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# Sex differences in wheelchair propulsion biomechanics and mechanical efficiency in novice young able-bodied adults

**Dhissanuvach Chaikhot, Matthew Taylor, Florentina Hettinga (correspondence)**

University of Essex, School of Sport, Rehabilitation and Exercise Sciences

## Abstract

An awareness of sex differences in gait can be beneficial for detecting the early stages of gait abnormalities that may lead to pathology. The same may be true for wheelchair propulsion. The aim of this study was to determine the effect of sex on wheelchair biomechanics and mechanical efficiency in novice young able-bodied wheelchair propulsion. Thirty men and thirty women received 12-minutes of familiarization training. Subsequently, they performed two 10-metre propulsion tests to evaluate comfortable speed (CS). Additionally, they performed a 4-min submaximal propulsion test on a treadmill at CS, 125% and 145% of CS. Propulsion kinetics (via Smart$^{wheel}$) and oxygen uptake were continuously measured in all tests and were used to determine gross mechanical efficiency (GE), net efficiency (NE) and fraction of effective force (FEF). Ratings of perceived exertion (RPE) were assessed directly after each trial. Results indicated that CS for men was faster (0.98 ± 0.24 m/s) compared to women (0.71 ± 0.18 m/s). A lower GE was found in women compared to men. Push percentage, push angle and local RPE were different across the three speeds and between men and women. NE and FEF were not different between groups. Thus, even though their CS was lower, women demonstrated a higher locally perceived exertion than men. The results suggest sex differences in propulsion characteristics and GE. These insights may aid in optimizing wheelchair propulsion through proper training and advice to prevent injuries and improve performance. This is relevant in stimulating an active lifestyle for those with a disability.

**Keywords:** *Pushrim kinematics, comfortable speed, pushing economy, wheelchair exercise, gender*

## Introduction

Differences in gait parameters between the sexes have been reported during walking (Cho, Park, & Kwon, 2004). Additionally, psychophysical measures such as rating of perceived exertion (RPE) were found to be related to changes in walking speed (Chiu and Wang, 2007), where women demonstrated a higher local RPE than men in their lower back and rear thigh during normal walking speed (0.83 m/s - 1.38 m/s). Clearly, relevant differences exist in gait biomechanics and perceived psychophysiological measures between men and women. The same may be true for a different form of daily mobility relevant for those with a disability: wheelchair propulsion. However, sex differences in wheelchair propulsion biomechanics, psychophysical measures and comfortable speed have yet to be established. Most studies have been conducted in a male population, and not much is known about female-specific propulsion characteristics.

American census data showed that 58.84% (or 941,000 persons) of the total wheelchair user population were women (Kaye, Kang, & LaPlante, 2000). About 100,000 persons were young women aged in the range of 18-44 years (Kaye, et al., 2000). The number of women wheelchair users is expected to increase even more with the growing of the ageing population and the further increase in incidence of women with spinal cord injury (SCI), from 18.2% in 1980 to 20% in 2016 ("Spinal Cord Injury (SCI) 2016 Facts and Figures at a Glance," 2016). It has been well documented that women tend to be smaller in body size and weaker in muscle strength than men in both the SCI population as well as in the able-bodied population (Fay, Boninger, Cooper, Koontz, & Fitzgerald, 2000; Nicholas, Robinson, Logan, & Robertson, 1989). In persons with a SCI, shoulder torque was found to be 62%–96% lower in women than in men (Hatchett et al., 2009; Souza et al., 2005). Additionally, women have shorter upper extremities relative to their body length with narrower shoulder girdles compared to men (Boninger et al., 2003; Schultz, Lee, & Nance, 2001). These anthropometrical characteristics result in a biomechanical disadvantage for upper extremity activities leading to a high repetitive load on the shoulder joint (Boninger, et al., 2003; Hatchett, et al., 2009). Hence, the unique upper extremity structure of women accompanied by weaker muscles associated with a higher incidence of shoulder pain than observed in men engaging in the same levels of physical activities (Andersson, Ejlertsson, Leden, & Rosenberg, 1993). Although these sex differences in anthropometrics and strength between men and women have been established (Schultz, et al., 2001; Souza, et al., 2005), the potential impact of these differences on wheelchair propulsion biomechanics is unclear. The present study aimed to investigate the differences between novice young able-bodied men and women and how this impacted on propulsion speed, propulsion biomechanics, force effectiveness, mechanical efficiency and psychophysical parameters. Able-bodied individuals were selected to compare results of homogenous groups of men and women, and to eliminate unknown effects of different disabilities into the outcome parameters.

## Methods

### *Participants*

Thirty men (mean age: 26 ± 4 years, height: 1.75 ± 0.07 m, mass: 73.7 ± 13.4 kg) and 30 women (mean age: 27 ± 5 years, height: 1.62 ± 0.07 m, mass: 59.2 ± 12.7 kg). The participants were recruited using volunteer and convenient sampling method. Inclusion criteria were: 18-40 years, 150 - 190 cm tall, less than 90 kg of body mass to fit the wheelchair used (MacPhee, Kirby, Bell, & MacLeod, 2001), inexperienced in wheelchair use, absence of any musculoskeletal problems. An additional inclusion criterion was the ability to fit in the study wheelchair of width 0.42m. All participants completed a PAR-Q questionnaire and gave written informed consent prior to participation. Approval for the project was obtained from the University of Essex Ethics Committee.

### *Experimental Design*

All participants were given 12-minute familiarization as described by Vegter et al. (2014): four 3-minute over-ground familiarization blocks to roll a wheelchair over ground in a straight-line at their comfortable speed (CS) with a 2-minute break between blocks were completed (Vegter, de Groot, Lamoth, Veeger, & van der Woude, 2014). After familiarization, participants performed two trials of 10 seconds of over-ground propulsion at their CS. The comfortable speed from the averaged two trials was used for further testing on the treadmill. A further 5-minute familiarization was conducted on the treadmill with 8-minute subsequent recovery as described by previous studies (Kwarciak, Turner, Guo, & Richter, 2011), followed by the 3 x 4-minute submaximal wheelchair tests in the standardized wheelchair instrumented with a Smart$^{\text{wheel}}$ (Three Rivers Holdings, Arizona, USA) on the treadmill to investigate propulsion kinetics (torque produced at the hub; $M_z$, effective or tangential force; $F_t$ and total force applied; $F_{tot}$), timing parameters (push percentage, push frequency, push time, cycle time, and push angle) and efficiency parameters (fraction of effective force; FEF, net efficiency; NE and gross mechanical efficiency; GE). The submaximal tests were conducted at CS, 125% of CS and 145% of CS with 8 minutes of rest between trials.

Resting oxygen consumption ($\dot{V}O_{2rest}$) was collected by CPX (Jaeger, Hoechberg, Germany). During each trial, HR (Polar Electro, Kempele, Finland) and $\dot{V}O_2$ (Jaeger, Hoechberg, Germany) were continuously measured. After each trial, participants were immediately asked to report their perceived exertion of the whole body using the 15-point Borg scale of perceived exertion (central RPE 15) (Borg, 1970) and the perceived exertion of the arm and shoulder area by the 10-point scale for local perceived exertion (L-RPE 10) (Borg, 1982).

The timing parameters were determined from the torque signal as done in De Groot et al. (2003) (De Groot, Veeger, Hollander, & Van der Woude, 2003). The push frequency was defined as the number of pushes per minute. The push time was defined as the time duration that the hand applied a positive torque on the hand rim. The cycle time was defined as the amount of time from the onset of one push phase to the onset of the next. The push angle was defined as angle at the end of the push minus the angle at the start. The push phase was expressed as a percentage of the cycle time (%push phase) (De Groot, et al., 2003; Vegter, Lamoth, De Groot, Veeger, & Van der Woude, 2013). FEF was defined as the ratio between the magnitude of $F_{tot}$ and $F_t$ and expressed as a percentage, see Equation 1. GE was defined as the percentage of energy input that appears as useful external work, see Equation 2. In NE, energy expended was corrected for resting metabolism, see Equation 3.

*Experimental protocol*

The submaximal wheelchair test was performed in a standardized wheelchair. A non-folding ultra-light wheelchair (Quickie, USA) (seat height: 0.50m; diameter of the wheels: 0.64m; chair width: 0.42m; chair depth 0.41m*)* was mounted with a force- and torque-sensing SMART$^{\text{Wheel}}$ (3 Rivers Holdings, Mesa, AZ) to the right wheel to collect kinetic data (mass of 4 kg, wheel diameter of 0.64 m and handrim diameter of 0.56m) with a mass-matched dummy wheel on the left side. The total mass of the wheelchair was 14 kg.

Participants completed the familiarization sessions over ground and on the motor-driven treadmill (Saturn, HP-Cosmos, Nussdorf, Germany, 1.0 x 2.7 m) and comfortable speed was determined. Once the familiarization period was completed, participants were given 8 minutes to rest. After an 8-minute resting period, participants were asked to propel the wheelchair on the driven-motor treadmill as naturally as possible at three randomly imposed speeds: CS, 125% and 145% of CS. Each exercise bout lasted 4 minutes with an 8- minute rest interval to allow for HR to return close to their baseline. Participants did not receive any instructions on wheelchair propulsion style.

Oxygen consumption and HR were continuously collected during the trials. Kinetic data and physiological outcomes were calculated as an average value over 20 seconds of the steady state of the last minute. The last minute was used to evaluate physiological outcomes to ensure the steady-state oxygen consumption during wheelchair propulsion as described in previous studies (J. Lenton et al., 2013; Yang, Koontz, Triolo, Cooper, & Boninger, 2009). The total force ($F_{tot}$) and the tangential force ($F_t$) were calculated and derived from the SMART$^{Wheel}$ (Cooper, Robertson, VanSickle, Boninger, & Shimada, 1997). FEF was calculated and expressed as the time average FEF over the 20-min measurement period:

$FEF = F_t \cdot F_{tot}^{-1} \cdot 100$ (%) (1) (Veeger, Van der Woude, & Rozendal, 1991)

GE and NE were obtained. GE was calculated as the ratio of the external work to the metabolic energy expended during exercise. External work done was determined from the mean power output ($PO_{mean}$) values derived from the SMART$^{Wheel}$ during the handrim wheelchair propulsion for all speeds. GE was obtained during submaximal wheelchair exercise and calculated as the ratio between $PO_{mean}$ and total metabolic production of energy during exercise (En). Where En was calculated by multiplying oxygen uptake with the oxygen equivalent according to Garby and Astrup (Garby and Astrup, 1987).

$GE = PO_{mean} / En \cdot 100$ (%) (2)(Whipp and Wasserman, 1969)

Secondly, NE was calculated, an efficiency measure in which the energy expended during exercise was corrected for resting metabolism (Er).

$$NE = PO_{mean}/(En - Er) \cdot 100\ (\%) \qquad (3)$$

(Whipp and Wasserman, 1969)

The 15-point Borg scale of perceived exertion (central RPE 15) was applied to assess the rate of perceived exertion, where 6 represents ‘extremely light’ and 20 represents ‘extremely hard’ (Borg, 1970). The 10-point scale for local rate of perceived exertion (local RPE 10) was used to assess the feelings of exertion experienced at arms and shoulders, where 0 represents ‘nothing at all’ and 10 represents ‘extremely hard’ (Borg, 1982). Both RPE scales were reported immediately after each trial.

*Statistical analyses*

The data were analyzed using the Predictive Analytics Software (SPSS for Mac Version 19; SPSS Inc., Chicago, USA). Standard descriptive statistics (mean with standard deviations) were calculated for all variables. An independent t-test was performed to compare sex differences in demographic data and comfortable speed. A mixed analysis of variance (ANOVA) was applied to compare timing parameters, efficiency outcomes, HR and RPE between in men and women in the three submaximal wheelchair propulsion bouts. When a difference was found, a Bonferroni post hoc test adjusted for multiple comparisons were conducted to determine the sex and speed, which were significantly different from each other. A statistical significance level was set at $p < 0.05$.

## Results

*Resting heart rate and oxygen consumption*

No significant differences in $HR_{rest}$ (men 73.23±9.69 beats.min$^{-1}$ ; women 78.20±10.70 beats.min$^{-1}$; p = 0.065) and resting $\dot{V}O_2$ (men 4.62±1.00 ml/kg.min; 4.58±1.15 ml/kg.min; p = 0.86) were found between men and women.

*Comfortable speed*

The results showed comfortable speed for men was faster (0.98 ± 0.24 m/s) compared to women (0.71 ± 0.18 m/s) (p < 0.001).

*Timing parameters*

Comparisons of timing parameters obtained during CS, 125% of CS and 145% of CS between groups are shown in Table I. There was a significant (p < 0.001) speed effect for push percentage. There was a significant (p = 0.001) sex effect for push percentage whereby: men exhibited a significant lower push percentage than women at CS (p = 0.001), 125% of CS (p = 0.002) and 145% of CS (p = 0.005). No significant interactions between speed and sex (p = 0.865) were found for push percentage. There was a significant (p = 0.007) speed effect for push time. No significant sex effect and interactions between speed and sex for push time were found (p >0.05).

*Please insert table I about here*

There was a significant (p < 0.001) speed effect for push angle. There was a significant (p = 0.003) sex effect for push angle: men exhibited a significantly greater push angle than women at CS (p = 0.003), 125% of CS (p = 0.008) and 145% of CS (p

= 0.009). No significant interactions between speed and group were observed for push angle ($p = 0.09$). No significant main effects and interactions for push frequency and cycle time were detected.

### *Efficiency outcomes*

Means and standard deviations of the efficiency outcomes at CS, 125% of CS and 145% of CS are shown in Table II. There were no significant sex effects and interaction effects between speed and sex for FEF and NE. There was a significant ($p < 0.001$) speed effect for GE. There was a significant ($p < 0.05$) sex effect for GE with a significantly higher GE in men than women at CS ($p = 0.012$), at 125% of CS ($p = 0.038$) and at 145% of CS ($p = 0.006$). No significant interactions between speed and sex were found ($p = 0.66$).

*Please insert table II about here*

### *Heart rate and Psychophysiological parameters*

Means and standard deviations of HR during the final minute of propulsion, as well as central RPE and local RPE of the three trial speeds for men and women, are presented in Table III. There was a significant ($p < 0.001$) speed effect for HR. Men showed HR increased significantly between CS and 145% of CS ($p = 0.025$). Women showed HR increased significantly between CS and 125% of CS ($p = 0.003$), between CS and 145% of CS ($p < 0.001$), and between 125% of CS and 145% of CS ($p < 0.001$). There was no significant main effect for sex ($p = 0.727$) and interaction between speed and sex ($p = 0.075$) for HR.

*Please insert table III about here*

There was a significant ($p < 0.001$) speed effect for central RPE. No significant main effect for sex ($p = 0.686$) and no interaction between speed and sex ($p = 0.19$) for central RPE were found.

There were significant main effects ($p < 0.001$ and $p < 0.05$ for speed and sex, respectively) and interactions between speed and sex for local RPE. Bonferroni corrected post hoc tests showed that both groups experienced a significant increase in local RPE between CS and 125% of CS ($p < 0.001$), and between CS and 145% of CS ($p < 0.001$), and between 125% of CS and 145% of CS ($p < 0.001$); both men and women showed local RPE at CS was significantly lower than at 125% ($p < 0.05$) and at 145% of CS ($p < 0.001$) and local RPE at 125% of CS was significantly lower than 145% of CS ($p < 0.05$). Women exhibited a significantly higher local RPE than men at CS ($p < 0.001$), 125% of CS ($p < 0.001$) and at 145% of CS ($p < 0.001$).

## Discussion

The novice finding of the present study in novice young-able-bodied participants was that sex differences seem to exist in wheelchair propulsion. Men exhibited a faster comfortable propulsion speed compared to women. Interestingly, even though their propulsion speeds were lower, women rated their local perceived exertion higher, and demonstrated a lower GE compared to men. Sex-dependent differences were also found in propulsion characteristics. Men demonstrated a lower push percentage, a lower push frequency and a higher push angle compared to women. The demonstrated sex differences in propulsion characteristics seem to be relevant for clinical applications. More awareness of these differences might be needed, for example for appropriate wheelchair fitting and appropriate design of exercise programs and the development of optimal propulsion instructions in rehabilitation.

Comfortable speed in this study was comparable to those reported in the previous able-bodied studies (0.75 m/s – 0.98 m/s) (Hers, Sawatzky, & Sheel, 2016; Robertson, Boninger, Cooper, & Shimada, 1996). The present study demonstrated that women propelled themselves at lower comfortable propulsion speed compared to men. This can be explained by women bearing a shoulder strength deficit (Schultz, et al., 2001) coupled with a propulsion biomechanical disadvantage due to a shorter humerus bone relative to body length and a narrow shoulder girdle (Boninger, et al., 2003; Hatchett, et al., 2009). Muscular strength and anthropometric measures are greatly dependent on sex. Additionally, based on their relatively smaller body mass, women were propelling a proportionally heavier wheelchair. The 14-kg wheelchair was 24% of women's body mass compared to 19% of men's body mass. These could contribute to sex differences in comfortable propulsion speed and its characteristics, resulting in differences in PO and kinetic parameters. Based on these findings, propulsion biomechanics of men and women should be analyzed separately in wheelchair propulsion studies.

The greater feeling of physical effort (L-RPE) in women during wheelchair propulsion, even at their comfortable speed, might be associated with the higher incidence of shoulder pain compared to men engaging in the same levels of physical activities in both able-bodied and SCI population (Andersson, et al., 1993; Gutierrez, Newsam, Mulroy, Gronley, & Perrey, 2005). It could be implied that at the same relative wheelchair propulsion speeds, women demonstrate a greater relative contribution of the muscles around the shoulder joint. As mentioned earlier, women propelled a proportionally heavier wheelchair  to their body weight coupled with the relative strength deficit of rotator cuff muscles (Hatchett, et al., 2009), it is therefore not surprising that local RPE was higher compared to men. In the present study, the very low local RPE of men was comparable to those reported in the previous studies (Qi, Ferguson-Pell, Salimi, Haennel, & Ramadi, 2015). Our study was the first to report the local RPE of women during comfortable speed, at 5 or ‘hard’ level.

Mechanical efficiency indices reflect efficiency and economy of wheelchair propulsion. The values of mechanical efficiency were reported to vary between 5-16% for NE (Hintzy and Tordi, 2004; Knowlton, Fitzgerald, & Sedlock, 1981; J. P. Lenton, Fowler, Van der Woude, & Goosey-Tolfrey, 2008) and 2-1(Mason, Lenton, Leicht, & Goosey-Tolfrey, 2014)1% for GE in able-bodied and SCI individuals (De Groot, De Bruin, Noomen, & Van der Woude, 2008; Hers, et al., 2016; J. Lenton, et al., 2013; J. P. Lenton, et al., 2008; Van der Woude, Veeger, Dallmeijer, Janssen, & Rozendaal, 2001; Vanlandewijck, Theisen, & Daly, 2001; Veeger, et al., 1991; Yang, et al., 2009). Consistent with the literature, both groups of the present study demonstrated that NE ranged around 8.6% -10.6% and GE varied 4.1%-6.3% across the three speeds. We found that men performed wheelchair propulsion more efficiently (GE) compared to women across the three speeds. The difference in GE between men and women also supports the hypothesis of previous studies that GE of wheelchair propulsion depends on user characteristics (De Groot, et al., 2008; Medola, Elui, da Silva Santana, & Fortulan, 2014). However, it needs to be noted that men performed at higher velocities, and higher absolute exercise intensities were found to be associated with a higher efficiency (Moseley and Jeukendrup, 2001) due to the lower relative contribution of resting metabolism at higher velocities. When looking into NE, an efficiency parameter that corrects gross-efficiency for the relative contribution of basal metabolism (Moseley and Jeukendrup, 2001), no differences were found between sexes. This suggests that the lower gross-efficiencies found for women are associated with their lower propulsion velocities.

Push frequency is considered an important timing parameter of wheelchair propulsion. Push frequency at CS in this study was in agreement with the literature, 55-70 pushes/min (De Groot, et al., 2008; Hers, et al., 2016; J. Lenton, et al., 2013). Our finding showed that women propelled themselves with a higher frequency and a less push angle. This implies that an increased push frequency increases muscle contraction and energy expended, leading to a significantly higher local RPE found in women compared to men (Goosey-Tolfrey and Kirk, 2003). Our study showed push angles of 30° - 45° in accordance with the push angle in the literature, ranged 22° - 45° (Mason, et al., 2014; Rudins, Laskowski, Growney, Cahalan, & An, 1997). Push angle in men was significantly higher compared to women across the three speeds. Higher push angle in men might be due to anatomical and biomechanical advantage (Boninger, et al., 2003; Fay, et al., 2000; Hatchett, et al., 2009). Push percentages of 24% - 32% over the three speeds in the present study were consistent with the literature, ranging between 25% and 40% of the total cycle (J. Lenton, et al., 2013; Shimada, Robertson, Bonninger, & Cooper, 1998; Vanlandewijck, et al., 2001). Push percentage was significantly higher in women across the three speeds.  Sex differences in anthropometric and physiologic data may contribute to differences in push angle and push percentage between men and women. In women, shorter arms, narrower shoulders and a shorter torso (Schultz, et al., 2001) could result in increased elbow flexion, increased shoulder extension and increased shoulder abduction while gripping the top dead centre of the handrims. These joint positions would limit push arc range, decrease push angle and lower propulsion efficiency (Kotajarvi et al., 2004; Richter, 2001). Brubaker et al. (1984) noted that users with longer arms demonstrated an increase in propulsion efficiency over those users with shorter arms (Brubaker, McClay, & McLaurin, 1984). Push angle was also found to be affected by the horizontal seat position relative to the users total arm length (Hughes, Weimar, Sheth, & Brubaker, 1992). In the present study, higher push percentage and increased push time in women may be also related to smaller muscles with a greater proportional area of type I fibres resulting in slower contraction velocity and decreased power compared with men (Hunter, 2014).

An analogy with gait can be seen where women walk slower but with a higher step frequency and shorter step length compared to men (Bohannon, 1997). It has been suggested that walking with shorter steps and a higher step frequency could increase compressive loading to the joints, placing women at the high risk of lower limb injuries (Hunt, Birmingham, Giffin, & Jenkyn, 2006). In the same way, a higher push frequency with shorter push angle in wheelchair propulsion may cause women to experience greater shoulder pain and injury (Boninger, et al., 2003). Lenton et al. speculated that a decreased push frequency could be contributing to lowered intramuscular pressure along with a decreased oxygen transport resulting in improved efficiency and reduced shoulder pain (J. Lenton, et al., 2013).

Based on the reported sex differences, we suggest that women should receive more specific attention regarding their physical capacity, propulsion speed and propulsion technique as well as wheelchair selection. Lighter weight wheelchairs may be more suitable for women's functional features because they are easier to operate and less force is required (DiGiovine et al., 2000; Medola, et al., 2014). This could help to reduce mechanical load and the risk of developing upper extremity injuries in women users (Medicine, 2005). To prescribe wheelchair training or exercise, or any intervention to women, experts should be considering the difference in psychophysical responses to wheelchair propulsion between men and women. Our findings also enhance better understanding of wheelchair propulsion efficiency in men and women. More importantly, awareness of sex differences may aid in optimizing wheelchair propulsion through proper training and advice to prevent injuries and improve performance.

There are limitations to the present study. Firstly, the use of the same standardized ultra-light wheelchair (Quickie, USA) without individual adjustments relative to anthropometrics of the participants could be a limitation, as a proper fit of the manual wheelchair to the user has been found to be important for optimal wheelchair propulsion (Kotajarvi, et al., 2004). However, the literature in able-bodied novice users has consistently used the similar non-adjustable wheelchair to all participants to evaluate kinetics and efficiency outcomes during wheelchair propulsion (J. Lenton, et al., 2013; Mason, et al., 2014) and using the standardized wheelchair configuration has as benefit that it excludes the impact of different wheelchair setups on physiological and biomechanical parameters (Kotajarvi, et al., 2004). As the aim of this study was to investigate the impacts of sex on speed, kinetics and psychophysiology of wheelchair propulsion, it was crucial to eliminate any bias caused by wheelchair model/setups.

Secondly, we chose to include able-bodied participants. This leads to a homogenous group of subjects, where differences between severity and type of disability will not interfere with our data. However, it limits the transferability of our results to wheelchair users, and it will be of interest to also look into sex differences on wheelchair propulsion in persons with different disabilities.

Considering the sex differences in this study merits not only awareness of these differences, but also provides useful data to be able to interpret any deviations from this able-bodied pattern due to disabilities. It has also been suggested that able-bodied novice wheelchair exercisers share similar features with newly injured individuals (Van Den Berg, De Groot, Swart, & Van Der Woude, 2010). Therefore, our findings could be, at least, transferable to the newly injured population in the initial stages of rehabilitation.

## Conclusion

Differences between men and women were found in wheelchair comfortable propulsion speed, gross efficiency and several propulsion characteristics. Able-bodied young men demonstrated a faster comfortable propulsion speed, a lower push percentage and greater push angle compared to the able-bodied young women. Even though their propulsion speed was slower, women experienced higher locally perceived exertion ratings compared to men. Awareness of these differences may aid in optimizing wheelchair propulsion through proper training and advice to prevent injuries and improve performance. This research can be used as a starting point to initiate more specific research into gender differences in different disability groups, and will be relevant in stimulating an active lifestyle for those with a disability.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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Table I. Mean values ± SD of the timing parameters at CS, 125% and 145% of CS for men and women

| Variable | Sex | Speed | | | Post hoc |
|---|---|---|---|---|---|
| | | CS | 125% | 145% of CS | |
| Push percentage [%cycle][a,b,c,d,e,f] | M | 26.63 ± 5.71 | 25.04 ± 5.65 | 23.82 ± 6.29* | CS>125%,<br>CS>145% |
| | W | 32.01 ± 6.09 | 30.00 ± 6.00* | 28.65 ± 6.60* | |
| Push frequency [pushes/min] | M | 63.70 ± 18.12 | 65.30 ± 24.63 | 66.50 ± 22.98 | - |
| | W | 70.60 ± 23.45 | 74.60 ± 23.63 | 74.60 ± 23.26 | |
| Push time [s][a] | M | 0.27 ± 0.09 | 0.25 ± 0.08 | 0.25 ± 0.12 | CS>125%,<br>CS>145% |
| | W | 0.30 ± 0.11 | 0.26 ± 0.09* | 0.25 ± 0.08* | |
| Cycle time [s] | M | 1.06 ± 0.40 | 1.03 ± 0.32 | 1.10 ± 0.54 | - |
| | W | 0.95 ± 0.34 | 0.93 ± 0.40 | 0.91 ± 0.32 | |
| Push angle [degree][a,b,d,e,f] | M | 38.61 ± 11.97 | 41.75 ± 11.61 | 45.16 ± 12.93*,† | CS<125%<145% |
| | W | 29.66 ± 9.99 | 32.68 ± 13.75 | 35.90 ± 13.74*,† | CS<125%<145% |

[a] Significant main effect for Speed, [b] Significant main effect for Sex, [c] Significant interaction between Speed x Sex, [d] significant men to women pairwise comparison in CS, [e] significant men to women pairwise comparison in 125% of CS, [f] significant men to women pairwise comparison in 145% of CS, * = the value is different from CS, † = the value is different from 125% of CS, - = post hoc analysis was not performed due to non-significant main effect, M = men, W = women, CS = comfortable speed. All differences are $P < 0.05$.

Table II. Mean values ±SD of efficiency outcomes (GE, NE and FEF) at comfortable speed, 125% and 145% of comfortable speed for men and women

| Variable | Sex | Speed | | | Post hoc |
|---|---|---|---|---|---|
| | | CS | 125% | 145% | |
| FEF [%] | M | 69.27 ± 14.68 | 69.29 ± 11.50 | 72.32 ± 11.73 | - |
| | W | 67.81 ± 12.80 | 64.83 ± 13.90 | 64.23 ± 12.81 | |
| NE [%] | M | 9.60 ± 3.25 | 10.48 ± 2.97 | 10.67 ± 3.89 | - |
| | W | 8.72 ± 2.84 | 9.12 ± 3.08 | 8.64 ± 2.80 | |
| GE [%]$^{a,b}$ | M | 5.16 ± 1.67 | 5.50 ± 1.55 | 6.30 ± 1.80$^{*,\dagger}$ | 125%<145%, |
| | W | 4.14 ± 1.34 | 4.68 ± 1.44 | 5.12 ± 1.36$^{*}$ | CS%<145% |

[a] Significant main effect for Speed, [b] Significant main effect for Sex, * = the value is different from CS, † = the value is different from 125% of CS, - = post hoc analysis was not performed due to non-significant main effect, M = men, W = women, CS = comfortable speed. All differences are P < 0.05.

Table III. Mean values ± SD of the heart rate (beats.min$^{-1}$), the central rate of perceived exertion (Central RPE 15) and the local rate of perceived exertion (Local RPE 10) after completion of the exercise bouts for the men and women

| Variable | Sex | Speed | | | Post hoc |
|---|---|---|---|---|---|
| | | CS | 125% | 145% | |
| HR [beats.min$^{-1}$][a] | M | 97.18 ± 16.96 | 100.55 ± 16.16 | 104.52 ± 17.81* | CS<125%<145% |
| | W | 95.07 ± 25.09 | 102.47 ± 19.83* | 109.83 ± 23.01*,† | |
| Central RPE15[a] | M | 9.93 ± 2.12 | 10.93 ± 2.12* | 12.33 ± 2.73*,† | CS<125%<145% |
| | W | 9.93 ± 2.45 | 10.83 ± 2.74* | 11.67 ± 3.21*,† | |
| Local RPE10 [a,b,c,d,e,f] | M | 2.82 ± 1.83 | 3.48 ± 2.05* | 4.50 ± 2.13*,† | CS<125%<145% |
| | W | 5.50 ± 1.89 | 6.10 ± 2.02* | 6.85 ± 2.31*,† | |

[a] Significant main effect for Speed, [b] Significant main effect for Sex, [c] Significant interaction between Speed x Sex, [d] significant men to women pairwise comparison in CS, [e] significant men to women pairwise comparison in 125% of CS, [f] significant men to women pairwise comparison in 145% of CS, * = the value is different from CS, † = the value is different from 125% of CS, - = post hoc analysis was not performed due to non-significant main effect, M = men, W = women, CS = comfortable speed. All differences are $P < 0.05$.