Kinematic Variability of the Trunk is Related to Shoulder Variability During Wheelchair Propulsion
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INTRODUCTION
A high incidence of upper extremity pathology, specifically for the shoulder complex, is reported for manual wheelchair users [1]. Contributing factors include continuous repetitive movements and loading, muscle imbalance, and malalignment of the limbs [1]. Larger propulsive forces, which are associated with larger shoulder sagittal flexion and internal rotation moments, have been linked to a higher prevalence of shoulder pathology [1]. A high-level spinal cord injury, generally accompanied by upper limb involvement and low trunk stability, is also associated with an increased number of shoulder disorders [2]. Given the adjacent locations of the trunk and shoulder within the kinetic chain, kinematics of one would be expected to affect the kinematics of the other. A more complete understanding of how shoulder and trunk motions are coupled during wheelchair propulsion may provide additional insights regarding musculoskeletal repetitive injuries.

The purpose of this study was to determine the relationship between cycle-to-cycle variability in trunk and shoulder kinematics. We hypothesized that larger cycle-to-cycle variability in trunk motion would be associated with larger cycle-to-cycle variability in shoulder motion, and that individuals with higher-level spinal cord injury would have larger cycle-to-cycle variability in trunk kinematics.

METHODS
Twelve subjects (8 males, age: 37±13 yrs, height: 1.7±0.1 m, mass: 83±17 kg, years of wheelchair use: 10±6 yrs) who use a manual wheelchair as a primary means of mobility were recruited for this institutionally approved study. All subjects gave written informed consent prior to their participation. A three-dimensional motion capture system operating at 120 Hz (Motion Analysis, Santa Rosa, CA) was used to collect kinematic data. Reflective markers were placed on the trunk and upper extremities of each subject [3, 4]. Subjects propelled their manual wheelchair at a constant velocity on a set of wheelchair rollers (McClain, USA) for two minutes. A trial completed by each subject at a fixed speed between 2.0 and 3.0 km/h was selected for data analysis.

Angles of the trunk and right upper extremity were calculated using custom-written software [4]. Shoulder kinematics were calculated by referencing the humerus to the trunk, as described in the ISB reporting standards [3]. Trunk flexion, lateral flexion, and rotation, and shoulder external rotation, plane of elevation, and elevation angle were analyzed. The data from each subject were divided into propulsion cycles that started and ended at the beginning of the push phase. Phase planes were plotted for each of the variables (Figure 1) and the centroid locations of the phase planes were calculated for each propulsion cycle.

The total path length that the centroid travelled during consecutive propulsion cycles, divided by the total number of analyzed cycles (87±27), was calculated. The resulting quantity was the mean distance the centroid traveled between consecutive cycles. A larger path length corresponded to larger variability [5]. Pearson’s correlations were used to test the hypothesis that trunk variability is associated with shoulder variability.

Subjects were classified as having either good or poor trunk control based on two independent criteria: (1) by injury level, or (2) by centroid path length of trunk flexion/extension. In the first method, subjects with an injury level at or above the
fourth thoracic vertebra, and those diagnosed with multiple sclerosis, were assigned to the poor trunk control group and remaining subjects were assigned to the good trunk control group. In the second method, those with below-median trunk flexion path lengths were assigned to the good trunk control group, while those with above-median path lengths were assigned to the poor trunk control group. For both classification methods, Student’s t-tests were used to compare trunk and shoulder variability (i.e. centroid path lengths) and ranges of motion (ROM; maximum – minimum values) in the two groups. A p-value less than 0.05 was considered statistically significant for all tests.

RESULTS AND DISCUSSION

Seven of the nine possible combinations of trunk and shoulder path-length variables were significantly correlated with one another (Table 1). Trunk extension and shoulder elevation variability had the closest relationship (Figure 2). When subjects were classified into good/poor trunk control groups based on median trunk flexion path length, the good trunk control group had greater shoulder external rotation ROM (78 ± 20° vs. 51 ± 21°, p=0.047) and plane of elevation ROM (84 ± 19° vs. 54 ± 22°, p=0.028). In contrast, when subjects were classified according to injury level there were no significant differences between groups in any variable.

![Figure 2](Image)

**Figure 2 Relationship between trunk and shoulder centroid path lengths**

The absence of a difference between injury level groups may be due to the low demand of propulsion conditions; a speed that all subjects were able to execute was selected, and propulsion was over a smooth (roller) surface without an incline. During low-demand tasks, even subjects with relatively high injury levels may be able to compensate for lack of muscle enervation through changes in coordination or by having greater strength. A low-level injury, generally linked to better trunk control, is associated with a lower prevalence of shoulder pathology [2]. In our study, ROM was significantly larger for individuals with smaller trunk variability, suggesting that ROM is an important factor for individuals who propel with greater trunk control.

The extent that propulsion cycle consistency is related to shoulder pathology is still unknown. The current functional interpretations of variability differ. Some suggest that high variability allows the individual to adapt to different environmental conditions potentially reducing the risk for injury, while others suggest that decreased variability is a protective mechanism against the progression of injury [5]. The potential cause of these discrepancies may be that methods of quantifying variability differ between studies. If high cycle-to-cycle variability in shoulder kinematics were linked to the development of shoulder pathology, then interventions that improved trunk control and increased shoulder ROM during propulsion might be helpful.

**CONCLUSIONS**

Our hypothesis that larger cycle-to-cycle variability in trunk motion would be associated with larger cycle-to-cycle variability in shoulder motion was supported. When subjects were classified according to trunk control, larger trunk variability was associated with smaller shoulder ROM. This relationship was absent when subjects were classified according to injury level. The relationship between musculoskeletal variability and pathology should be investigated to determine if interventions could assist with injury prevention.

**REFERENCES**