Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Kwarciak et al. 2012 USA Post-Test N=25	**Population:** Mean age: 35.7 yr; Gender: males=23, females=2; Level of injury: paraplegia (T3-L1)=17, spina bifida(T10-L1)=6, tetraplegia(C6-7)=1, spinal lipoma=1; Mean use of w/c:16.9 yr. **Intervention:** Four propulsion patterns (single loop (SL), arcing (ARC), double loop (DL) and semi-circular (SC)) were compared to the participants' normal pattern. Parameters measured were cadence, peak force, contact angle, braking moment, and impact, as well as EMG muscle activity in specific upper extremity muscles or muscle groups. Data collection was completed for each participant's normal pattern after an acclimation period. Subsequent stroke patterns were randomly assigned with a period of instruction and practice prior to data collection. Each data collection period lasted 60 sec with 30 sec warm up prior and rest times between to avoid fatigue. **Outcome Measures:** Surface electrodes were used at to measure muscle activation at the shoulder (upper and middle trapezius, pectoralis major, anterior, middle and posterior deltoid), elbow (long head of triceps and biceps), and wrist (wrist extensors and flexors). Data for stroke pattern were collected on the right hand (MCP joint) and wheel (3 points on the hub of wheel). Propulsion variables were measured by an instrumented rear wheel while the participant propelled on a wheelchair treadmill that was normalized to the individual's parameters on low pile carpet as determined at the start of the study.	1. Normal propulsion patterns: DL=15, SL=6, ARC=2, SC=2. 2. Comparisons across patterns were based on average of normal (across low pile carpet and self-selected speed) and experimental propulsion trials. 3. Hand rim biomechanics: DL=smallest cadence, largest contact angle, smallest braking moment compared to ARC pattern (all $p<0.05$). The latter 2 were also significantly different than the SL pattern ($p<0.05$). Though not significant, DL had highest peak force value and SC the lowest peak force as well as lowest impact. 4. Contact angle of SC was significantly larger compared to arching pattern ($p<0.05$). 5. Muscle activity: No significant differences were found in muscle activity between stroke patterns.
Raina et al. 2012b USA Post-Test N=34	**Population:** Mean age: 74.5 yr; Gender: males=31, females=3; Level of injury: paraplegia=16(T6-L1), tetraplegia=18(C6-7), all AIS A or B motor complete; Mean height: 1.75 m. **Intervention:** Participants propelled their own manual w/c on a stationary ergometric normalized to propelling on tile floor for a 30 sec period to achieve steady state propulsion followed by 10 sec of data collection for each of four propulsion	1. Velocity of wrist prior to contact was significantly correlated ($r=0.74$, $p<0.05$) with the magnitude of impact force for all participants; tetraplegia=0.81±0.24 m/second, 0.062±0.02 N/kg; paraplegia=0.95±0.37 m/second, 0.061±0.03 N/kg. 2. Correlation between wrist velocity prior to contact and magnitude of impact force normalized to body

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	patterns (arcing (ARC), single–loop-over propulsion (SLOP), semi-circular (SC), double–loop-over propulsion (DLOP)). **Outcome Measures:** Push pattern analysis included velocity prior to contact, peak impact force, and the effectiveness of the force at impact. Force was measured at the contact point with the hand rim for the period when force was more than 5 N as measured using the Smart Wheel (3 strain force transducers). Propulsion patterns were tracked using a 6-camera system with 16 reflective markers placed on the manubrium, xiphoid process, spinous processes of T3&T10, greater tubercle of the humerus, medial and lateral epicondyles, deltoid tuberosity, mid forearm, radial and ulnar styloids, and head of 3rd and 5th metacarpals, three markers on the wheel.	weight was stronger for participants with paraplegia (r=0.92) than tetraplegia (r=0.45). 3. No significant differences in magnitude of impact force between participants with paraplegia and tetraplegia (p>0.05). 4. Participants with tetraplegia had significantly higher (p=0.02) radial component of impact force than participants with paraplegia (9.2% & 4% respectively). 5. Percent of impact force applied in tangential direction (effective force) was significantly higher (p=0.005) in paraplegia group (94%) than in tetraplegia group (88%) – suggest lower effectiveness of force application at impact for tetraplegia group. 6. ARC, SC and SLOP patterns were preferred by both participant groups. 7. The most common propulsive pattern in the combined sample population was the SLOP. 8. DLOP not used by participants with tetraplegia; the SC pattern was observed in only one participant with paraplegia. 9. Impact force between hand movement patterns was not significantly different between patterns (p>0.05) (force normalized to arm weight to account for between subject body mass differences). 10. Force effectiveness was not significantly different between propulsion patterns. 11. Percent of effective force at contact varied between 0-25% and 25-95% for participants with tetraplegia and paraplegia, respectively. 12. The same pattern showed different percentages of force effectiveness in the two participant groups (paraplegia versus tetraplegia).
Feng et al. 2010 Taiwan Post-Test N=10	**Population:** SCI (n=9); Mean age: 28.9 yr; Gender: NR; Level of injury: Lumbar=2.2, Thoracic=7.8; Mean time since injury: 11.3	1. There were not significant differences in the temporal variables between the two stroke techniques (similar time spent in

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	yr; Experience using manual w/c range 2-18 yr. **Intervention**: To investigate the glenohumeral kinematic difference between circular and pumping stroke wheelchair propulsion in glenohumeral joint (GHJ) excursion related to shoulder impingement (defined as internal or external rotation beyond 30° of forward flexion or 30° of abduction). Participants used a study w/c set up to standardize arm position in an optimal position in relation to wheel. Testing done on a roller system, following a protocol of 5 min warm up and three tests of 10 cycles of propulsion for each propulsion pattern; patterns randomly assigned. **Outcome measures**: Zebris Motion analysis system with six markers (acromion process, lateral epicondyles, ulnar styloids, and a rigid cross placed on sternum to capture three planes) to measure temporal parameters [push time(s); recovery time (s); push phase (% of cycle); recovery cycle (% of cycle)] and kinematic parameters [Initial and end position flexion-extension, abduction-adduction, and internal-external rotation (degrees)] of each propulsion technique, in addition to impingement excursion.	the pushing and recovery movements). 2. Circular and pumping strokes showed a ratio of 4:6 between push and recovery times. 3. In the sagittal plane the starting and ending positions were similar between the two stroke techniques with both starting and ending with approximately 40° of shoulder extension. 4. There were significant differences between stroke patterns in the frontal and transverse planes;1) on average pumping stroke compared to circular started in larger abduction (56.6°+9.5° versus 44.7°+7.4°, p=0.001), and internal rotation (3.6°+10.3° versus-10.3°+6.7°, p=-.020). 2). End position for pumping was larger than circular for abduction (57.6°+5.1° versus 45.4°+6.2°. p=0.001) and internal rotation (34.1°+11.8° versus-13.4°+7.3°, p=0.001). 5. The pumping stroke also had a significantly greater excursion in the sagittal, (71.4°+11.4° versus 55.9°+ 11.8°, p=0.001), frontal, (57.6°+5.1° versus 45.4°+6.2°) and transverse planes (42.4°+11.8° versus 25.7°+7.3°) compared to the circular stroke. 6. A greater percentage of the GHJ movement met impingement excursion (almost three times) during the pumping stroke compared to circular stroke (11.6+11.2% versus 30.9+6.0%, t=-4.670, p<0.001).
Koontz et al. 2009 USA Post-Test N=29	**Population:** Mean age: 47.0 yr; Gender: males=28, females=1; Injury etiology: SCI=24 (cervical=5, thoracic=14, lumbar=5), amputation=3, neuropathy=1, spina bifida=1; Length of time using w/c: 14.2 yr. **Intervention:** Patients propelled their manual wheelchairs on randomly selected test surfaces consisting of linoleum (1.20 m by 4.50 m), high-pile carpet (1.50 m by 4.50m) and a plywood ramp (1.20 m by 3.60 m, 5° grade) for three test trials.	1. The single looping (SL) over propulsion pattern was most commonly used for the initiation of motion (44.9%), followed by arc (35.9%), double looping (DL) over propulsion (14.1%) and semicircular (SC) pattern, (5.1%). 2. The number of strokes used and the type of surface had no significant effect on the pattern used. 3. Body weight, body and wheelchair weight combined, and age were not significantly different between patterns

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	Outcome Measures: 2 SMARTWheels and a camera set up to collect data for stroke pattern and propulsion variables of applied force, velocity, distance per stroke, contact angle and moment.	4. Duration of wheelchair use was significantly different between patterns types onlinoleum for the 1st and 2nd strokes. ($p=0.036$ and $p=0.008$ respectively) Participants in the DL and SC pattern group had been using wheelchairs longer (stroke 1: DL/SC=28.0±12.5 yr, SL=11.8±9.7 yr, arc=13.7±8.0 yr; stroke 2: DL/SC=22.0±11.5yr, SL=10.3±6.7 yr, arc=10.5±6.7 yr). 5. On linoleum: • Between group differences approached significance in regard to contact angle with DL/SC having a larger contact angle at stroke 1 ($p=0.069$) (DL/SC=56.70±11.10 °, SL=45.00±5.55 °, arc=31.30±5.1 °). • Between group differences approached significance in regard to average velocity with DL/SC having a faster average velocity ($p=0.075$) (DL/SC: 0.92±0.06 m/s, SL=0.75±0.06 m/s, arc=0.73±0.07 m/s) • DL/SC covered significantly more distance per stroke at stroke 2 compared to arc ($p=0.016$) (DL/SC=0.53±0.08 m, arc=0.44±0.10 m). 6. On carpet: • Between group differences were significant in regard to peak moment at stroke 3 ($p=0.009$) (DL/SC=0.26±0.02 m, SL=0.23±0.01 m, arc=0.18±0.02m), average velocity at stroke 3 (DL/SC=1.07±0.08 m/s, SL=0.82±0.06 m/s, arc=0.70±0.09 m/s) and distance per stroke at stroke 3 ($p=0.036$) (DL/SC=0.53±0.12 m, SL=0.45±0.08 m, arc=0.42±0.13 m). • Compared to arc, DL/SC had a significantly greater peak moment ($p=0.07$), average velocity ($p=0.019$) and distance per stroke ($p=0.043$) at stroke 3. 7. On the ramp: • Between group differences were significant in regard to peak resultant force at stroke 3

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		(p=0.049) (DL/SC=1.64±0.20, SL=1.37±0.11, arc=1.07±0.13). • Compared to arc, DL/SC had a non-significantly greater peak resultant force at stroke 3 (p=0.066).
Richter et al. 2007a USA Post-Test N=26	**Population:** Mean age: 36.0 yr; Gender: males=19, females=7; Mean wheelchair use=17 yr; Mean weight: 69.8 kg; Level of injury: paraplegia; Chronicity=chronic. **Intervention:** Self propulsion in personal wheelchair on a treadmill set to level, 3° and 6° grades. **Outcome Measures:** Stoke pattern – semicircular (SC), single looping (SLOP), double looping (DLOP), arcing (ARC), Speed, Peak force, Push angle, Push frequency, Power output.	1. Level stroke pattern: 42% ARC; 30% SLOP; 27% DLOP; 0% SC. 2. 3° slope stroke pattern: 69% ARC; 19% SLOP; 12% DLOP; 0% SC. 3. 6° slop stroke pattern: 73% ARC; 23%SLOP; 4% DLOP; 0% SC. 4. From level to 6° slope: 63% decrease in speed (p=0.000); 218% increase in peak force (p=0.000); 25.5% decrease in push angle (p=0.002); 21.6% decrease in push frequency (p=0.042). 5. Power output at 3° slope and 6° slope were 2.8 and 3.1 times higher than those at level (p=0.000).
Boninger et al. 2002 USA Post-Test N=38	**Population:** Mean age: 35.1 yr; Gender: males=27, females=11; Mean weight=167.2 lbs; Mean height=69 in; Handedness: left handed=5, right handed=33; Level of injury: paraplegia=38; Mean time since injury: 11.1 yr. **Intervention:** Self propulsion of personal wheelchair on a dynamometer at 0.9m/sec and 1.8m/sec. **Outcome Measures**: Stroke pattern – semicircular (SC), single looping (SLOP), double looping (DLOP), arcing (ARC); Axle position; Beginning stroke angle; Total stroke angle; Cadence; Mean velocity; Push time; Recovery time; Total time in propulsion.	1. Stroke patterns observed: 45% SLOP; 25% DLOP; 16% SC; 14% ARC. 2. 58% used similar stroke patterns at both speeds, on both sides; however, the remaining subjects alternated patterns between sides and speeds. Most notably, SC pattern use decreased as the speed increased. 3. DLOP and SC patterns had lower cadence than ARC (p<0.01) and SLOP (p<0.05). 4. ARC and SC spent the most time in propulsion (p<0.05).