EFFECTS OF SEAT POSITION ON JOINT LOADS OF THE UPPER EXTREMITIES DURING HANDCYCLING IN WHEELCHAIR-DEPENDENT INDIVIDUALS

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The current study aimed to quantify the joint moments of the upper extremities with different seat positions during handcycling in wheelchair-dependent individuals. Sixteen subjects performed handcycling while the handgrip reaction forces were measured by a handgrip instrumented with a six-component load cell and body segment kinematic data by a motion capture system. Both data sets were used to calculate joint moments of the upper limbs during a crank cycle. The loads at the shoulder were affected mostly by the vertical seat positions. The higher the seat, the greater loads transmitted by the muscles with relatively greater strength. The current data will be helpful for future handcycle design and fitting for wheelchair-dependent individuals.

KEY WORDS: handcycle, cyclic exercise, joint moments, upper extremities.

INTRODUCTION: Tricycles with manual crank propulsion design has become widely used in wheelchair-dependent individuals for recreations and/or outdoor mobility. Hand cyclic exercises are also used in the rehabilitation of various patient groups for improving their cardiopulmonary function, inter-joint coordination and muscular strength. Compared to hand-rim-propelled wheelchairs, these crank-propelled tricycles showed better mechanical efficiency and less muscle straining (van der Woude, et al., 1986, 2001). Individuals using handcycles for long distance travels are at an increased risk of injury especially under an improper seat position. Knowledge of the upper limb joint loads at different seat positions in wheelchair-dependent users is thus helpful for injury prevention, improving rehabilitation efficacy and handcycle design. Although limited joint kinetics studies during handcycling exist (Faupin, A. et al., 2010, Arnet, U. et al., 2012), few have used wheelchair-dependent subjects whose loading characteristics are presumably different from those of healthy inexperienced users. The current study aimed to fill the gap by quantifying the moments at the shoulder, elbow and wrist at different seat positions in wheelchair-dependent individuals during handcycling.

METHODS: Sixteen wheelchair-dependent individuals (twelve with poliomyelitis, two with spinal cord injury and two with defective lower limbs; age: 49.3 ± 7.9 years, height: 156.8 ± 9.0 cm, mass: 54.2 ± 11.8 kg, arm length: 71.3 ± 4.9 cm) participated in the current study with informed written consent as approved by the Institutional Research Board. Each subject wearing 20 skin markers on specific bony landmarks of the thorax and upper extremities performed handcycling exercise on an instrumented handcycle at an average resistance of 4.14Nm measured at the arm cranks. (Fig. 1). The crank length (the distance between the handgrip spindle and the crank axle) was 152.5mm. A metronome was used to control the handcycling speed to around 40 rpm. Each subject performed handcycling at 9 seat positions in random order, each corresponding to a combination of three horizontal and three vertical seat positions. At the beginning of the experiment, the subject self-selected a preferred position, and then the other two horizontal positions were set at 8% of the arm length anterior to the preferred position and 5% posterior. The other two vertical positions were set at 12% of the trunk length (the distance between the shoulder and hip) above and below the preferred position. The 3D marker trajectories were measured using a 7-camera motion capture system at a sampling rate of 120Hz (Vicon 512 Motion System Ltd. UK) and the handgrip reaction forces were measured by a 6-component load-cell (FS6-500, AMTI, USA) installed in the right handgrip. A marker cluster was also fixed to the right handgrip and a static system calibration was performed to identify the pose of the load-cell relative to the marker cluster (van Drongelen et al., 2011). Anatomical reference frames were defined for each upper limb segment following the ISB recommendation (Wu, G. et al., 2005). The handgrip reaction forces and the marker data were used to calculate the joint moments using inverse dynamics analysis. Joint moments were normalized to the peak crank torque in the same crank cycle and the peak values for each joint within the crank cycle were extracted for subsequent statistical analyses. Two-way repeated measures ANOVAs (one for each variable) were used to test differences in the calculated variables between the horizontal and vertical seat positions. Post hoc linear trend detection and pairwise comparisons were performed when a main effect (horizontal, vertical) was found. The significance level was set at 0.05.

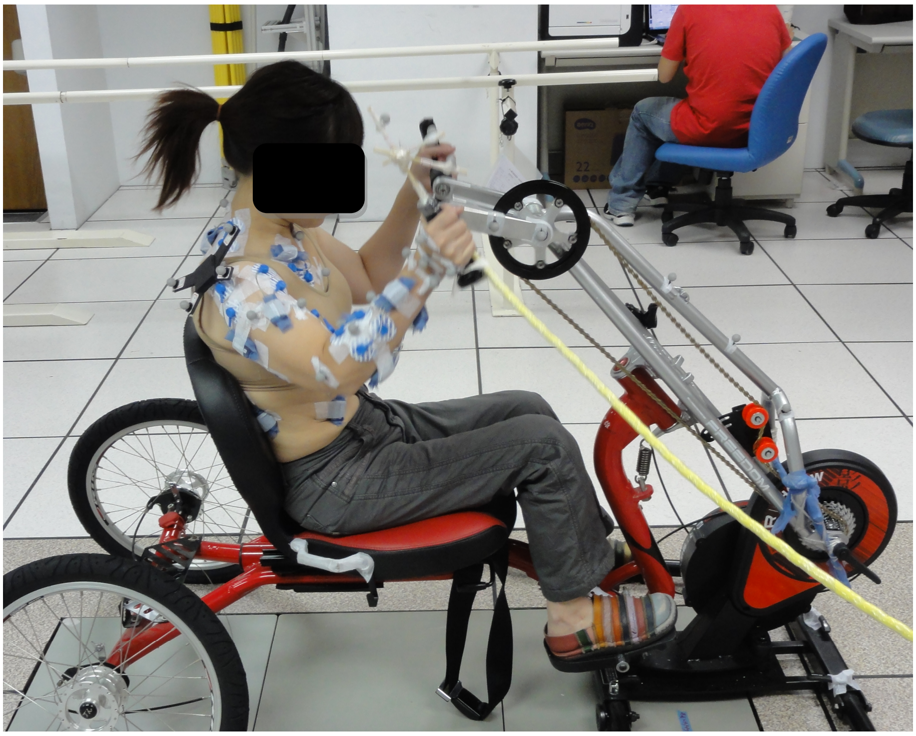

Figure 1: A subject performing handcycling on a handcycle with its front wheel replaced by a resistance training platform. The handgrip was instrumented with a 6-component load cell to measure the handgrip reaction forces. The seat could be moved horizontally and vertically to the tested positions.

RESULTS: No interactions between the main factors were found for any variables ($p > 0.05$) so only significant main effects are reported here. With the seat moving downward from the highest position, significant linear increasing trends were found for the normalized peak moments in the shoulder adductors (41.4 to 47.6, $p < 0.001$), internal rotators (31.9 to 39.5, $p = 0.037$) and external rotators (16.3 to 24.6, $p < 0.001$) (Fig. 2). But, those in the shoulder flexors (44.5 to 37.5, $p = 0.004$) and extensors (44.4 to 31.8, $p < 0.001$) were significantly decreased with a linear trend (Fig. 2). For the peak normalized elbow moments, the abductors showed significant linear increasing trend (17.2 to 22.8, $p = 0.005$) but the internal rotators showed the opposite (33.1 to 27.8, $p = 0.036$) (Fig. 2). With the seat moving anteriorly from the most posterior position, the peak shoulder external rotator moments were linearly decreased (24.1 to 16.1, $p < 0.001$) (Fig. 3) but those for the elbow flexors were increased (24.6 to 31.9, $p = 0.001$) (Fig. 3). For the wrist, significant linear increasing trend was found in the peak moments of the radial deviation muscles (29.3 to 37.1, $p = 0.011$) and flexors (16.4 to 21.3, $p < 0.001$) but the peak supinator moments showed the opposite (41.4 to 36.9, $p = 0.029$) (Fig. 3).

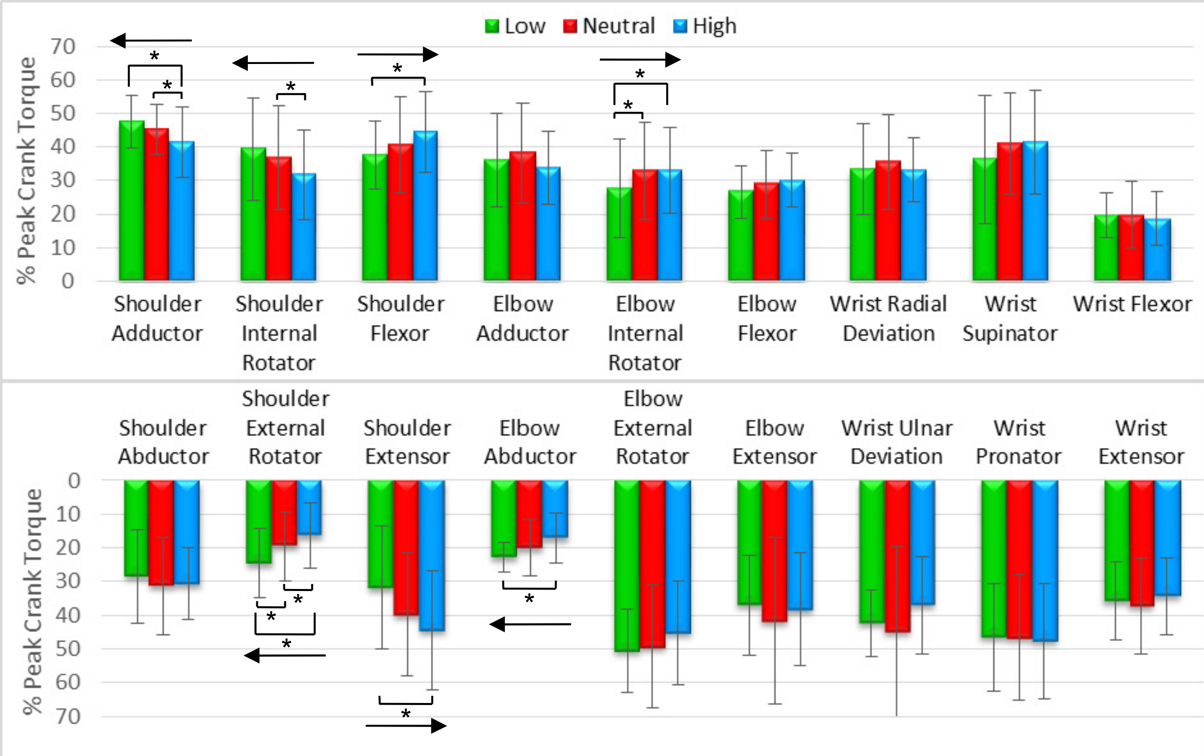

Figure 2: Mean (standard deviation as vertical bars) peak moments at the shoulder, elbow and wrist at three vertical seat positions. An arrow indicates a significant linear trend. A star indicates a significant difference in pairwise comparisons.

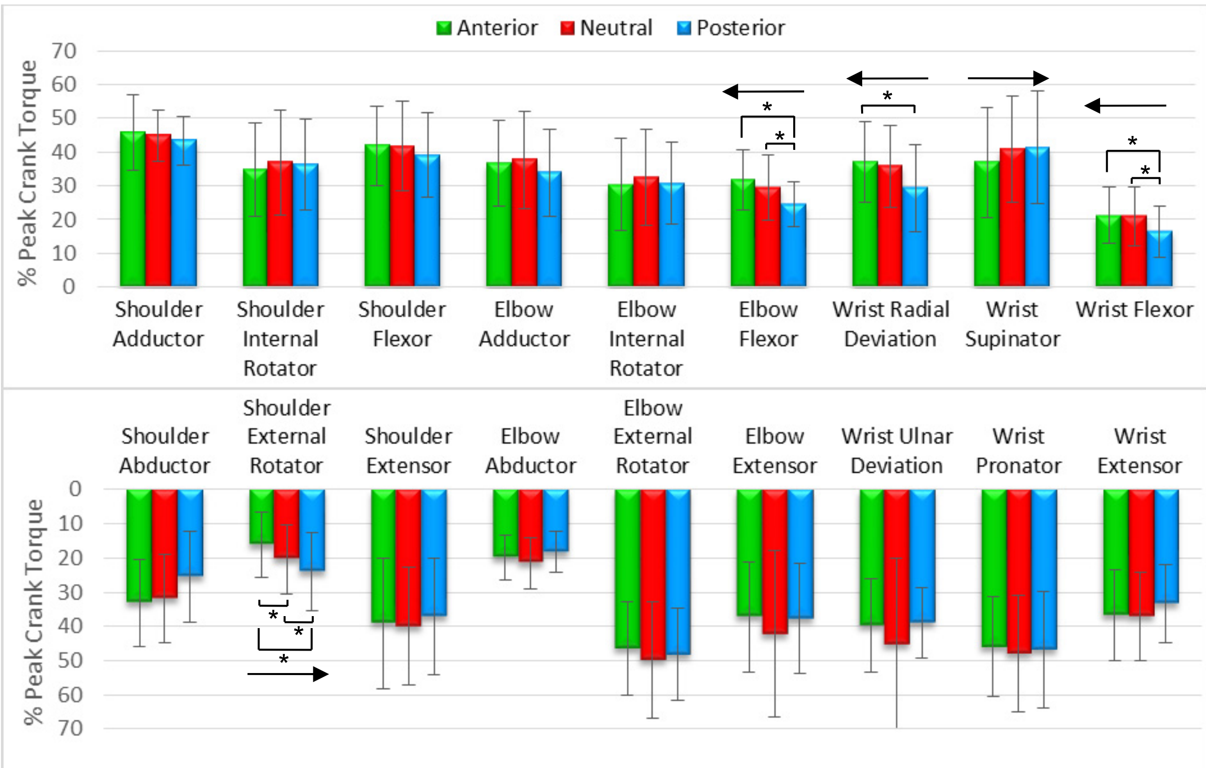

Figure 3: Mean (standard deviation as vertical bars) peak moments at the shoulder, elbow and wrist at three horizontal seat positions. An arrow indicates a significant linear trend. A star indicates a significant difference in pairwise comparisons.

DISCUSSION: The shoulder moments were sensitive to vertical seat positions except those of the abductors. While moving the seat downward reduced the shoulder flexor and extensor moments, those for the adductors, internal and external rotators were increased. The loads in the elbow extensors, the most important muscle during handcycling (Arnet, U. et al., 2012), did not appear to be affected by seat height nor horizontal position. In contrast, those in the elbow flexors were affected by the horizontal seat positions. The effects of seat positions on the loads at the elbow may be affected by the trunk motions involved at more posterior seat positions when the subject attempted to pull the handgrip backward by extending the trunk rather than flexing the elbow during pulling phase. Increased trunk motion may induce higher loads at the abdomen and lower back. The trunk strategy may not be possible for people with high-level spinal cord injuries. Moving the seat backward reduced the loads of the muscles for wrist radial deviation and flexion. These muscles are considered to be of lesser endurance than the supinators whose loads were increased with more posterior seat positions. Loads of the shoulder external rotators were also increased slightly with more posterior seat positions. It is suggested that the horizontal seat positions may be adjusted for changing the muscular loadings during prolonged use of handcycles.

CONCLUSION: Joint loads of the upper extremities at different horizontal and vertical seat positions were investigated in the study. Loads of the shoulder joint were sensitive to seat height. For injury prevention, higher seat positions may be used to help reduce loads of the weak muscles and transfer loads to the muscles with greater strength. Moving the seat posteriorly induced more trunk motion and may help shifting loads among the muscles but should be adjusted carefully. The current results provide a better understanding of the loads in the upper extremities at different seat position in wheelchair-dependent individuals. This knowledge will help user-specific seat positioning for injury prevention during handcycling and for rehabilitation purposes.

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