Linear-elliptical-circular trainer: An apparatus for upper arm strength and co-ordination training

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Abstract

We have developed a novel arm cycling device that enables nine different movement modalities/trajectories ranging from purely circular trajectory to four elliptical and four linear trajectories where the direction of movement may be varied. Muscle synergies were assessed in a group of healthy individuals in the form of electromyographic activity of four selected muscle groups of the shoulder and the elbow. The results have shown that muscle synergies during elliptical and even more so during linear movement modalities considerably differ from purely circular trajectories. This implies that such a device may significantly extend the scope of strength and coordination training which is in current clinical practice done through arm cycling.

1 Introduction

Arm strength and co-ordination training in clinical practice is usually exercised with the help of arm cycling devices that can provide circular, reciprocal movement of upper extremities, supported through assistive or resistive action of a motorized crank (1,2). While such a movement is beneficial it is also constrained only to circular paths of both hands thus promoting single mode of movement requiring rather simple muscle synergies. He hypothesize that more elliptical or even linear cycling movement where also the direction of movement may be varied would promote development of various upper-arm muscle synergies that may be closer to those observed in functional reaching movement.

2 Methods

2.1 Apparatus

We have developed an innovative kinematic linkage, using a planetary gearing concept, which is capable of transforming circular crank movement into circular, elliptical or linear movement of hand handle. Figure 1 shows kinematics of the conceived mechanism. The main idea is to couple the planetary disc onto which a hand handle may be attached at nine different locations with the movement of the crank, which is motor driven. This coupling is such that the orientation of the planetary disc and the orientation of the motor axis are kinematically coupled through the chain running around the motor axis sprocket on one end and the planetary disc sprocket on the other end. Figure 1 shows one possible mechanical solution, which is however not very practical because of the size of the planetary disc. Equivalent trajectories may be obtained also by reducing the radius of the planetary disc, however in this case the point of attachment of the planetary disc onto the crank on one side and the point of attachment of the hand handle on the other side must be appropriately selected as shown in Figure 2. In total nine different movement paths can be selected: circular, elliptical with four different movement directions of the elliptic long axis (vertical, horizontal, diagonal-up, diagonal-down) and linear with the same four movement directions as in elliptical mode. The device is motor-driven and may assist in movement or can provide resistance.

2.2 Measurement protocol and data processing

The device was evaluated in a group of four healthy individuals performing reaching movements with their arms while driving the trainer in nine different configurations - modes (circular, four elliptical and four linear) where we assessed and compared electromyographic (EMG) activity of selected four muscle groups bilaterally: anterior deltoid, medial deltoid, biceps and triceps. The EMG electrodes were positioned over the
palpated muscle bellies, the area underneath the electrodes was properly cleaned and the electrical impedance was checked to assure optimal EMG recordings. The sampling frequency was set to 1 kHz. EMG signals processed as follows: de-meaning of the raw signal, band pass filtering (20 – 300 Hz), notch filtering (49-61Hz), full-wave rectification, and moving average window filtering (150 ms). All EMG signals were normalized to the maximal value for each particular muscle group when performing movement in the “circular” mode.

Each individual first performed one-minute warm-up movement in order to familiarize with the required movement demands (Figure 3). After this initial period assessment of EMG signals followed for approximately one minute of cyclical, reciprocal arm movement while holding onto the handles of mechanical apparatus in each of 9 different movement modes (always in the same order of repetition): circular, elliptical-horizontal, linear-horizontal, elliptical-vertical, linear-vertical, elliptical-up, linear-up, elliptical-down and linear-down. During the assessment period approximately 25 cycles were repeated by each individual. The THERA-Vital controller/display (medica Medizintechnik Gmbh, Hochdorf, Germany) was used to control the electrical motor. The frequency of movement was set to 20 repetitions per minute while the resistance was set to level 5 as indicated on the display. All subjects were instructed to maintain the power of movement around 10 W as indicated on the display in order to assure comparable testing conditions. For each subject the last 10 full-cycle repetitions were selected for averaging. Finally, group mean and standard deviations were calculated by taking average values of each individual subject for each of nine movement modes.

Figure 1. Kinematical and mechanical concept of linear-elliptical-circular trainer.

Figure 2. Nine different movement directions depend on the position and orientation of planetary disc with respect to the driven crank on one side and the position of attachment of the hand handle.
Figure 3. A photograph of a subject during movement exercise on the developed prototype of linear-elliptical-circular trainer.

3 Results and discussion

Figure 4 shows the mean values and standard deviations of EMG of the selected four muscle groups on the left arm for all nine movement modalities. As we were interested in the comparison between the muscle synergies between circular and all other elliptic/linear movement a coefficient of correlation was calculated. Also, correlation between the corresponding EMG responses on the left and the right arm (one being first shifted for 50% of movement cycle) was calculated. The general impression when looking at the EMG activities is that the activity of left and right arm is almost identical when a phase shift of 50% is taken into account. This was expected and holds for all nine movement modes. Also when observing only circular movement it is apparent that both elbow antagonists (biceps and triceps) are perfectly out of phase when observing their activity on the same arm and perfectly in phase when observing their activity at both arms.

Activity of both deltoid muscle groups is similar to activity of triceps. However, when comparing activities of all muscle groups among different elliptical/linear movement modes and circular movement mode it is apparent that considerable differences exist in muscle synergies. The general impression is that there exist movement modes where for example some muscles that are active in the circular mode are quiet (most obvious example is biceps in linear-up movement mode or anterior deltoid in linear-down movement mode). Also it is clear that some movement modes for example elliptic-up and linear-up are such that much higher and more pronounced muscle activity is necessary (medial deltoid being the most obvious). Another general observation is that all elliptical modes are much more similar to circular mode as is the case when comparing linear modes with circular mode. This is also understandable because in all linear modes the movement in a half of a movement cycle is such that there is first an acceleration phase followed by movement with approximately constant speed and concluded by a deceleration phase to a full stop prior to change of movement direction.

The results indicate that each of four elliptical and four linear modes of movement require different muscle synergies, which was from a biomechanical and functional point of view expected. This implies that an “elliptical/linear” trainer may considerably extend the concept of cyclical arm training used for strength and coordination training in various neurological conditions. This remains to be tested with suitable selected clinical cases.
Figure 4. EMG activity of the selected muscle groups on the left arm in a group of healthy individuals for all nine movement modalities. Group mean values and standard deviations are shown. Correlation coefficients between each linear or elliptical movement modality and cycling movement are given as indication of similarity/dis-similarity of EMGs of the observed muscles.

4 References


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