Author, Year Country Study Design Sample Size	Population Intervention Outcome Measure	Results
(Schottler, Graf et al. 2019) USA Pre-Post (N=23)	**Population:** Age: 11.9 (7-19) yr; Gender: males=13, females=10; Level of injury: C6-L2; duration of manual wheelchair use 43.6 (3-132) mo; 26% had shoulder pain. **Intervention:** SmartWheel wheelchair training program. **Outcome Measures:** Peak force; peak backwards force; speed; push length; push frequency; peak/average force ratio; average push force; push mechanical effectiveness before and after training; Wheelchair User's Shoulder Pain Index.	1. After completion of the wheelchair training program, participants showed statistically significant improvements in mean peak backwards forces (reduction of 0.71 N) and pushing effectiveness (increase of 5.6%). 2. These changes suggest training improved participants' ability to translate energy into forward propulsion, but the clinical significance is unclear. 3. The effect sizes were small for these improvements. Other parameters neared statistical significance; as this was a pilot study, additional research is required as this may have been underpowered.
(Slavens et al., 2015) USA Observational N=12	**Population:** Age: 13.2±5.0 yr; Gender: males=10, females=2; Height: 137.4±29.9 cm; Weight: 41.8±13.4 kg. **Intervention**: A SmartWheel with an air tire, replaced the wheel on the dominant side of the subject's wheelchair for kinetic data collection; the SmartWheel companion wheel replaced the subject's wheel on the nondominant side. A 10-camera Vicon MX system captured the 3D marker trajectories at 120 Hz, while simultaneously the SmartWheel collected the 3D forces and moments occurring at the hand-handrim interface at 240 Hz. Vicon Nexus was used to process the marker trajectories. **Outcome Measures**: Upper Extremity Biomedical model – 3D joint angles, forces, and moments; Segment coordinate systems (SCS); wheelchair stroke cycle phases and periods; peak joint forces, angles, and moments.	1. The average propulsion speed was 1.23±0.26 (0.79-1.6) m/s with an average cadence of 1.1±0.2 strokes/sec. 2. The average contact phase occurred from 0-35.8% stroke cycle with a range of 25-45% stroke cycle. Within the contact phase, the initial contact period occurred on average from 0-3.6% stroke cycle, the propulsion period on average occurred from 3.6-34.1% stroke cycle, and the release period occurred on average from 34.1-35.8% stroke cycle. 3. One subject used the single-looping overpropulsion (SLOP) pattern, 3 subjects used the double-looping overpropulsion (DLOP) pattern, and 3 subjects used the recommended semicircular (SC) pattern. The remaining five subjects used a mixture of patterns making the primary pattern unidentifiable. 4. The average contact phase angle was 85.6 ± 15.7° and the average propulsion period angle was 72.6 ± 11.9°. 5. The average peak resultant handrim force was 10.1% BW ± 3.7% BW. 6. The elbow joint range of motion was statistically significantly higher than the acromioclavicular (AC; p<0.001) and thorax (p<0.001) joint ranges of motion in the sagittal plane. The elbow joint range of motion was significantly higher than the wrist (p<0.001), AC (p<0.001), sternoclavicular (SC; p<0.001) and thorax (p<0.001) joint ranges of motion in the transverse plane. 7. The glenohumeral (GH) joint range of motion was significantly higher than the elbow (p<0.001), AC (p<0.001), SC (p<0.001) and thorax (p<0.001) joint ranges of motion in the sagittal plane. The GH joint range of motion was significantly higher than the wrist (p<0.001), AC (p<0.001), and thorax (p<0.001) joint ranges of motion in the transverse plane. The GH joint range of motion was significantly higher than the AC (p<0.001), SC (p<0.001), and thorax (p<0.001) joint ranges of motion in the coronal plane. 8. The wrist joint range of motion was significantly higher than the AC (p<0.001),

		and thorax (p<0.001) joint ranges of motion in the sagittal plane. The wrist joint range of motion was significantly higher than the thorax joint range of motion in the transverse plane (p<0.001) and the AC (p<0.001) SC (p<0.001), and thorax (p<0.001) joint ranges of motion in the coronal plane. 9. The AC joint range of motion was significantly higher than the thorax joint range of motion in the transverse plane (p=0.015) and the coronal plane (p=0.002), while the SC joint range of motion was significantly higher than the thorax joint range of motion in the transverse plane (p=0.002). 10. The GH joint forces were statistically significantly higher than the wrist joint forces directed superiorly (p<0.001), laterally (p=0.019), and posteriorly (p<0.001). The wrist joint forces in the anterior (p=0.033) and inferior (p=0.046) directions were significantly greater than those at the GH joint. 11. The GH joint experienced significantly higher joint forces directed superiorly (p<0.001) and posteriorly (p<0.001) than the elbow joint. 12. The elbow joint experienced significantly higher forces than the wrist in the superior (p<0.001) and posterior (p<0.001) directions. 13. The GH joint experienced significantly greater moments in flexion (p=0.009) and extension (p<0.001) than the wrist joint. 14. The elbow was significantly greater than the wrist in the extension moment (p<0.001). 15. The GH joint experienced significantly higher moments than the elbow joint in internal rotation (p=0.043) and extension (p=0.002). The elbow experienced significantly higher flexion moment than the GH joint (p=0.001).
(Schnorenberg, Slavens, Graf, et al., 2014) USA Observational N=12	**Population**: Age: 13.2±5.0 yr; Gender: males=10, females=2; Height: 137±30 cm; Weight: 42±13 kg. **Intervention**: A SmartWheel (Out-Front, Mesa, AZ) replaced the wheel on the dominant side of the subject's wheelchair for kinetic data collection. A 14-camera Vicon MX System captured the 3D marker trajectories at 120 Hz, while the SmartWheel simultaneously collected 3D forces and moments occurring at the hand-hand-rim interface at 240 Hz. **Outcome Measures**: UE model – 3D joint angles, forces and moments; stroke cycles; peak forces and moments.	1. The average propulsion speed was 1.23±0.26 m/s. The average contact and recovery phases occurred from 0-35.8% stroke cycle and 35.8-100% stroke cycle, respectively. The relative transition time between phases occurred on average at 35.8% stroke cycle, with a range of 25-45% stroke cycle. 2. Within the contact phase, the initial contact period occurred on average from 0-3.6% stroke cycle, and the release period occurred on average from 34.1-35.8% stroke cycle. 3. One subject used the single looping over-propulsion (SLOP) pattern, 3 subjects used the double looping over-propulsion (DLOP) pattern, and 3 subjects used the semicircular (SC) pattern, which is recommended in the literature. The remaining 5 subjects used a variety of patterns. 4. The GH joint demonstrated the highest average peak forces, with 6.5% BW in the posterior direction and 6.1% BW in the superior direction, which were significantly higher (p<0.001) than the posteriorly and

		superiorly directed forces at the elbow and wrist joints. 5. The highest average joint moment was 1.36% BWxH of elbow flexion, with the GH joint flexion moment significantly less than both the elbow and wrist joint flexion moments ($p<0.01$). 1. The highest average peak GH joint moment was 1.2% BWxH of extension, which was significantly higher than the average peak extension moment of the elbow and wrist joints ($p<0.01$).
(Schnorenberg, Slavens, Wang, et al., 2014) USA Case Report N=1	**Population:** 17 yr, male, C7 SCI. **Intervention:** None. Measurements taken during wheelchair propulsion using a SmartWheel manual wheelchair system and passive reflective markers applied to the bilateral upper extremity joints. **Outcome Measures:** Bilateral upper extremity joint dynamics (for motion and loading patterns).	1. Asymmetry in joint forces and range of motion is common across the UE joints during manual wheelchair propulsion, but the clinical significance of this is unclear.