycles, respectively, of reverse arm cranking compared to forward arm cranking. The percent on-time duration values of the deltoid muscle did not differ between conditions. The infraspinatus muscle displayed a 30% greater amplitude during the first half-cycle and a 33% greater on-time duration for the second half-cycle of reverse arm cranking compared to forward arm cranking (Tables 1 and 2).

Peak angular displacements for the shoulder and elbow joints were not statistically different between conditions, whereas peak wrist flexion values were 9% less for reverse than for forward arm cranking (Tables 3 and 4). The pattern of
Figure 2 — EMG activity patterns (linear envelopes) for one participant during forward and reverse arm cranking. Crank arm defined as 0° when positioned horizontal and away from participant. Crank angles are positive in the direction of motion. Biceps brachii and triceps brachii displayed similar regions of activity between conditions; deltoid and infraspinatus displayed a 180° phase shift in muscle activity during reverse arm cranking.
### Table 1  Mean EMG Amplitudes (±SD) for Both Half-Cycles of Forward and Reverse Arm Cranking

<table>
<thead>
<tr>
<th>Muscle</th>
<th>1st Half-Cycle</th>
<th>2nd Half-Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>77 (29)</td>
<td>74 (28)</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>10 (4)</td>
<td>10 (3)</td>
</tr>
<tr>
<td>Deltoid</td>
<td>14 (6)</td>
<td>30 (14)*</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>19 (7)</td>
<td>27 (12)*</td>
</tr>
</tbody>
</table>

*Significantly different from forward arm cranking condition, \( p < 0.01 \).

### Table 2  Mean % On-Time Durations (±SD) for Both Half-Cycles of Forward and Reverse Arm Cranking

<table>
<thead>
<tr>
<th>Muscle</th>
<th>1st Half-Cycle</th>
<th>2nd Half-Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward</td>
<td>Reverse</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>77 (10)</td>
<td>87 (9)*</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>33 (17)</td>
<td>33 (20)</td>
</tr>
<tr>
<td>Deltoid</td>
<td>54 (15)</td>
<td>61 (13)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>75 (14)</td>
<td>68 (8)</td>
</tr>
</tbody>
</table>

*Significantly different from forward arm cranking condition, \( p < 0.01 \).

### Table 3  Peak Flexion Kinematics (mean ±SD) for Forward and Reverse Arm Cranking Exercise

<table>
<thead>
<tr>
<th>Joint</th>
<th>Displacement (deg)</th>
<th>Velocity (deg/s)</th>
<th>Acceler. (deg/s^2×10^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward</td>
<td>Reverse</td>
<td>Forward</td>
</tr>
<tr>
<td>Wrist</td>
<td>154 (11)</td>
<td>170* (14)</td>
<td>−642 (320)</td>
</tr>
<tr>
<td>Elbow</td>
<td>77 (7)</td>
<td>75 (9)</td>
<td>−331 (88)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>109 (7)</td>
<td>107 (7)</td>
<td>−307 (31)</td>
</tr>
</tbody>
</table>

*Significantly different from forward arm cranking condition, \( p < 0.01 \).
Table 4  Peak Extension Kinematics (mean ± SD) for Forward and Reverse Arm Cranking Exercise

<table>
<thead>
<tr>
<th>Joint</th>
<th>Displacement (deg)</th>
<th>Velocity (deg/s)</th>
<th>Acceler (deg/s²×10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forward</td>
<td>Reverse</td>
<td>Forward</td>
</tr>
<tr>
<td>Wrist</td>
<td>207 (17)</td>
<td>213 (11)</td>
<td>547 (194)</td>
</tr>
<tr>
<td>Elbow</td>
<td>147 (10)</td>
<td>152 (10)</td>
<td>394 (140)</td>
</tr>
<tr>
<td>Shoulder</td>
<td>160 (8)</td>
<td>161 (7)</td>
<td>233 (47)</td>
</tr>
</tbody>
</table>

*Significantly different from forward arm cranking condition, \( p < 0.01 \).

angular displacements for the shoulder and elbow joints for one cycle of forward arm cranking and reverse arm cranking was similar between conditions, yet the shoulder joint values were 180° out of phase (Figure 3). The wrist joint angles exhibited high variability and no clear pattern of motion (Figure 3). Peak angular velocities and accelerations about the wrist, elbow, and shoulder joints did not differ between conditions (Tables 3 and 4). The shoulder and elbow velocity profiles were similar between conditions while the wrist displayed a disorganized velocity profile (Figure 4).

Oxygen consumption responses (VO₂ L·min⁻¹) also did not differ between conditions. That is, VO₂ values (mean ± SD) for reverse arm cranking (1.27 ± .19) were statistically similar to values obtained during forward arm cranking (1.25 ± .23) at comparable work rates \( (p = 0.25) \).

Discussion

The purpose of this study was to compare muscle activity, kinematic, and oxygen consumption characteristics between forward and reverse arm cranking. We hypothesized there would be muscle activity and kinematic differences, with no difference in oxygen consumption between conditions. The results of the study generally supported our hypothesis and showed that the biceps brachii, deltoid, and infraspinatus muscles displayed greater amplitudes and on-time durations for select half-cycles of reverse arm cranking compared to forward arm cranking. Peak wrist flexion was less during reverse arm cranking, and oxygen consumption responses did not differ between conditions.

The EMG findings of this study for the biceps brachii muscle support the contention that reverse arm cranking relies more heavily on the elbow flexors (Langbein & Maki, 1995). If the elbow flexors are more active, some populations may have a greater advantage in using arm cranking as a form of exercise or wheelchair propulsion. For example, patients with C6 level quadriplegia, who have normal motor abilities in the elbow flexors but weakness in the elbow extensors, may be able to arm crank more effectively using the reverse cranking pattern. There have been some clinical observations to support this idea (Langbein & Maki), but future research with spinal-cord-injured populations may be warranted.

Our results suggest the deltoid muscle has increased activity in reverse arm cranking. Researchers have argued that the deltoid muscle closely matches the
Figure 3 — Angular displacement patterns for the wrist, elbow, and shoulder joints during one cycle of forward and reverse arm cranking. Each plot represents the mean ($\pm$ SD) of all participants. Crank arm defined as 0° when positioned horizontal and away from the participant. Crank angles are positive in the direction of motion. Movement patterns for forward arm cranking were nearly identical in the reverse direction with an offset of 180° at the shoulder joint.
Figure 4 — Angular velocity patterns for the wrist, elbow, and shoulder joints during one cycle of forward and reverse arm cranking. Each plot represents the mean of all participants. Crank arm was defined as 0° when positioned horizontal and away from the participant. Crank angles are positive in the direction of motion. Shoulder and elbow velocity profiles were similar between conditions while the wrist displayed a disorganized pattern.
activity profile of the supraspinatus muscle, a rotator cuff muscle not available with surface electrodes (Inman, Saunders, & Abbot, 1944; Kronberg, Nemeth, & Brostrom, 1990; Liu, Hughes, Smutz, Niebur, & Nan-An, 1997; McCann, Wootten, Kadaba, & Bigliani, 1993). The infraspinatus is also a rotator cuff muscle, and in this study exhibited greater on-time durations during the first half-cycle and greater amplitudes during the second half-cycle of reverse versus forward arm cranking. Collectively, these activity profiles of the deltoid and infraspinatus muscles may give clinicians better insight into the arm cranking direction that maximizes rotator cuff muscle activity, which is often the aim of shoulder rehabilitation (Souza, 1994; Wilk, Harrelson, Arrigo, & Chmielewski, 1998).

From our results it appears that the deltoid and infraspinatus muscles displayed their greatest activity during crank angles involving an elevation or upward acceleration of the hand. Because upward motion of the hand occurs at different regions of the crank cycle for each condition, i.e., near 180° in forward arm cranking and near 0° in reverse arm cranking, it is not surprising that the region of peak activity for these muscles was 180° phase-shifted in reverse cranking. Ting et al. (1999) reported a similar 180° phase shift in lower extremity muscles (e.g., biceps femoris and rectus femoris) that contribute to anterior and posterior accelerations of the leg during reverse pedaling. During arm cranking, anterior and posterior accelerations occur during the same region of the crank cycle for each condition. Accordingly, the muscles that contribute to these accelerations, the biceps brachii and triceps brachii, do not exhibit phase shifts, as evidenced by the results of this study.

Angular displacement and velocity patterns in this study for the elbow joint were in agreement with those reported by Fujii and Nagasaki (1995). Fujii and Nagasaki observed a significantly greater peak elbow velocity for reverse versus forward arm cranking and suggested that the greater kinematic value may have been attributed to a less coordinated movement pattern near 0° and 180° of the crank cycle. Our data showed a trend toward greater peak elbow and shoulder velocities for reverse arm cranking that were not statistically significant (p = 0.03–0.06). A post hoc power analysis using means and standard deviations as reported in Table 3 indicated that our sample size was sufficient, as the probability to detect differences was between 80 and 85%. Indeed, more study participants, a less conservative alpha level, or a decrease in measurement variability would likely lead to significant differences.

To explore the contention presented by Fujii and Nagasaki that movement patterns are less coordinated during reverse arm cranking, an elbow-shoulder angle-angle diagram was generated and is shown in Figure 5. In general the curves display similar patterns. The only notable difference, which may not be statistically appreciable, is the smoother curve in forward arm cranking at 0° of the crank cycle (i.e., the transition between elbow extension to flexion). During cyclical activities, a smoother curve often indicates greater coordination between respective joints (Enoka, 2002). Participants may have exhibited less coordination during reverse arm cranking because the motion pattern is less familiar than forward arm cranking. Fujii and Nagasaki suggested that the motion pattern of forward arm cranking is similar to other normal activities such as crawling and pedaling a bicycle, and therefore is more rehearsed than motion patterns of reverse arm cranking.

The oxygen consumption data of this study, which suggested that the economy of propulsion is similar between forward and reverse arm cranking in healthy per-
Effect of Arm Cranking Direction

sons, is consistent with pedaling data reported by Bressel et al. (1998). Our results contradict the findings of Langbein and Maki (1995), who reported greater economy during reverse arm cranking in a group of quadriplegic patients. The discrepancy in results is likely related to the different participant populations used in each study and the greater elbow flexor activity requirements observed in reverse arm cranking. Because EMG data of several muscles examined in this study were greater during reverse arm cranking, oxygen consumption would also be expected to be greater. The inequality of these results suggest that other muscles, not examined in this study, may have been less active during reverse cranking, or that the workload used in this study may not have been great enough to reveal differences in oxygen consumption.

Given the clinical objectives of this investigation, it is important to note that our results are specific to a healthy adult population, average age 30 yrs, under a strict experimental setup that did not consider variations in workload or postural positions relative to the ergometer. We suspect that variations in experimental conditions will likely mimic the muscle activity trends of the lower extremity during ergometer pedaling (Gregor, Broker, & Ryan, 1991) and influence the magnitude of muscle activity, but not the profile or EMG differences between forward and reverse arm cranking. For instance, in a previous study we reported that forearm

---

**Figure 5** — Elbow-shoulder angle-angle diagram of left arm during forward (FC) and reverse arm cranking (RC). Each plot represents the mean of all participants. Diagram shows a smoother curve in forward arm cranking at 0° of the crank cycle, suggesting that participants may have been more coordinated between respective joints during forward vs. reverse arm cranking.
position during forward arm cranking influenced the magnitude of EMG activity of select upper extremity muscle but not the temporal profile (Bressel et al., 2001). However, future research is needed to test variations in experimental conditions, which will ultimately improve the efficacy of arm cranking as a modality for cardiovascular fitness, shoulder rehabilitation, and wheelchair propulsion.

In summary, the results of this study indicate there may be no oxygen consumption or kinematic advantages or disadvantages to using reverse arm cranking exercise. The EMG data of this study showed that the biceps brachii, deltoid, and infraspinatus muscles displayed greater amplitudes and on-time durations for select half-cycles of reverse arm cranking in comparison to forward arm cranking.

References


