Author Year Country Research Design Score Total Sample Size	Methods	Outcome
Martin-Lemoyne et al. 2016 Canada RCT PEDro=5 N=10	**Population:** Mean age= 36.0 yr; Gender: males=6, females=4; Level of injury range: C6-T11; Mean time since injury: 11.9 yr. **Intervention:** Mechanical load and muscular demands were measured for manual wheelchair (MWC) users using a SMARTWheel installe don participant's own w/c, an Optotrack motion analysis system, and surface electromyography on the shoulrder muscles. Participants propelled up a ramp with and without a mobility assistance dog (AD_{Mob}). The course had a 4 metre long, 8.5º ramp covered with a thin layer of asphalt. Each intervention was completed 3 times by each participant with rest periods between as needed **Outcome Measures:** Spatiotemporal parameters: push phase, recovery phase, propulsion cycle, contact angle, speed; Pushrim kinetic: total force (F_{tot}), tangential force (F_{tan}), mechanical effective force (MEF); Shoulder moments: flexion(flex)-extension(ext), adduction (add)-abduction (abd), internal rotation (IR)-external rotation (ER); Muscular utilization ratio (MUR); Perception of upper limb effort as measured on a 10 point visual analog scale	1. The use of an AD_{Mob} allows manual wheelchair users to ascend the ramp significantly faster while requiring significantly less upper limb efforts. 2. Traction significantly increased (p=0.037) wheelchair speed with the AD_{Mob} compared with the same task without the $AD_{Mob.}$ 3. A significantly shorter (p=0.013) push phase and significantly longer (p=0.028) recovery phase when using the AD_{Mob} compared to without. 4. F_{tot} and F_{tan} were significantly reduced with the use of the AD_{Mob} compared to without (p=0.005, and p=0.002, respectively). 5. The maximum shoulder flexion (p=0.047), add-abd (p=0.017), and IR-ER (p=0.028) net joint moments were significantly reduced with the traction provided by an $AD_{Mob.}$ 6. MUR was significantly reduced for all tested muscles ($p \leq 0.022$). 7. The perception of upper limb effort was significantly reduced (p=0.005) when performing the experimental task with traction provided by the $AD_{Mob.}$

Gagnon et al. 2015 Canada Pre-Post N=18	**Population:** Mean age: 40.8 yr; Gender: males=17, females=1; Level of injury: cervical=1, thoracic=17; Level of severity: AIS A=12, AIS B=3, AIS C=2, AIS D=1; Mean time since injury: 8.2 yr. **Intervention:** Participants propelled their manual wheelchair (MWC) at a self-selected natural speed on a treadmill at different slopes (0, 2.7, 3.6, 4.8, and 7.1 degrees) which reflected an increase from one unit in height to 20, 16, 12 and 8 units of length respectively. Each angle had two trials lasting 1 min with a 2 min rest between tests. **Outcome Measures:** The last 10 consecutive complete propulsion cycles were used to calculate outcomes Temporal parameters (push phase duration, Recovery phase duration, Total cycle duration, Trunk and shoulder movement kinematics (minimum, maximum, excursion movement amplitudes), Shoulder kinetics (flexion/extension, adduction/abduction, internal/external rotation moments), Peak and mean muscular utilization ratio (MUR) and the indicator of muscle work (IMW) for the anterior deltoid, Posterior deltoid, Pectoralis major clavicular fibers, Sternal fibers. Significance was inferred at $p \leq 0.0125$.	1. The average durations of the push phase were similar for all tested slopes ($p=0.267$), whereas the average duration of the recovery phase declined as the slope become steeper ($p=0.043$). 2. The total duration significantly decreased as the slope became steeper, except for during the 2.7° to 3.6° where the slope increment remained similar ($p \leq 0.001$). 3. At the trunk, all minimum, maximum, and excursion movement amplitudes significantly increased as the slope became stepper ($p<0.0125$), except for minimum and maximum values during the 2.7° to 3.6° slope increment that remained similar ($p>0.0125$). At the 7.1° slope the greatest maximum forward trunk flexion (60.9°) and the greatest forward trunk excursion (22.4°) was reached. 4. The mean and maximum shoulder flexion moments significantly improved as the slope increased ($p<0.0125$), except for the 3.6° to 4.8° and 4.8° to 7.1° slope increments. 5. The mean adduction moments only significantly improved as the slope increased between 0° and 2.7° ($p<0.001$), whereas the peak mean value only significantly improved as the slope increased between 0° to 2.7° ($p<0.001$), 3.6° to 4.8° ($p=0.002$), and 4.8° to 7.1° ($p=0.002$) slope increments. 6. The mean and maximum internal rotation moments significantly increased as the slope became steeper ($p<0.0125$), except for the 3.6° to 4.8° slope increment. 7. The mean and maximum MURs and their indicator of muscle work value, significantly increased (ANOVA $p<0.001$) as the slope became steeper except for the posterior deltoid and that remained comparable between 2.7° to 3.6° slope increment.

Gagnon et al. 2014 Canada Pre-Post N=18	**Population:** Mean age: 40.8 yr; Gender: males=17, females=1; Level of injury: cervical=1, thoracic=17; Injury severity: AIS A=12, AIS B=3, AIS C=2, AIS D=1; Mean time since injury: 8.2 yr. **Intervention:** Participants propelled their manual wheelchair (MWC) at a self-selected natural speed on a level treadmill and then at randomly assigned slopes (0°, 2. 7°, 3.6°, 4.8°, and 7°) Each angle had two trials lasting 1min with a 2min rest between trials. Self-selected speeds were determined by timing propulsion over a 20m tile floor three times with a 2min rest between trials **Outcome Measures:** Data was divided into the push phase (hand in contact with rim) and the recovery phase (hand not in contact with rim). Data was collected using the SMARTWheel on the non-dominant side. The last 10 consecutive complete propulsion cycles for each trial were used to calculate means for: 1) duration of push and recovery phases and propulsion cycle (both push and recovery phases), 2) contact angles, 3) total force, 4) tangential force, 5) mechanical effective force (MEF), 6) perceived effort. Significance was inferred at p<0.001.	1. The recovery phase at 0° was 54 to 70% longer than for the other different slopes (recovery phase at: 0°=0.59±0.22, 2.7°=0.27±0.10, 3.6°=0.26±0.09, 4.8°=0.22±.0.08, 7.1°=0.18±0.05; p<0.001). 2. The final contact angle was similar across all slopes except for the 0° slope, which was significantly lower than all other slopes (final contact angle at: 0°=45.97±9.04, (p≤.001) 2.7°=52.04±9.20, 3.6°=53.46±10.36, 4.8°=57.92±11.82, 7.1°=65.54±9.82,). 3. Total contact angle remained greater during the level surface than all other slopes ((p≤.005) with the slopes presenting similar total contact angles (p=0.14, p=0.24). 4. The greatest mean difference of total force and tangential force was found between 0° and 2.7° slopes compared with the differences observed between the other consecutive slopes (mean total force at: 0°=39.56±11.15, 2.7°=76.25±19.55, 3.6°=81.49±18.86, 4.8°=95.49±21.16, 7.1°=119.21±18.42; p<0.001. mean tangential force at: 0°=24.52±8.84, 2.7°=48.04±13.08, 3.6°=52.25±14.27, 4.8°=58.00±14.69, 7.1°=68.05±16.61; p<0.001). 5. The MEF values were similar across all slopes located at approximately 80% of the propulsion phase (MEF values at: 0°=0.43±0.09, 2.7°=0.44±0.06, 3.6°=0.45±0.10, 4.8°=0.42±0.06, 7.1°=0.38±0.10; p>0.05). 6. The perceived effort increased as slope angle increased, with the 0° slope having the lowest perceived effort and the 7.1° slope showing the greatest perceived effort (perceived effort at: 0°=1.18±1.10, 2.7°=3.78±2.83, 3.6°=4.06±2.69, 4.8°=5.27±2.80, 7.1°=6.86±2.68; no p-value provided).

Pierret et al. 2014 France Pre-Post N=25	**Population:** Mean age: 38.9 yr; Gender: males=25, females=0; Level of injury: T3-L4; Mean time since injury: 10.6 yr. **Intervention:** Participants performed two tests: 1) a test involving sub-maximal exertion on an arm ergocycle on the first day to estimate peak oxygen uptake up to 85% maximum heart rate, and 2) eight laps of a 50 m propulsion track with a cross slope (Cs) of 0, 2, 8, and 12 % each at two different velocities (one self-selected, one imposed rate). The intersession interval between tests was at least 2 days. **Outcome Measures:** Heart rate (HR), absolute cardiac cost (ACC), relative cardiac cost (RCC), peak oxygen uptake (VO_2), energetic cost per meter travelled and per kg weight (ECmkg), relative energetic cost (REC), Rating of Perceived Exertion (RPE) scale.	1. 5 participants were unable to complete the last 50 m lap under all test conditions. 2. No significant differences were noted in HR or VO_2 for the 0% and 2% Cs. 3. The HR, ACC, and RCC are all significantly altered by the velocity conditions (F>95; p<0.001) and, for each velocity, by the three different Cs (p<0.001).ACC also increased by user weight (p<0.001), age (p<0.001), injury level (p<0.001) and VO2 max decrease (p<0.001). 4. The VO_2, ECmkg and the REC values (energetic strain) are all significantly altered by the velocity conditions (p<0.005) and by the Cs for each velocity (p<0.001). The energetic strain increases when age (p<0.001) or body mass index (p<0.001) increase or when physical activity (p<0.001), injury level (p<0.001) or VO2Max (p<0.001) decrease. 5. The RPE results remain unaltered by the velocity (p>0.04), but the Cs increase significantly the RPE (p<0.001).
Marchiori et al. 2014 Canada Post Test N=11	**Population:** Mean age: 31.8yr; Gender: males=9, females=2. **Intervention:** Participants were instructed to approach an obstacle 8 cm high at a comfortable speed, then lift the caster wheels off then ground just before it, without stopping, and ascend it, using their own wheelchair. The ascent was divided into three phases based on the angle formed between the wheelchair frame and the ground: caster pop (P1), rear-wheel ascent (P2), and post ascent (P3). Participants used their own manual wheelchair. **Outcome Measures:** SMARTWheel and eight camera video system to capture 3D joint power, 3D angle between the wrist, shoulder and elbow joint moments and angular joint velocity (moment).	1. The highest moment and peak net moment of the three joints (i.e., shoulder, elbow, and wrist) was found during P2 in flexion. 2. Forward trunk flexion started early in the caster pop phase 3. According to the 3D angle: • The wrist was more in a stabilizing configuration during P1 and P2, and generated energy during P1. • The shoulder joint was in a stabilizing configuration during obstacle ascent and generated energy during P3. • The elbow was in a stabilizing configuration during P3, absorbing energy during P1 and P2.

Lalumiere et al. 2013a Canada Post-Test N=15	**Population:** Mean age: 38.0 yr; Gender: males=14, females=1; Level of Injury: T2=1, T4=1, T5=1, T6=2, T7=2, T8=8, T10=3, T11=2, T12=2; Level of severity" AIS A=13, AIS B=1, AIS C=1; Mean time since injury: 9.5 yr. All MWU >4 hr/day, and self-reported independence with curb ascents of ≤12 cm with no shoulder pain. **Intervention:** Participants were asked to complete three curb ascend tasks (curb height=4cm, 8cm, and 12cm) at a self-selected speed in their own w/c with 3m approach. **Outcome Measures:** Trunk and upper extremity kinematics and shoulder, elbow and wrist net joint moments using: a motion analysis system (Optotrak) with 23 skin-fixed markers and four markers attached to w/c frame; two instrumented rear wheels (SMART wheels) and; surface electromyography. Measures compared at caster pop, rear-wheel ascent and post ascent phases to determine related effect of curb height.	1. All participants ascended 4 and 8 cm curbs; 80% (n=15) were able to ascend the 12 cm curb. 2. Curb approach speeds differed significantly ($p<0.0001$) with speeds progressively increasing as the curb height increased. 3. Curb height did not affect total duration ($p=0.7$), the duration of the caster pop phase ($p=0.849$) or the rear wheel ascent ($p=0.077$). 4. In the sagittal plane of motion most movement differences were noted. maximum trunk flexion along with the total excursion of trunk flexion, maximum shoulder flexion, and greater flexion, extension and movement excursion in the plane of motion at the elbow, all progressively increased as the height of the curb was increased from 4cm to 8 cm ($p\leq0.001$, $p\leq0.0001$, $p\leq0.004$ respectively), and then from 8cm to 12cm ($p\leq.0001$, $p=0.008$, $p\leq0.004$ respectively). However, the excursion of shoulder movement in the sagittal plane only improved significantly when the curb height was increased from 4 cm to 8 cm ($p\leq0.0001$). No movement difference was confirmed at the wrist across the various curb heights ($p>0.05$). 5. Compared to the 4 cm curb, all mean and peak total net moments produced at the shoulder, elbow and wrist significantly increased when ascending the 8 cm ($p\leq0.0001$) or 12 cm curb ($p\leq0.01$). 6. Compared to the 8cm high curb, only the mean shoulder ($p=0.001$) as well as the peak and mean elbow total net joint moments ($p\leq0.009$) further increased to a significant extent when ascending the 12cm high curb. 7. Compared to the height of 4 cm, the peak rate of rise (ROR) values of the total shoulder net joint moment and of the shoulder flexion net joint moment were found to be significantly greater when ascending a height of 8 or 12 cm ($p\leq0.005$). However, these values were similar when ascending an 8cm or 12 cm curb ($p\geq0.299$). 8. All mean ($p\leq0.031$) and peak ($p\leq0.039$) muscular utilization ratio (MUR) values for the upper extremity muscles assessed differed significantly across all heights.

Lalumiere et al. 2013b Canada Post-Test N=16	**Population**: Mean age: 38.1yr; Gender: males=15, females=1; Level of injury: T=15 (T2-12), C=1 (C7); Mean time since injury: 9.2 yr. **Intervention:** Compare the effects of four distinct rolling resistances (RRs) on the intensity of handrim kinetic measures on the non-dominant upper-limb (U/L) as well as symmetry (i.e., dominant versus on-dominant) of forces during the execution of wheelies among manual wheelchair users with SCI. Four wheelies per four randomized RRs including: (1) natural surface of painted high-grade smooth composite board (NAT), (2) 5-cm thick urethane soft yellow foam (LOW), (3) 5-cm medium viscoelastic pink memory foam (MOD), and (4) two 5-cm high wooden blocks with rear wheels completely blocked (HIGH). **Outcome Measures:** Handrim kinetics: resultant force (Ftot), medial force (Fz) and tangential component of the resultant force (Ftg) measured using two instrumented wheels (Smart Wheels) during four phases of the wheelie: preparation, take-off, balance, and landing as measured by the angle between the w/c frame and ground surface. Motion analysis system used to synchronize data from instrumented wheels; symmetry index intensity measured to verify if forces were similar bilaterally.	1. No significant differences in duration of each phase of the wheelie, except for the wheels blocked (High) for take-off and landing which were longer than all other surfaces. 2. The mean and maximal Ftot were greater (p=0.001-.009) during the HIGH RR compared to the other RRs. During the preparation phase, Ftg patterns showed a forward force application compared to a quick backward force with all other RRs. 3. The maximal Fz was similar across all RRs. 4. The mean and max Ftot were greater during the take-off phase of performing a wheelie, compared with the other phases (preparation, balance, and landing phases) for all RRs. The mean and max Ftg were greater also during the take-off phase compared with all other phase regardless of RR. The mean Fz was similar during the balance and landing phases, however was significantly greater during the take-off phase compared to the preparation phase.
Nagy et al. 2012 USA Post-Test N=23	**Population:** Mean age: 38 yr; Gender: males=20, females=3; Level of injury: tetraplegia=5 (C6-T1), paraplegia=19 (T4-L3); Mean time since injury: 14.8 yr. **Intervention:** All participants used their own ultra-lightweight manual wheelchair and seating. Each had one practice and then one test trial of a series of eight of the following skills from the Wheelchair Skills Test: 10m tile surface, 10m of carpet surface, soft surface, 5° and 10° ramps, 2 cm, 5 cm and 15 cm curbs. **Outcome Measures:** SmartWheel used to analyze push rim forces exerted during propulsion. Peak force for the first four skills was calculated from the entire performance; peak for the remaining skill were taken from the pushes that allowed successful completion. Mean peak force comparisons were completed using paired t-test for each skill to the 10 m tile skill.	1. The mean peak pushrim forces were as follows for the skills: 10 m tile=101 N, 10 m carpet=103 N, soft surface=148 N, 5° ramp=138 N, 10° ramp=157 N, 2cm curb=119 N, 5 cm curb=155 N, 15 cm curb=232 N. ***Only 6 szzubjects completed the 15cm curb).* 2. Comparison between mean peak forces of each skill compared to 10 m tile were all statistically significant (p=0.0001-.267) except the 10m carpet.

Morrow et al. 2010 USA Post-Test N=12	**Population:** Mean age: 43 yr; Gender: males=11, females=1; Injury etiology: SCI=11, spinda bifida=1; Duration of manual w/c use: 18 yr. **Intervention:** Five trials, with rest between, propelling at a self-selected speed for each condition in the following order: 1) push phase of level propulsion, 2) push phase of ramp propulsion (1:12 incline), 3) push phase of start, 4) negative acceleration phase of stop, 5) weight relief maneuver (push up and hold for 3 sec). **Outcome Measures:** Two instrumented rear wheels (SmartWheels) on participants on manual wheelchair to capture force data at handrim; Motion analysis system (Real-time Eagle) with 15 markers on the trunk and right upper extremity and three each on the rear wheels to capture moments; Force of direction was defined as anterior (+) and posterior (-) of the x axis, medial (+) and lateral (-) of the y axis and superior (+) and inferior (-) of the z axis. Moment direction was defined as flexion or extension about the trunk z axis, elevation abduction and elevation adduction about the humerus x axis and internal and external rotation about the humerus z axis.	1. There was a significant main effect of condition for the shoulder intersegmental forces in 4 of 6 force directions: anterior (p=0.001), posterior (p<0.001), medial (p=0.003), and superior (p<0.001). 2. Post hoc analysis of the intersegmental shoulder forces indicated that: 1) in ramp condition the anterior force was significantly higher than level propulsion, weight relief , start and stop conditions, 2) posterior force of the ramp and weight relief conditions were significantly higher than level, start and stop conditions, 3) weight relief medial force was significantly higher than level, start and stop conditions, 4) the level, start and stop conditions were all statistically equivalent for all force conditions. 3. There was a significant main effect for the shoulder intersegmental moments for three of six moment directions: extension (p<0.001), adduction (p=0.009), and external rotation (p=0.004). 4. Post hoc analysis of the intersegmental shoulder moments indicated that: 1) extension moment for weight relief was equal to start but significantly greater than level, ramp and stop conditions, 2) Adduction moment for ramp was significantly higher that level condition, 3) external rotation moment of ramp and start were significantly greater that in the level condition, 4) abduction (p=0.092) or internal rotation (p=0.102). There was no main effect of condition for flexion.

Hurd et al. 2008 USA Post-Test N=12	**Population:** Mean age: 43.6 yr; Gender: males=11, females=1; Injury etiology: SCI=11, spina bifida=1; Level of injury range: T4-L10; Duration of w/c use: 18 yr. **Intervention:** Evaluated U/L symmetry during self-selected propulsion rates across eight different terrain conditions consisting of propelling straight forward in laboratory, outdoor community and indoor community. The outdoor community was a single continuous 500m concrete sidewalk that progressed across four conditions in this order; 1) 2° right side lower cross slope; 2) smooth level surface; 3) level aggregate (textured) surface; 4) 3° ramp (1:19 rise to run) smooth surface. Indoor community =1) 10 m level, low pile carpet and 2) 4.8° ramp (1:12 rise to run) with low pile carpet. Laboratory= 1) 10 m smooth level tile surface and 2) dynamometer with level surface. 1 trial completed for outdoor community items; three trial of indoor community and 1st laboratory items and; 1 30 trial on dynamometer. **Outcome Measures:** Three push cycles using two instrumented rear wheels (Smart Wheels) were averaged to capture propulsion timing, effort and force using variables of moment, total force, tangential force, fractional effective force, time-to-peak propulsion moment, average work in joules, contact (length of push cycle) and instantaneous power. Symmetry index was used to determine symmetry of U/L propulsion (perfect symmetry=0 used for comparison).	1. Symmetry indexes were significantly different within each condition across all variables. 2. Between conditions, symmetry variables were also significantly different (propulsion moment, p<0.001; total force, p=0.004; tangential force p<0.001; fractional effective force, p<0.001; time-to-peak propulsion moment, p=0.001; work, p<0.001; contact, p<0.001; power, p<0.001) 3. Comparing the within lab conditions (tile floor versus dynamometer) indicated no differences in symmetry indices for any variable 4. Comparing the lab versus indoor conditions indicated no significant differences in symmetry indices for any variable. 5. Comparing lab versus outdoor conditions resulted in significant differences in symmetry indices for all variables with outdoor being greater than lab except for time-to-peak moment (p=0.188) 6. No patterns of dominant versus non-dominant upper limb contribution to propulsion were noted.
Richter et al. 2007b USA Post-Test N=26	**Population:** Mean age: 36 yr; Gender: males=19, females=7; Level of injury: paraplegia=24, spina bifida=2; Chronicity: chronic. **Intervention:** Propulsion of personal wheelchair on a treadmill set at level, 3° and 6° inclines. **Outcome Measures:** Speed, Force, Torque and loading rate, Cadence, Push angle, Power output, Push distance.	1. All kinematic factors increased significantly when the incline increased from level to 6°: peak handrim force, 1.4 increase; loading rate, 1.3 increase; axial moment, 1.8 increase (p=0.00). Push angle and cadence were not affected. 2. As the incline increased, distance traveled forward per push dropped (3°, p=0.034; 6°, p=0.00). Subjects utilized approximately 80 and 100 more pushes/km for the 3° and 6° inclines. 3. Coast time decreased from 0.43 sec (level) to 0.35 sec (6° incline). 4. Power output for the downhill wheel increased 1.6 and 2.3 times more than level for 3° and 6° (p=0.00).