The effect of handgrip position on upper extremity neuromuscular responses to arm cranking exercise

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Abstract

The purpose of this study was to determine if handgrip position during arm cranking exercise influences the neuromuscular activity of muscles biceps brachii (BB), lateral head of triceps brachii (TB), middle deltoid (DT), infraspinatus (IS) and brachioradialis (BR). Fifteen participants cranked an arm ergometer using three different handgrip positions (supinated, pronated, and neutral). Electromyographic (EMG) data were recorded from the aforementioned muscles, and relative duration of EMG activation and amplitude were quantified for the first and second 180° of crank angle. EMG measures were analyzed with MANOVA and follow-up univariate procedures; alpha was set at 0.01. The relative durations of EMG activation did not differ between handgrip positions. Muscle IS exhibited 36% less amplitude in the supinated versus neutral handgrip position (second half-cycle), and muscle BR displayed 63% greater amplitude across cycles in the neutral versus supinated and pronated handgrip positions. The greater BR activity displayed in the neutral handgrip position may reflect its anatomical advantage as an elbow flexor when the forearm is in neutral position. Muscle IS exhibited less activity in the supinated position and may be clinically relevant if it allows arm cranking to occur without subsequent shoulder pain, which is often the aim of shoulder rehabilitation. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Upper body exercise; Electromyography; Wheelchair propulsion; Upper extremity rehabilitation

1. Introduction

Arm cranking is an exercise found in a variety of settings including rehabilitation clinics, research laboratories, fitness centers, and Olympic training centers. The modality has been used for cardiovascular fitness, shoulder rehabilitation, and wheelchair propulsion. Since the 1970s, a considerable amount of research has focused on cardiorespiratory responses of arm cranking exercise validating its use as a tool for research and cardiovascular fitness [6,20,26,28]. Conversely, the neuromuscular responses of the task have been given little attention [3,12] and may provide valuable insight into the efficacy of the apparatus.

The neuromuscular response of upper extremity musculature may differ, for example, if the hands are positioned differently on the grips. An examination of arm cranking apparatuses will show that the overall movement trajectories are similar across manufacturers however, the handgrip designs to propel the cranks differ considerably (e.g., Monark and Biodex). Some ergometers come equipped with horizontal pegs allowing for a supinated or pronated handgrip, and others have more vertically oriented pegs that allow for a neutral handgrip position (i.e., between the pronated and supinated positions). The reason for employing different handgrip positions during arm cranking exercise is not well documented and may influence the desired outcome of the task.

Patients with quadriplegia are especially sensitive to hand position for various upper extremity motor tasks. Patients with C6 level quadriplegia are able to propel a wheelchair independently even though they lack muscu-
lar recruitment of the triceps which is a prime mover during wheelchair propulsion [25,27]. The patient achieves this by turning the hand backwards (i.e., into supination) on the push-rim [8] and thrusting the chair forward during the pulling phase of the wheelchair cycle [29]. The change in handgrip position allows the patient to use elbow flexors to perform a pulling action that propels the wheelchair. Considering that push-rim wheelchair propulsion and arm cranking have similar propulsive features, handgrip position during arm cranking may have a large impact on the motor abilities of patients with quadriplegia.

Regarding upper extremity rehabilitation, researchers previously showed that electromyographic (EMG) characteristics of the rotator cuff and other upper extremity muscles are related to shoulder position during upper extremity exercises [1,19,22]. Since handgrip position during arm cranking potentially influences shoulder position, EMG amplitudes from a given muscle may exhibit different values depending on the handgrip position. Knowledge of this information may be used by clinicians to more effectively choose a handgrip position during arm cranking that either minimizes or maximizes upper extremity muscle activity depending on the treatment objectives. In view of the preceding discussion, it was the purpose of this study to determine how handgrip position influences the neuromuscular activity of upper extremity muscles during arm cranking exercise.

2. Methods

2.1. Subjects

Nine male and six female subjects volunteered for this investigation. The participants were recruited from a university campus community. All participants read and signed a consent form approved by the local Internal Review Board outlining the purpose, methods, and risks of this investigation. Participants had the following physical characteristics (mean, ±SD): mass=71.24, ±19.88 kg; height=171, ±5.1 cm; and age=22.6, ±3.1 years.

2.2. Procedures

The subjects attended one test session that was conducted in a 1-h period. Subjects were asked to engage in three arm cranking exercise bouts and to use a different handgrip position for each bout. The three handgrip positions were pronated, supinated, and neutral (Fig. 1), and were randomly assigned. All subjects arm-cranked at each condition for 3 min using a Monark 812E arm ergometer with an external workrate set at 25 W (60 rpm). A metronome was used to maintain the target arm crank rate. The external workrate was chosen for comparative purposes [28,30] and to reflect loads typically encountered during rehabilitation [20] and daily-use wheelchair operation [13,21].

The participants’ seating position in relation to the ergometer was standardized for each condition. Crack axis height was positioned at shoulder level and the distance of the subject from the ergometer was set according to the subject’s preference. Standard horizontal pegs (Monark-Crescent AB, Varberg, Sweden) were employed to accommodate the supinated and pronated handgrip positions and tennis balls enclosed over the ends of the horizontal pegs were used to accommodate the neutral handgrip position. The Monark ergometer was calibrated prior to each test session, and workrates during testing were carefully monitored, and adjusted if necessary to insure equal workloads between conditions.

EMG signals were recorded using silver–silver chloride bipolar surface electrodes, which contained preamplifiers (35×) potted in plastic enclosures (Therapeutics Unlimited, Iowa City, IA). The electrode configuration included an inter-electrode distance of 22 mm and a diameter of 8 mm. The surface electrodes were positioned on the skin over the midline of the muscle belly [9]. No attempts were made to position the surface electrodes over a motor point or innervation zone. The following muscles of the right upper extremity were monitored: short head of biceps brachii (BB), lateral head of triceps brachii (TB), middle deltoid (DT), infraspinatus (IS), and brachioradialis (BR). The DT muscle, which has been shown to reflect supraspinatus activity [1,16,19], and the IS muscle were selected to reflect rotator cuff involvement. As the IS muscle lies deep to numerous other muscles, a systematic approach described by Cram and Kasman [7] was used for positioning the electrode. First, the spine of the scapula and the junction between the medial border and spine of the scapula were located using palpation. The electrode was then placed parallel and approx. 3 cm below the spine over the lateral aspect of the infrascapular fossa. The BB, BR, and TB muscles were chosen as they may have a large impact on motor ability in quadriplegic patients during arm cranking exercise [20,29].

Prior to electrode placement, skin was shaved and cleaned with rubbing alcohol to reduce electrical resistance. Adhesive pads and electrode cream were used to insure good contact of surface electrodes and high fidelity of the signal, respectively. A common reference electrode was placed on the lateral malleolus of the right leg. To identify if the affixed electrodes were detecting “cross talk,” the investigator performed muscle function tests on all participants using standardized manual muscle testing techniques described by Kendall [18]. If an unwanted EMG signal was detected through activation of a nearby muscle of interest, the electrode was repositioned. The number of times an electrode was repositioned during this procedure was negligible.
Top dead center of the crank arm with respect to the ergometer was monitored with a photocell-based event marker system. As the right crank arm passed through top dead center of the crank cycle (0°–360°) a voltage associated with the event marker system was transmitted to a computer and allowed for synchronization of EMG data with crank arm position. During the last minute of each exercise bout, 5 s of EMG and event marker data were collected from a computer. 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 of 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 1000 Hz with an analog-to-digital expansion board (MetraByte DAS-1400, Keithley Instruments, Inc., Taunton, MA) and subsequently used for analytical procedures.

2.3. Data analysis

Raw EMG data were full-wave rectified and low-pass filtered (cut-off frequency=15 Hz). Pilot testing suggested a 15 Hz cut-off frequency would provide sufficient smoothing while maintaining features of the actual data. Muscle onset and cessation were identified using an interactive computer-graphics program that plotted the subjects’ linear envelope of each channel against time. Onset and cessation of each muscle were identified from prominent bursts of activity with respect to event markers. It has been argued by Walter [31] that this method of temporal EMG analysis allows the experimenter “to fully utilize the pattern recognition capabilities of the human brain” (p. 162), and is more desirable than an automated interactive procedure based on absolute threshold. Relative durations of EMG activation and amplitudes for each half-cycle (first 180° and second 180° of crank angle) were quantified from the temporally analyzed EMG data. The relative duration of EMG activation was calculated as a percentage of the half-cycle, and the mean amplitude value was calculated by integrating the linear envelope of each half-cycle and dividing the value (mV s) by the relative duration of activation for that half-cycle (mV) [9].

The relative duration and mean amplitude calculations have been shown in previous research to be valuable measures for assessing the EMG temporal and magnitude responses of muscles during running [15], ergometer pedaling [4], and arm cranking [3] under different experimental conditions. Considering the within-subject design of this study and in view of the limitations of normalizing EMG measures with maximal voluntary contractions (MVC) of the upper extremity muscles [2,10], the amplitude values were not normalized. It was felt the non-normalized amplitude values would have clinical relevance regardless of their relation to MVC. For example, an 11 mV deficit, regardless of whether it is at 1% or 50% of MVC, may be clinically helpful if it allows an individual to arm crank without subsequent shoulder pain.
Table 1
Relative duration of EMG activation (percentage) for the first half-cycle of arm cranking (mean, ±SD)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Pronated</th>
<th>Supinated</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>30.1 (18.5)</td>
<td>31.7 (23.6)</td>
<td>31.1 (22.6)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>34.1 (19.6)</td>
<td>37.5 (20.0)</td>
<td>44.1 (20.6)</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>43.1 (20.5)</td>
<td>39.0 (14.1)</td>
<td>39.4 (14.4)</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>48.7 (9.1)</td>
<td>40.5 (11.7)</td>
<td>44.2 (14.4)</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>52.0 (17.6)</td>
<td>49.4 (21.2)</td>
<td>46.4 (18.1)</td>
</tr>
</tbody>
</table>

2.4. Statistical analysis

The relative duration and mean amplitude values served as the dependent variables and were averaged over three complete cycles for statistical analyses. A multivariate test (Wilks’ Lambda) was employed to determine if the group of dependent variables were different between handgrip positions (i.e., supinated, pronated, and neutral). Next, individual differences among the dependent variables were assessed using a repeated measures analysis of variance (ANOVA). Mauchly’s test of sphericity showed the required assumptions for this test were met (\(\varepsilon=1.0\)). Where main effects were found with the ANOVA procedure, follow-up post hoc comparisons (Newman–Keuls) were performed. The probability associated with a Type I error was set at 0.01 for all observations.

3. Results

The multivariate Wilks’ Lambda indicated there were differences between handgrip positions \((p<0.01)\), and follow-up univariate statistics showed that different handgrip positions did not influence relative duration values (Tables 1 and 2). In contrast, significant differences were found during the comparison of EMG amplitudes \((p<0.01)\).

During the first half-cycle, muscle BR displayed a 52% greater amplitude in the neutral than supinated handgrip position (Table 3). No other differences in the means were found during the first half-cycle when considering the DT, IS, BB, and TB muscles. During the second half-cycle of arm cranking, the IS muscle displayed a 57% greater amplitude in the neutral than supinated handgrip position (Table 4). Additionally, muscle BR exhibited 64% and 73% greater amplitude during the neutral grip position when compared to the supinated and pronated handgrip positions, respectively during the second half-cycle (Table 4). EMG amplitude means for muscles DT, BB, and TB were not different during this phase of the crank cycle.

Muscle activity patterns (linear envelopes) for one cycle of arm cranking in the supinated and neutral handgrip positions are shown in Figs. 2 and 3, respectively. It was observed that by displaying the linear envelopes with representative data of one subject, rather than as the mean of all subjects, features of the actual data were not compromised. The muscle activity patterns shown in Figs. 2 and 3 illustrate some of the main differences reported in mean amplitudes (see Tables 3 and 4). In general, the DT and IS muscles exhibited a region of peak activity (amplitude) during the second half-cycle of arm cranking; whereas muscles BB, BR, and TB displayed a prominent burst of activity near 180° of the crank angle (see Figs. 2 and 3).

Table 3
Mean (±SD) EMG amplitudes (mV) during the first half-cycle of arm cranking

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Pronated</th>
<th>Supinated</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>7.4 (2.7)</td>
<td>6.5 (2.2)</td>
<td>7.1 (3.1)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>11.7 (9.5)</td>
<td>11.2 (8.1)</td>
<td>12.5 (8.1)</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>22.5 (14.1)</td>
<td>22.5 (11.1)</td>
<td>29.8 (16.0)</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>27.8 (19.6)</td>
<td>20.6 (12.5)</td>
<td>31.3 (18.4)</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>23.1 (10.5)</td>
<td>21.6 (12.6)</td>
<td>23.7 (15.2)</td>
</tr>
</tbody>
</table>

\(a\ p<0.01\). Significantly greater than the supinated condition.

Table 4
Mean (±SD) EMG amplitudes (mV) during the second half-cycle of arm cranking

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Pronated</th>
<th>Supinated</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>22.7 (9.9)</td>
<td>19.1 (12.2)</td>
<td>20.4 (11.8)</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>20.6 (11.0)</td>
<td>14.7 (7.1)</td>
<td>23.1 (12.1)</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>32.5 (20.7)</td>
<td>35.9 (17.9)</td>
<td>46.2 (23.7)</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>27.4 (15.2)</td>
<td>28.9 (21.8)</td>
<td>47.4 (21.4)</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>36.3 (14.3)</td>
<td>34.1 (14.0)</td>
<td>33.6 (14.2)</td>
</tr>
</tbody>
</table>

\(a\ p<0.01\). Significantly greater than the supinated and pronated conditions.
4. Discussion

This study tested whether handgrip position during arm cranking influenced EMG characteristics of select upper extremity muscles. The major findings were that muscle BR displayed greater activity for the neutral handgrip condition compared to the other handgrip conditions, and that muscle IS displayed greater activity for the neutral versus supinated handgrip condition. Temporal values, as evidenced by the relative duration activation, were not influenced.

Relative duration and amplitude values of this study for the standard pronated handgrip position were consistent with previous research [3]. Similar relative duration values between the conditions of the present study suggest the neural coordination required to propel the cranks is not influenced by handgrip positions. With respect to the amplitude values, it was not surprising the BR muscle displayed greater activity during the neutral handgrip position considering that anatomically, BR acts most effectively as an elbow flexor when the forearm is in a neutral position [1,17]. A similar amplitude difference may be expected from muscle BB in the supinated versus pronated handgrip positions considering its anatomical
Fig. 3. Representative EMG activity patterns (linear envelopes) for one subject in the neutral handgrip position. Crank arm was vertically oriented at 0° and 360°.

arrangement. Instead, the results of this study suggest the BB may be less influenced by handgrip position compared to muscle BR (see Tables 3 and 4). Under the conditions of this study, the BB may play a coordinating role rather than one involved in propulsion of the crank. Ergometer pedaling studies have suggested that bi-articular muscles, such as the rectus femoris, coordinate movement and mono-articular muscles, such as the vastus muscles generate the propulsive force [11,24]. The same functional difference between mono and bi-articular muscles in the lower extremity may apply to the mono and bi-articular muscles of the upper extremity during arm cranking exercise.

The greater amplitude of muscle IS in the neutral versus supinated handgrip may be related to the degree of shoulder abduction between handgrip positions. Harburn and Spaulding [14] found the degree of shoulder abduction during wheelchair propulsion to influence shoulder muscle activity during the task. For example, a participant exhibiting the least amount of shoulder EMG activity during wheelchair propulsion performed the task with the shoulders adducted whereas a participant dis-
playing shoulder abduction (>70°) throughout the task exhibited the greatest amount of shoulder muscle activity [14]. The relationship between shoulder kinematics and EMG activity found during wheelchair propulsion [14] may apply to arm cranking exercise and explain the decreased EMG activity of muscle IS during the supinated grip condition. Visual inspection of the humerus when the hands are in the supinated versus neutral handgrip position during arm cranking supports this scenario, however kinematic data are clearly warranted. The observation of muscle IS having less activity during the supinated grip condition may be relevant in shoulder rehabilitation. During the early stages of shoulder rehabilitation, painful exercise of the involved tissues is contraindicated [5], and the decreased activity of muscle IS when the forearm is supinated may be helpful if it allows arm cranking to occur without subsequent shoulder pain. In addition, the handgrip position employed by the patient during arm cranking may be used to systematically increase the activity of the rotator cuff muscle IS. That is, patients may begin with the supinated grip position, and then progress to the pronated and neutral grip positions respectively, as more activity occurs with the latter two conditions. Therapeutic exercise involving the different handgrip positions during arm cranking ergometry may ultimately strengthen the rotator cuff, which is a goal of shoulder rehabilitation [5,32].

The results of this study may have practical application to wheelchair bound individuals who use arm cranking as a method of propelling a wheelchair or as a method for improving upper extremity strength and endurance. With the quadriplegic population having limited motor recruitment of select upper extremity muscle groups [8,23,25,29], an outcome of increased motor activity of available muscles, such as from the elbow flexors, is desired if it improves motor performance [14]. The results of this study showed greater activity in muscle BR, an elbow flexor, during arm cranking in the neutral handgrip position. This suggests quadriplegics may propel the cranks of an arm cranking apparatus more easily using the neutral handgrip position in comparison to the supinated and pronated positions.

5. Conclusion

Temporal values, as evidenced by the relative duration of EMG activation, were not influenced by handgrip position and suggest the neural coordination required to propel the cranks is similar between conditions. Muscle BR displayed greater activity in the neutral handgrip position, which may reflect its anatomical effectiveness as an elbow flexor when the forearm is in a neutral position. Muscle IS, a rotator cuff muscle, exhibited less activity in the supinated handgrip position. This may be clinically relevant if it allows arm cranking to occur without subsequent shoulder pain, which is often the aim of shoulder rehabilitation. Further research in this area will need to focus on the shoulder kinematic differences between handgrip positions and other experimental conditions such as workload as the results of this study are only relevant to the workload chosen and may be different at different workloads.

References


Eadric Bressel is an assistant professor in the health, physical education, and recreation department at Utah State University in Logan, UT. He received his B.S. (1994) and M.S. (1995) in exercise science from California State University, Fresno, and he received his Ed.D. in biomechanics from the University of Northern Colorado (1999). His research examines neuromechanical adaptations to therapeutic exercise, anatomical and biomechanical determinants of Achilles tendon rupture, and neuromechanics of cycling. He is a member of the American and International Societies of Biomechanics and of the American College of Sports Medicine.

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Michael Marquez received his B.A. in kinesiology from the University of Northern Colorado in 1999. This paper is the culmination of Michael’s work with Dr Bressel and Dr Heise in the McNair Scholars Program at the University of Northern Colorado. Michael currently is pursuing a Master’s degree in the physician assistant program at the University of Colorado Health Sciences Center in Denver, CO.

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