Validity of two wheelchair-mounted devices for estimating wheelchair speed and distance travelled

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Background

- Methods to assess physical activity in people using wheelchairs are limited.[4]
- **Wheelchair-mounted devices** such as accelerometers and gyroscopes - have been shown to exhibit acceptable reliability and validity for quantifying activity during **outdoor sports, treadmill-based pushing and standardised, overground pushing tasks**.[2-4]
- However, findings from these studies **cannot be confidently generalised to wheelchair activity performed in free-living environments.**[4]

1. Conger SA, Scott SN, Fitzhugh EC, Thompson DL, Bassett DR. Validity of Physical Activity Monitors for Estimating Energy Expenditure During Wheelchair Propulsion. J Phys Act Health. 2015;12(11):1520-6.
2. Lemay V, Routhier F, Noreau L, Phang SH, Ginis KA. Relationships between wheelchair skills, wheelchair mobility and level of injury in individuals wi spinal cord injury. Spinal Cord. 2012;50(1):37-41.
3. Sonenblum SE, Sprigle S, Caspall J, Lopez R. Validation of an accelerometer-based method to measure the use of manual wheelchairs. Med Eng Phys. 2012;34(6):781-6.
4. Hiremath SV, Ding D, Cooper RA. Development and evaluation of a gyroscope-based wheel rotation monitor for manual wheelchair users. J Spinal Cord Med. 2013;36(4):347-56.

Background

- Commonly used device to monitor distance and speed during wheelchair-based aerobic exercise sessions are **commercially available cycling computers, including the Cateye®**. Evidence indicates that **cycling computers provide valid measures of distance and speed during continuous wheelchair driving on a motor driven treadmill and linear track tests.** [5-7]
- Recently, a wheelchair-mounted, gyroscope-based device called **Wheeleri** has been **developed specifically for the purpose of monitoring speed and distance of wheelchair-based activities in free-living environments**. However, the **validity of the device has not yet been evaluated.**

5.. Litchke LG, Russian CJ, Lloyd LK, Schmidt EA, Price L, Walker JL. Effects of Respiratory Resistance Training With a Concurrent Flow Device on Wheelchair Athletes. The Journal of Spinal Cord Medicine. 2008;31(1):65-71.
6. Wilson SK, Hasler JP, Dall PM, Granat MH. Objective assessment of mobility of the spinal cord injured in a free-living environment. Spinal Cord. 2008;46(5):352-7.
7. Levy CE, Buman MP, Chow JW, Tillman MD, Fournier KA, Giacobbi P. Use of Power Assist Wheels Results in Increased Distance Traveled Compared with Conventional Manual Wheeling. American Journal of Physical Medicine & Rehabilitation. 2010;89(8):625-34.

The aim of the study

- **The aim of this study** was to **evaluate the validity** of two wheelchair-mounted devices - the **Cateye® and the Wheeleri –using** a standardised protocol designed to replicate **activities of daily living** typically performed by manual wheelchair users.

Cateye®

Wheeleri

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Device setting

Cateye®

Cateye® magnet

Cateye® speed sensor

Cateye® computer (data logger)

Wheeleri

Wheeleri the data acquisition unit

Wheeleri magnetic plate

Wheeleri mobile App

Methods

- This study was part of a larger body or research investigating the validity of multiple physical activity measures in wheelchair users, with data collected in Finland and in Australia.
- The **validity of the speed and distance estimates of the Cateye® and the Wheeleri was evaluated using separate protocols.** The criterion measure was **measured speed and measured distance**.
- **Agreement** between measured and estimated speed (km/h) and measured and estimated distance (m) were **evaluated by** calculating **mean bias with 95% limits of agreement and mean absolute percentage error (MAPE).**
- The accuracy level for MAPE was classified as:
  - "good" = MAPE was ≤5%;
  - "moderate" when MAPE was >5% but ≤10%;
  - "poor" when MAPE was >10% but ≤20%; and
  - "very poor" when MAPE was >20%.

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Speed protocol

- In speed protocol an unoccupied chair was mounted on a calibrated **treadmill.**
- An incremental speed protocol was used, beginning at 1.5km/h and increasing by 0.5km/h after every minute until 10km/h

  (in total 17 minutes).

Distance protocol

- Testing was undertaken in the **participant's own wheelchair in public sporting gymnasiums**.
- Participants completed **18 discrete tasks** (with 30 activities), that were designed to reflect the common wheelchair-based activities of daily living.
- **Tasks were divided into four categories for analysis:**
  1. Wheelchair propulsion – linear, discontinuous;
  2. Wheelchair propulsion – continuous with turning in one direction;
  3. Wheelchair propulsion – with maneuvering;
  4. Confined Space Maneuvering.

Categories (4)	Tasks (18)	Distance (m)
1. Wheelchair propulsion – linear discontinuous	1. Push chair forward 20m at self-selected COMFORTABLE pace with stop at 10m; 2. Push chair forward 20m at self-selected BRISK pace with stop at 10m 3. Push chair forward 20m at self-selected FAST pace with stop at 10m 4. Reverse chair backward 20m at self-selected pace with stop at 10m 5. Push chair forward 18m at self-selected pace with stops at 6, 12 and 18m 6. Pushing the chair backward 18m at self-selected pace with stops at 6, 12 and 18m	20m 20m 20m 20m 18 m 18 m **Total; 116m**
2. Wheelchair propulsion – continuous with turning in one direction	7. Push chair forward with a 90° turn to the left every 10 m until two squares have been completed (80 m). Repeat to right (80 m). 8. As per Activity #7 but wheelchair user is passive while their wheelchair is pushed by an assistant 9. Continuous forward push around the perimeter of 4 rectangles of increasing size – the first 10m x 1m, the next 10m x 3m, then 10m x 5m and finally 10m x 7m. Total push distance of 125.6m. The task was first completed with all turns to the left, then to the right.	80m (L) 80m (R) 80m (L) 80m (R) 125.6m (L) 125.6m (R) **Total: 571.2m**
3. Wheelchair propulsion – with maneuvering*	10. Five markers evenly spaced over 1.10m with the wheelchair user beginning to the left of the first marker and passing through the next three markers in a slalom fashion, turning 180° at the last marker, returning to the start, turning 180° at the first marker and repeating the task completing 22.4m a total push distance. Repeat to the right. 11. Shopping aisle push - participants push a straight-line distance of 5 m with a stop every 1 m to, alternately, "take an item" from a bottom shelf on the left and then reach for an item above head height crossing to the right side completing 5m total push distance. Repeat to right. 12. Pushing 1m flat surface, pushing up a 1.65meter ramp, turning 180° left and pushing down a ramp and 1m flat surface completing 7.3m total push distance. Repeat to the right. 13. Pushing chair over 5 thresholds 1cm high and 80cm wide, each 1 m apart for a total push distance of 5m. Repeat. 14. Pushing chair forward 2 meters to a 10cm curb, mount the curb and turning 180° left at the top of the curb, dismount the curb and push chair forward 2 meters completing a total push distance of 5m. Repeat with 180° turn right.	22.4m (L) 22.4m (R) 5m (L) 5m (R) 7.3m (L) 7.3m (R) 5m (L) 5m (R) 5m (L) 5m (R) **Total: 89.4m**
4. Confined space maneuvering	15. Push chair forward with a four 90° turn to the left every 1.10 m completing a total push distance of 4.4m. Repeat to right. 16. Three markers evenly spaced over 1.10m with the wheelchair user beginning to the left of the first marker and push the chair forward 1.10m to a second marker. making a 360° spin to the left. Push the chair forward 1.10m to the last marker and making a 360° spin to the left completing 6.55m total push distance. Repeat to the right. 17. Six 0.72m wide parking spaces marked on the ground. Wheelchair user push chair forward 0.72m and reversing the chair to the parking space and push forward 0.72m and reverse to a next parking space completing 6 reverse and 20.7m total push distance. Repeat to the right. 18. Seven markers spaced on zigzag figure over 0.55m. Wheelchair user beginning toes behind the first marker push the chair forward 0.55m to a second marker. Reversing the chair 0.55m with 45° left angle to the third marker. push the chair forward 0.55m to the fourth marker. Reversing the chair 0.55m with 45° left angle to the fifth marker. Push the chair forward 0.55m to the sixth marker. Reversing the chair 0.55m with 45° left angle to the seventh marker completing 6.6m total push distance. Repeat to the right.	4.4m (L) 4.4m (R) 6.55m (L) 6.55m (R) 20.7m (L) 20.7m (R) 6.6m (L) 6.6m (R) **Total: 76.5m**

Results: speed

Cateye® estimates:

- **good** for **speeds ≥ 3km/h**
- **very poor for speeds < 3km/h** (MAPE >20%).

Wheeleri estimates:

- good for all speeds (MAPE ≤5%)

Speed	Cateye	Wheeleri
<3km/h	Very poor (MAPE >20%)	Good (MAPE ≤5%)
≥ 3km/h	Good (MAPE ≤5%)	Good (MAPE ≤5%)

	Cateye			Wheeleri		
Speed	MAE	MAPE	Mean bias (±95% LoA) km/h	MAE	MAPE	Mean bias (±95% LoA) km/h
Speed 1.5 km/h	1.5km/h	100%	-1.5 (0.0-0.0)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 2.0 km/h	2km/h	100%	-2.0 (0.0-0.0)	0.03km/h	1.3%	0.0 (-0.07-0.02)
Speed 2.5 km/h	2.5km/h	100%	-2.5 (0.0-0.0)	0.03km/h	1.0%	0.0 (-0.02-0.07)
Speed 3 km/h	0.08km/h	2.5%	0.1 (0.03-0.1)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 3.5 km/h	0.08km/h	2.1%	0.1 (0.03-0.1)	0.03km/h	0.7%	0.0 (-0.02-0.07)
Speed 4 km/h	0.10km/h	2.5%	0.1 (0.0-0.0)	0.02km/h	0.6%	0.0 (-0.02-0.07)
Speed 4.5 km/h	0.10km/h	2.2%	0.1 (0.02-0.2)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 5 km/h	0.18km/h	3.5%	0.2 (0.13-0.22)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 5.5 km/h	0.10km/h	1.8 %	0.1 (0.0-0.0)	0.02km/h	0.5%	0.0 (-0.02-0.07)
Speed 6 km/h	0.10km/h	1.7%	0.1 (0.0-0.0)	0.03km/h	0.4%	0.0 (-0.02-0.07)
Speed 6.5 km/h	0.13km/h	1.9%	0.1 (0.08-0.17)	0.02km/h	0.4%	0.0 (-0.02-0.07)
Speed 7 km/h	0.13km/h	1.8%	0.1 (0.08-0.17)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 7.5 km/h	0.15km/h	2.0%	0.2 (0.09-0.21)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 8 km/h	0.15km/h	1.9%	0.1 (0.09-0.21)	0.00km/h	0.0%	0.0 (0.0-0.0)
Speed 8.5 km/h	0.15km/h	1.8%	0.1 (0.09-0.21)	0.02km/h	0.3%	0.0 (-0.02-0.07)
Speed 9 km/h	0.20km/h	2.2%	0.2 (0.0-0.0)	0.02km/h	0.3%	0.0 (-0.02-0.07)
Speed 9.5 km/h	0.20km/h	2.1%	0.2 (0.0-0.0)	0.02km/h	0.3%	0.0 (-0.02-0.07)
Speed 10 km/h	0.20km/h	2.0%	-0.2 (0.0-0.0)	0.00km/h	0.0%	0.0 (0.0-0.0)

Results: distance

- **Twenty-five participants** completed the distance protocol.
- Nineteen participants completed all 18 tasks and six participants completed 17 tasks.
- **Five** were **unable to perform** the 10cm **curb ascend** and **one** was **unable to perform the 20m backward** wheelchair propulsion test.

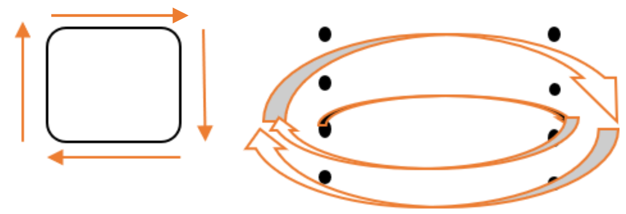
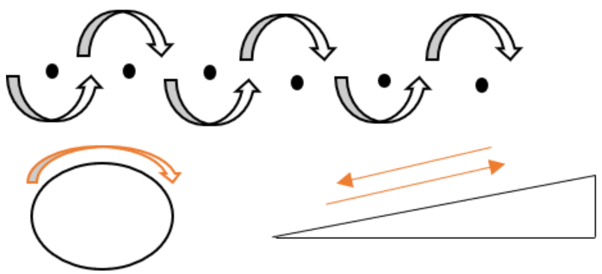
Characteristics (n=25)	Mean (SD)	
Age (years)	42 (13)	
Height (cm)	170.3 (17.9)	
Weight (kg)	80.0 (25.1)	
Time wheelchair use (years)	18.7 (12.5)	
Characteristics (n=25)	**n**	**%**
Sex		
Male	20	80
Diagnoses		
SCI	14	56
Spina bifida	3	12
Postinfectious autoimmune neuropathy	2	8
Epidural abscess	1	4
Transverse myelitis	1	4
Tumor	1	4
Cerebral Palsy	1	4
Osteogenesis imperfecta	1	4
Motor neuron disease	1	4
Hand Dominance		
Right	23	92
Country of testing		
Finland	12	48
Australia	13	52

SCI: Spinal cord injury

Results: distance

Cateye® estimates:

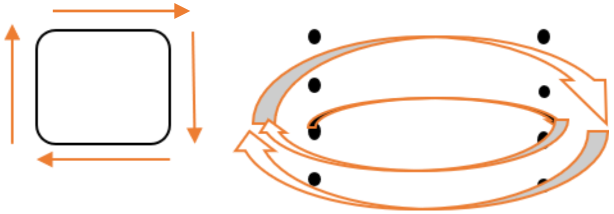
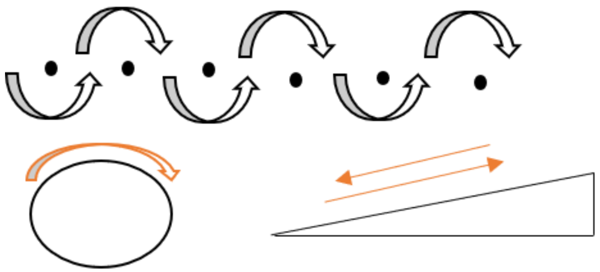
- moderate for continuous propulsion, turning in one direction
- very poor in the other categories.

Category		Cateye accuracy (MAPE %)
1. Wheelchair propulsion – linear, discontinuous		Very Poor 53.5%
2. Wheelchair propulsion – continuous with turning in one direction		Moderate 6.0%
3. Wheelchair propulsion – with maneuvering		Very poor 80.9%
4. Confined Space Maneuvering		Very poor 77.9%

Results: distance

Wheeleri estimates:

- good for linear discontinuous and continuous wheelchair propulsion
- moderate for propulsion with maneuvering
- very poor for maneuvering within a confined space.

Category		Wheeleri accuracy (MAPE %)
1. Wheelchair propulsion – linear, discontinuous		Good 1.3%
2. Wheelchair propulsion – continuous with turning in one direction		Good 5.3%
3. Wheelchair propulsion – with maneuvering		Moderate 9.6%
4. Confined Space Maneuvering		Very poor 28.4%

Discussion

- Both **Cateye® and Wheeleri provides accurate estimates of speed and distance** in activities with **continuous wheelchair pushing over 3km per hour**, such as pushing to school or to work, or when wheeling for exercise.

→ Results for the Cateye® was expected because it is **principally designed for use on bicycles** which are typically used for long, uni-directional, continuous cycling, similar to tasks with continuous wheelchair propulsion, turning in one direction.

Discussion

- **Wheeleri** also **provided accurate estimates of speed and distance at low speeds**.

→ The average speed for daily living activities for MWU's is approximately 1.7km/h.[2]

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2. Lemay V, Routhier F, Noreau L, Phang SH, Ginis KA. Relationships between wheelchair skills, wheelchair mobility and level of injury in individuals wi spinal cord injury. Spinal Cord. 2012;50(1):37-41.

Discussion

- **Wheeleri** was **accurate in all other categories except with confined space wheelchair propulsion.**
- All **inaccuracies for Wheeleri were due to over-estimations** and two factors are likely to explain these results:
  - Firstly, the challenge of following the optimal path increased with chair width and task difficulty

→Any and all departures from the optimal path would increase the distance estimated by the Wheeleri and increase the discrepancy between measured and estimated distance.

  - Secondly, there is the issue of **pivoting or spinning**, which can confound distance estimation because although **the physical location of the chair does not change** (i.e., it moves no distance), **the wheel rotation will be recorded** by the devices as a distance moved.

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Discussion

- The data were collected from participants varying in age, nationality and experience with using a manual wheelchair.

  → improves the external validity of the study and the generalizability of the findings.

- The protocol consisted of a range of tasks and short bouts of activity including mobilizing across a range of distances, directions, speeds and undertaking maneuvering tasks such as parking and travelling up ramps, which are representative of real-life situations for manual wheelchair users.[8]

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8. Sonenblum SE, Sprigle S, Lopez RA. Manual Wheelchair Use: Bouts of Mobility in Everyday Life. Rehabilitation Research and Practice. 2012;2012:753165.

Discussion

- As with all wheel mounted devices, either of these devices **does not provide an indication of the intensity** of activities performed.
- However, **Wheeleri** can **provide data on the frequency and duration** of daily wheelchair mobility

→ important feature for promoting physical activity in wheelchair users: **increasing frequency and duration of activity first** and then focusing **intensity**

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Conclusions

- In conclusion, both **Cateye® and Wheeleri provides** an accurate estimation of speed and distance for activities typical of wheelchair-based aerobic exercise.
- Furthermore, Wheeleri can provide manual wheelchair **users, clinicians and researchers a suitable indicator of individual's physical activity level** based on wheelchair moving time and distance **in free-living outdoor and indoor environments.**

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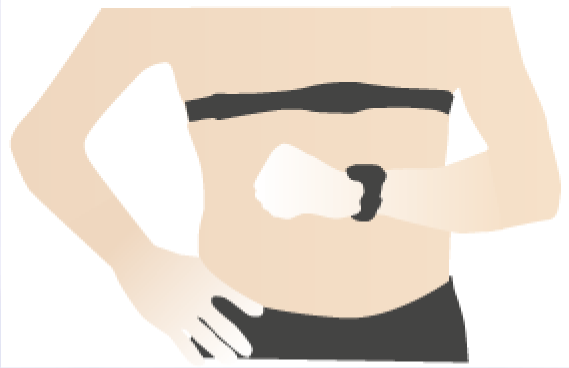
Future research

- Influence of **different pushing surfaces** to the accuracy
- **Excluding the influence of any extra movements** in order to capture the true travelled distance of the wheelchair by using a smart wheel or similar as a criterion measure.
- **Combining technology** of wearable and wheelchair-mounted physical activity monitors **to give all information of individuals physcial activity in one device**



Thank you for your attention!

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Welcome to my poster presentation at 16.00-17.30

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