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# A systematic review on the pros and cons of using a pushrim-activated power-assisted wheelchair

**Marieke GM Kloosterman[1], Govert J Snoek[1,2], Lucas HV van der Woude[3], Jaap H Buurke[1] and Johan S Rietman[1,4,5]**

## Abstract

**Objective:** To determine the (dis)advantages of transition to a power-assisted wheelchair, and derive the clinical implications for its use or prescription.

**Data sources:** Relevant articles published prior to May 2012 were identified using PubMed, Cochrane Library, REHABDATA, CIRRIE and CINAHL databases.

**Review methods:** Clinical or (randomized) controlled trials, published in a peer-reviewed journal, comparing power-assisted wheelchair use and hand-rim or powered wheelchair use were eligible. Data quality and validity were assessed by two reviewers independently using the Checklist for Measuring Quality developed by Downs and Black.

**Results:** A systematic search yielded 15 cross-over trails with repeated measurement design and one qualitative interview. Methodological quality scored between 9 and 15 points out of the maximum score of 32. Ten studies measuring body function and structure reported reduced strain on the arm and cardiovascular system during power-assisted propulsion compared to hand-rim propulsion. Twelve studies measuring activities and social participation reported precision tasks easier to perform with a hand-rim wheelchair and tasks which require more torque were easier with a power-assisted wheelchair. Social participation was not altered significantly by the use of a hand-rim, powered or power-assisted wheelchair.

**Conclusion:** Power-assisted propulsion might be beneficial for subjects in whom independent hand-rim wheelchair propulsion is endangered by arm injury, insufficient arm strength or low cardiopulmonary reserves. Also, subjects who have difficulty propelling a wheelchair in a challenging environment can benefit from power-assisted wheelchair use. Caution is warranted for the additional width and weight in relation to the usual mode of transportation and access to the home environment.

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## Introduction

A wheelchair increases independent mobility for people with lower limb impairments.[1] Independent hand-rim wheelchair mobility can be endangered by arm injury, pain, insufficient arm strength, low cardiopulmonary reserves, inability to maintain posture[1], but also a physical challenging environment (for example carpets or steep inclines).[2] To overcome these debilities and challenging environments, alternatives such as an assistant pushing the wheelchair, transition to a powered wheelchair or use of a mobility scooter might be preferred.[1] The risk of these alternatives is the possibility to develop a less physically active lifestyle which may predispose to many long term health problems.[3,4] To remain physically active in a wheelchair, crank or lever-propulsion can be considered. This propulsion technique is more efficient than hand-rim wheelchair propulsion, however, less useful for indoors.[3] Nowadays, transition to a power-assisted wheelchair is also an option. This might be an interesting alternative in the context of preservation of arm function as well as the need to remain physically active.[1,4]

Pushrim-activated power-assisted wheelchairs have been topic of scientific rehabilitation research for about a decade. Gradually these wheelchairs become available for use in clinical practice.[2] The power-assisted wheelchair is a hybrid between hand-rim and powered wheelchairs. It consists of a hand-rim wheelchair with electro-motors embedded into the wheels or wheelchair frame. When a subject exerts power on the hand-rim, the motor is activated and augments the delivered power.[5]

The transition to a power-assisted wheelchair may influence not only the arm function or the cardiopulmonary system of the subject,[3] but also, for instance, performance of daily activities and social participation. For example, the wheels are heavier than normal manual wheelchair wheels (approximately 10 kg per wheel), which might influence transportation possibilities and car transfers. In addition, because the control mechanism differs from the usual way of propulsion, the additional power and possible delay in applying additional power might influence the control over the wheelchair.[3]

In this systematic review we intend to present the current knowledge about transition from a hand-rim or powered wheelchair to a power-assisted wheelchair. The pros and cons of transition to a power-assisted wheelchair and their clinical implications are important information for the wheelchair user to make a deliberate choice about a possible transition to a power-assisted wheelchair. For healthcare professionals and healthcare policy this information is necessary to underpin their advice about use, prescription or reimbursement of a power-assisted wheelchair.

## Methods

This review was based on a systematic literature search of studies published till May 2012 in the following databases: PubMed, the Cochrane Library, REHABDATA (produced by National Rehabilitation Information Center for Independence), CIRRIE (Center for International Rehabilitation Research Information and Exchange) and CINAHL (Cumulative Index to Nursing and Allied Health Literature). We used the following search strategy in PubMed:

1) Wheelchair AND power assist*
2) Wheelchair [MeSH] AND power assist*
3) Wheelchair AND power support

4) Wheelchair [MeSH] AND power support
5) PAPAW

where * indicates a wildcard search; [MeSH], Medical Subject Headings; PAPAW, pushrim-activated power-assisted wheelchair.

The other databases were searched with line 1, 3 and 5 of this search strategy, so without the MeSH terms. In addition, we checked the references of the included studies for relevant additional publications.

We based the initial selection of articles on title and abstract. Two reviewers (MK, GS) independently selected and extracted data from the studies and scored their methodological quality using a systematic approach and checklist. The reviewers met regularly to discuss their findings and decisions. If consensus was not reached, a third reviewer could be consulted (HR).

A study was included in this review when it:

- investigated the effect of power-assisted wheelchair propulsion on human functioning compared to hand-rim or powered wheelchair propulsion;
- was a clinical trial or (randomized) controlled trial;
- was published as a full-length paper in a peer-reviewed journal in the English language.

We excluded studies which focused on engineering, for example studies testing a power-assisted wheelchair to ANSI/RESNA standards[5] or describing the control mechanism.[6,7] To enable the most comprehensive review of the current literature, we included studies involving wheelchair users as well as healthy subjects.

The 'Checklist for Measuring Quality' of Downs and Black[8] was used to assess the methodological quality of the included studies. This checklist is a valid and reliable checklist suitable for the assessment of randomized as well as non-randomized studies.[8,9] The checklist consists of 27 questions covering five areas of methodological quality: reporting, external validity, bias (internal validity), confounding (internal validity), and power.[8] All areas were assessed and a total score was calculated with a maximum score of 32. For inclusion in this review no minimum score for methodological quality was required.

We scanned the general contents of the studies for: methodology, design, study population, types of wheelchairs used, intervention, measurements, and main findings. The main findings were grouped into part 1: functioning and disability, and part 2: contextual factors, of the ICF (International Classification of Functioning, Disability and Health) model. Both parts comprised two components: (1a) body functions and structure, (1b) activities and participation, (2a) environmental factors, (2b) personal factors.[10] The results of the comparison between propulsion in a hand-rim or powered wheelchair and propulsion in a power-assisted wheelchair were considered to be positive if there was a significant difference, as calculated by an appropriate statistical test. For studies without statistical analysis, or without statistical significant results, the main findings according to the aim of this study were presented.

## Results

The systematic literature search in PubMed resulted in the identification of 264 studies. Fifteen of these studies fulfilled the selection criteria, and were included in the present review. Additional searches in databases of the Cochrane Library, REHABDATA, CIRRIE and CINAHL resulted in one additional inclusion. Checking the reference list of relevant publications did not result in new inclusions. Figure 1 depicts the literature search which resulted in 16 eligible studies for this review.[11–26]

Fifteen studies were cross-over trials with a repeated measurements design, comparing power-assisted to hand-rim or powered wheelchair use.[11–19,21–26] One study consisted of multiple qualitative interviews.[20] Two studies did not perform a statistical analysis.[20,25] Complete agreement about the scoring of the methodological quality was reached in 375 of the 405 scores (92.6%). Entire consensus was attained by discussion. The studies scored between

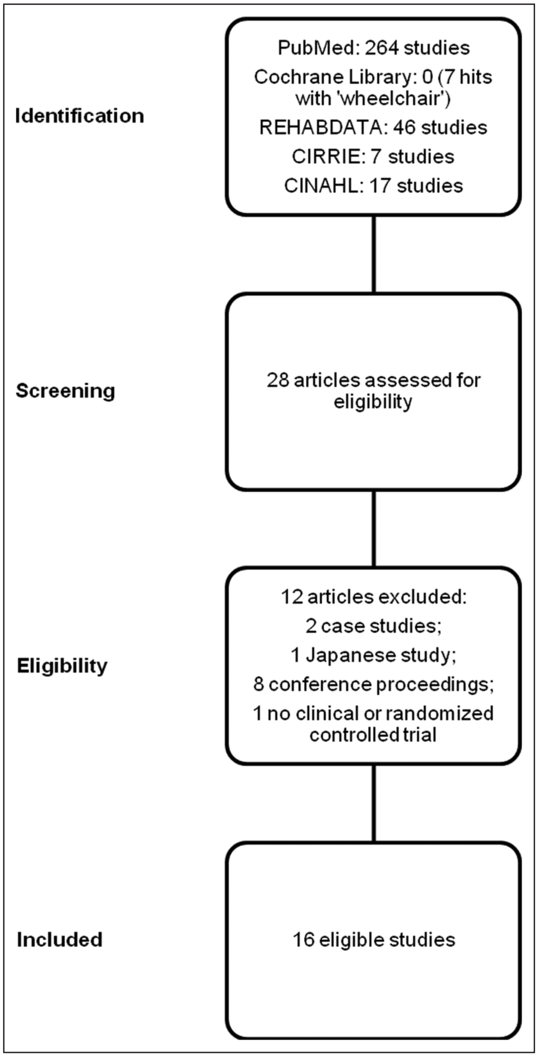


**Figure 1.** Flowchart showing the systematic literature search process.

9 and 15 points out of the maximum score of 32 (Table 1). The methodological quality of the study of Kloosterman et al.[12] is not rated and the content is not extensively reported in this study because of conflicting interest.

A detailed overview of the articles is presented in Table 2, below a summary of the main findings of the included studies.

The power-assisted wheelchairs used were Yamaha JWII (Yamaha Motor Company, Shizuoka, Japan. Available in the United States as Quickie Xtender, Sunrise Medical, Longmont, Colorado.),[11,13,14,16–19,24,25] Alber E.motion (Ulrich Alber GmbH, Albstadt-Tailfingen Germany),[15,20–22,25,26] Delta Glide[23] (DeltaGlide Inc., Hamden, Connecticut was available from Independence Technology as the iGLIDE (Independence Technology, Warren, New Jersey), no longer available) and a prototype power-assisted wheelchair (Indes Holding B.V., Enschede, The Netherlands not yet available).[12] The Alber E.motion and the Yamaha JWII systems are power-assisted wheels which fit on most of the hand-rim wheelchair frames. The DeltaGlide is an integrated system of motor and chair. The control system of the Yamaha JWII differs from the control system used by the Alber E.motion and DeltaGlide. The Yamaha JWII gives proportional assistance. For more demanding tasks more power is added by the system. The assistance given by the Alber E.motion or DeltaGlide depends on the chosen setting. The amount of power remained the same regardless the demands of the task.

Thirteen studies were performed in the USA.[11,13,14,16–20,22–26] Seven of them were carried out at the University of Pittsburgh and the Human Engineering Research Laboratory of Pittsburgh, Pennsylvania.[11,13,14,16–19] The three studies performed outside the USA were performed in Canada[15,21] and the Netherlands.[12] In the USA the Medicare policy determines that an individual receives one wheeled mobility device every five years.[22] This makes it impossible to use a power-assisted wheelchair next to a hand-rim or powered wheelchair or mobility scooter, which is a possibility in the Netherlands.

Movement analysis of the arm during power-assisted propulsion compared to hand-rim propulsion resulted in a significantly decreased wrist ulnar–radial deviation and flexion–extension.[17] At the shoulder, flexion–extension[12,17] and internal–external rotation[12,13] significantly decreased. Shoulder abduction tended to decrease, however, this was not significant.[13,17] The results on push frequency were not unambiguous.[13,16,17,24,25] Muscle activation patterns were compared between regular hand-rim and power-assisted propulsion[12,23,24] with different test

**Table 1.** Methodology quality according to the Checklist for Measuring Quality.[8]

| | Domains Checklist for Measuring Quality | | | | | |
|---|---|---|---|---|---|---|
| | Report | External validity | Internal validity | | Power | Total |
| | | | Bias | Confounding | | |
| Maximum score: | 11 | 3 | 7 | 6 | 5 | 32 |
| First author | | | | | | |
| Algood (2005)[11] | 7 | 0 | 4 | 1 | 1 | 13 |
| Algood (2004)[13] | 7 | 0 | 4 | 1 | 1 | 13 |
| Arva (2001)[14] | 7 | 0 | 4 | 1 | 0 | 12 |
| Best (2006)[15] | 7 | 0 | 4 | 1 | 2 | 14 |
| Cooper (2001)[16] | 7 | 0 | 4 | 1 | 0 | 12 |
| Corfman (2003)[17] | 7 | 0 | 4 | 1 | 2 | 14 |
| Ding (2008)[18] | 7 | 0 | 3 | 1 | 0 | 11 |
| Fitzgerald (2003)[19] | 5 | 0 | 3 | 1 | 0 | 9 |
| Giacobbi (2010)[20] | 5 | 1 | 3 | 0 | 0 | 9 |
| Giesbrecht (2009)[21] | 7 | 1 | 3 | 1 | 0 | 12 |
| Levy (2010)[22] | 8 | 1 | 5 | 1 | 0 | 15 |
| Levy (2004)[23] | 7 | 0 | 4 | 1 | 0 | 12 |
| Lighthall-Haubert (2009)[24] | 7 | 0 | 4 | 1 | 0 | 12 |
| Lighthall-Haubert (2005)[25] | 5 | 0 | 3 | 1 | 0 | 9 |
| Nash (2008)[26] | 7 | 1 | 4 | 1 | 0 | 13 |

protocol and measurement techniques (surface[12,23] and fine-wire electromyography[24]), therefore summarization of the results is difficult. However, all studies reported a significant decreased activity in the pectoralis major and in two studies activity in the triceps brachii significantly decreased[12,23] during power-assisted propulsion. Lighthall-Haubert et al.[24] found similar supraspinatus activity during hand-rim and power-assisted propulsion, probably because the available power-assisted wheelchair had a seat 18-inches (48 cm) wide, whereas for propulsion in the standard hand-rim wheelchair a seat width of 16 or 18 inches (41 or 48 cm) was selected based on the size of the subjects. This may have required increased glenohumeral abduction during power-assisted propulsion.[24]

Power-assisted propulsion tends to reduce the cardiovascular and respiratory strain compared to hand-rim propulsion. Heart rate was lower during power-assisted propulsion compared to hand-rim propulsion on an activities of daily living (ADL) course,[11] and at particular speed and resistance combinations in the dynamometer trials.[13,16] During propulsion on different surfaces, increase of heart rate from rest was significantly lower with a power-assisted wheelchair.[23] A study comparing propulsion in three different brands of power-assisted wheelchairs with hand-rim propulsion reported a reduced heart rate in four of the five subjects during power-assisted propulsion, regardless of brand.[25] Significantly lower oxygen consumption was detected during power-assisted propulsion compared to regular hand-rim propulsion on the dynamometer and stationary rollers.[13,14,16,26] During propulsion on a test track the oxygen consumption was significantly decreased for the Xtender and E.motion (not for the iGlide) compared to the regular hand-rim wheelchair.[25] Perceived exertion for propulsion[23,26] was significantly lower for power-assisted propulsion compared to hand-rim propulsion. In qualitative interviews, 16 out of 20 people reported less fatigue with a power-assisted wheelchair.[20]

Measuring daily activities on a test track showed that carpet, dimple strips, ramp and curb

**Table 2.** Details of eligible studies. The outcome measures are classified according to the four components of the ICF model: body functions and structure; activities and participation; environmental factors; and personal factors.

| First author (year)<br>*n* = Size and pathology population<br>**I** = Intervention<br>**M** = Measurements | Quality score total<br>Design | Significant changes in the outcome measurements | | | |
|---|---|---|---|---|---|
| | | Body functions and structure | Activities and participation | Environmental factors<br>Wheelchairs used<br>Setting comments | Personal factors |
| **Algood (2005)**[11]<br>*n* = 15; cervical SCI<br>**I:** self-developed ADL course with 18 tasks. Own MWC <-> PAPAW<br>**M:** Heart rate, time to complete tasks, questionnaires (difficulty of completing obstacles; ergonomics both wheelchairs) | 13<br>Cross-over trial with RM | Using PAPAW: lower heart rate | With PAPAW obstacles carpet, dimple strips, ramp, and curb cut easier to complete<br>In third trial compared to first trial carpet, ramp, bump, curb cut, toilet, bathroom sink, turning on kitchen faucet and bus docking space easier to complete | PAPAW: Yamaha JWII on Quickie 2<br>Pittsburgh, Pennsylvania<br>PAPAW easier to propel than MWC | N/A |
| **Algood (2004)**[13]<br>*n* = 15; cervical SCI<br>**I:** Dynamometer propulsion 0.9 m/s, with 10, 12 and 14 W resistance. Own MWC <-> PAPAW<br>**M:** Velocity, energy consumption, heart rate, push frequency, ROM shoulder, elbow, wrist | 13<br>Cross-over trial with RM | Using PAPAW: Lower energy consumption; *14 W*: lower HR; higher mean velocity; all ROMs decreased except shoulder ab-adduction. *10 and 12 W*: lower push frequency less ROM shoulder flexion–extension, internal–external rotation, horizontal flexion–extension, and wrist ulnar–radial deviation; *12 W* in addition less ROM in pro-supination. | Higher velocity with PAPAW at 14 W resistance | PAPAW: Yamaha JWII on Quickie 2<br>Pittsburgh, Pennsylvania | N/A |
| **Arva (2001)**[14]<br>*n* = 10; 9× SCI T2–T12, 1× MS<br>**I:** Dynamometer propulsion 0.9 m/s with 9, 12 and 13 W and 1.8 m/s with 24 and 30 W resistance. Own MWC <-> PAPAW<br>**M:** Torque hubs and physiological data | 12<br>Cross-over trial with RM | Using PAPAW: lower metabolic power (W) and user power (W applied to the dynamometer) | N/A | PAPAW: Yamaha JWII on Quickie 2<br>Pittsburgh, Pennsylvania<br>PAPAW higher mechanical efficiency | N/A |

**Table 2.** Continued

| First author (year)<br>*n* = Size and pathology population<br>**I** = Intervention<br>**M** = Measurements | Quality score total<br>Design | Significant changes in the outcome measurements | | | |
|---|---|---|---|---|---|
| | | Body functions and structure | Activities and participation | Environmental factors<br>Wheelchairs used<br>Setting comments | Personal factors |
| **Best (2006)**[15]<br>*n* = 30; able-bodied<br>**I:** Wheelchair Skill Test[30] (after 2 hours of training). MWC <-> PAPAW<br>**M:** Total scores, skill success scores | 14<br>Cross-over trial with RM | N/A | No significant differences in wheelchair skill scores | PAPAW: E.motion on Quickie LXI<br>MWC: Quickie LXI<br>Halifax Canada | N/A |
| **Cooper (2001)**[16]<br>*n* = 10; 9× SCI T2–L2, 1× MS<br>**I:** Dynamometer propulsion own MWC <-> PAPAW: 0.9 m/s with 10, 12 and 14 W and 1.8 m/s with 25 and 30 W resistance. ADL course of DiGiovine et al.[34]<br>**M:** Metabolic energy consumption, ADL evaluation with: subjects rating, time to complete, heart rate, and ergonomics | 12<br>Cross-over trial with RM | Using PAPAW: lower oxygen consumption all conditions; *1.8 m/s–30 W and 0.9 m/s–12 W lower* heart rate; *0.9 m/s–10 and 12 W* higher ventilation | Lower score on car transfer: taking of/putting on the wheels PAPAW trial 3 compared to PAPAW trial 1 lower completion time and higher rating large speed bump | PAPAW: Yamaha JWII on Quickie 2.<br>Pittsburgh, Pennsylvania<br>PAPAW higher score on stability | N/A |
| **Corfman (2003)**[17]<br>*n* = 10; 9× SCI T2–T12, 1× MS<br>**I:** Dynamometer propulsion 0.9 m/s with 10, 12 and 14 W and 1.8 m/s at 25 and 30 W resistance. Own MWC <-> PAPAW<br>**M:** Arm ROM, push frequency | 14<br>Cross-over trial with RM | Using PAPAW: *0.9 m/s (12 and 14 W) and 1.8 m/s at 30 W*: decreased shoulder flexion/extension, horizontal flexion/extension and wrist ulnar/radial deviation; *0.9 m/s, 14 W and 1.8 m/s, 25 W*: decreased elbow flexion/extension and wrist flexion/extension | N/A | PAPAW: Yamaha JWII on Quickie 2<br>Pittsburgh, Pennsylvania | N/A |

(Continued)

**Table 2.** Continued

| First author (year)<br>*n* = Size and pathology population<br>**I** = Intervention<br>**M** = Measurements | Quality score total<br>Design | Significant changes in the outcome measurements | | | |
|---|---|---|---|---|---|
| | | Body functions and structure | Activities and participation | Environmental factors<br>Wheelchairs used<br>Setting comments | Personal factors |
| **Ding (2008)[18]**<br>*n* = 15; cervical SCI<br>**I:** Normal wheelchair use:<br>2 weeks MWC <-> 2 weeks PAPAW<br>**M:** Data logger recorded mobility; Daily questionnaires on activities, 2-weekly PIADS (psychosocial impact) | 11<br>Cross-over trial with RM | N/A | Using PAPAW faster travelling<br>No significant differences in community participation and psychosocial impact | PAPAW: Yamaha JWII on Quickie 2 or Quickie GP<br>Pittsburgh, Pennsylvania<br>No significant differences in wheelchair satisfaction | No significant differences in psychosocial impacts |
| **Fitzgerald (2003)[19]**<br>*n* = 7; SCI (T3–T12)<br>**I:** Normal wheelchair use:<br>2 weeks MWC <-> 2 weeks PAPAW<br>**M:** Data logger recorded mobility; Weekly questionnaires on activities | 9<br>Cross-over trial with RM | N/A | No significant differences in activities between MWC and PAPAW usage | PAPAW: Yamaha JWII on Quickie<br>Pittsburgh, Pennsylvania<br>Weather did not impact whether the persons left the house or not | Personal reasons such as illness did not impact whether the person left the house or not |
| **Giacobbi (2010)[20]**<br>*n* = 20; varying pathologies<br>**I:** Normal wheelchair use 4 weeks own MWC -> 8 weeks PAPAW -> 4 weeks own MWC<br>**M:** Qualitative interviews | 9<br>Interview | Qualitative interviews, no test statistics performed | Qualitative interviews, no test statistics performed | PAPAW: E.motion on own MWC<br>Tucson, Florida | Qualitative interviews, no test statistics performed |
| **Giesbrecht (2009)[21]**<br>*n* = 8 dual users (MWC and PWC); varying pathologies<br>**I:** Normal wheelchair use: 3 weeks own PWC <-> 3 weeks PAPAW<br>**M:** Questionnaires on activity and social participation: QUEST, FEW, PIADS, COPM | 12<br>Cross-over trial with RM | N/A | No significant differences on activity and social participation between PWC and PAPAW use | PAPAW: E.motion on own MWC or Sunrise Quickie 2<br>Manitoba, Canada | Using PAPAW lower score on self-esteem |

**Table 2.** Continued

| First author (year)<br>*n* = Size and pathology population<br>**I** = Intervention<br>**M** = Measurements | Quality score total<br>Design | Significant changes in the outcome measurements | | | |
|---|---|---|---|---|---|
| | | Body functions and structure | Activities and participation | Environmental factors<br>Wheelchairs used<br>Setting comments | Personal factors |
| **Levy (2010)**[22]<br>*n* = 20 elderly; varying pathologies<br>**I:** normal wheelchair use: 4 weeks own MWC -> 8 weeks PAPAW -> 4 weeks own MWC<br>**M:** Bicycle computer recorded distance | 15<br>Cross-over trial with RM | N/A | Using PAPAW further traveling compared with both baseline and follow-up phases<br>Travelled distances in weeks 1–2 lower than in weeks 3–4 and 7–8 | PAPAW: E.motion on own MWC<br>Gainsville, Florida | N/A |
| **Levy (2004)**[23]<br>*n* = 11; elderly; varying pathologies<br>**I:** Propulsion on a linoleum floor (100 m), a thick polyester carpet (21 m), and an incline (6 m). Own MWC <-> PAPAW<br>**M:** sEMG extensor carpi radialis, triceps brachii, anteromedial deltoid, posteromedial deltoid, pectoralis major, latissimus dorsi, rectus abdominus and erector spinae, HR, questionnaires: PAS-LI, FSI, SIP, FIM, CAPAW | 12<br>Cross-over trial with RM | Using PAPAW: lower heart rate rise, and perceived exertion, reduced sEMG activity in extensor carpi radialis, triceps brachii, pectoralis major, latissimus dorsi | N/A | PAPAW: DeltaGlide on a Colours in Motion wheelchair<br>Gainsville, Florida | N/A |
| **Lighthall-Haubert (2009)**[24]<br>*n* = 14; SCI C6 or C7, ASIA grade A or B<br>**I:** propulsion at a stationary ergometer during free, fast and graded resistance (4% or 8%) propulsion. Own MWC <-> PAPAW<br>**M:** fine-wire EMG sternal or clavicular part pectoralis major, anterior deltoid, supraspinatus and infraspinatus; cycle length; cadence | 12<br>Cross-over trial with RM | Using PAPAW:<br>Decreased peak intensity all muscles and conditions except for the supraspinatus during free propulsion<br>Decreased median EMG intensity during fast and graded propulsion and for pectoralis major, anterior deltoid during free propulsion<br>Less perceived exertion | Using PAPAW: lower velocity and cadence with increased cycle length during fast propulsion.<br>Higher velocity and increased cycle length during graded trial | PAPAW: Quickie Xtender<br>Downey, California | N/A |

(Continued)

**Table 2.** Continued

| First author (year)<br>*n* = Size and pathology population<br>**I** = Intervention<br>**M** = Measurements | Quality score total<br>Design | Significant changes in the outcome measurements | | | |
|---|---|---|---|---|---|
| | | Body functions and structure | Activities and participation | Environmental factors<br>Wheelchairs used<br>Setting comments | Personal factors |
| **Lighthall-Haubert (2005)**[25]<br>*n* = 5; complete SCI C6, C7, T12<br>**I:** 20 minutes of continuous propulsion on SS speed over 126 m outdoor cement track. Own MWC <-> 3 PAPAWs<br>**M:** propulsion characteristics metabolic demands | 9<br>Cross-over trial with RM | Descriptive statistics | Descriptive statistics | PAPAW: iGlide, Xtender, and E.motion, last 2 were mounted on a Quikie 2<br>Downey, California | N/A |
| **Nash (2008)**[26]<br>*n* = 18; 12× paraplegia and 6× tetraplegia (ASIA A or B) confirmed shoulder pain<br>**I:** 6 min steady-state propulsion without resistance and 12 min intensity-graded propulsion on stationary rollers; both at greatest attainable speed<br>**M:** Metabolic energy consumption, RPE, questionnaire WUSPI | 13<br>Cross-over trial with RM | Using PAPAW lower energy costs. RPE only significant lower during resisted propulsion | Using PAPAW higher velocity | PAPAW: E.motion on own MWC<br>Miami, Florida | N/A |
| **Kloosterman (2012)**[12]<br>*n* = 9 healthy subjects<br>**I:** Propulsion at a treadmill at 0.9 m/s. Own MWC <-> PAPAW<br>**M:** shoulder kinematics; kinetics at rim and shoulder; sEMG anterior, middle, posterior deltoid; sternal head pectoralis major; middle trapezius; long head biceps brachii; long head triceps brachii | N/A<br>Cross-over trial with RM | Using PAPAW: significantly decreased maximum shoulder flexion and internal rotation angles and decreased peak force on the rim resulting in decreased shoulder flexion, adduction and internal rotation moments and decreased forces at the shoulder in the posterior, superior and lateral directions. Muscle activation in the pectoralis major, posterior deltoid and triceps brachii decreased | N/A | PAPAW: prototype, not yet commercial available<br>Enschede, The Netherlands | N/A |

<->compared to; ->, followed by; ADL, activities of daily living; ASIA, American Spinal cord Injury Association; C, injury on cervical level; CAPAW, Consumer Assessment of Power Assist Wheelchairs; COPM, Canadian Occupational Performance Measure; EMG, electromyography; FEW, Functioning Everyday with a Wheelchair; FIM, Functional Independence Measure; FSI, Jette Functional Status Index; HR, heart rate; MS, multiple sclerosis; L, injury on lumbar level; MWC, manual (hand-rim) wheelchair; N/A, not applicable; PAPAW, pushrim-activated power-assisted wheelchair; PAS-LI, Physical Activity Scale for Persons with Locomotor Impairments; PIADS, Psychosocial Impact of Assistive Devices Scale; PWC, powered wheelchair; QUEST, Quebec User Evaluation of Satisfaction with assistive Technology; RM, repeated measurements desingn; ROM, range of motion; RPE, rate of perceived exertion; SCI, spinal cord injury; sEMG, surface electromyography; SIP, Sickness Impact Profile; T, injury on thoracic level; WC, wheelchair; WUSPI, Wheelchair Users Shoulder Pain Index.

are significantly easier to complete with power-assist[11] and removing and replacing wheels was significantly more difficult.[16] Best et al.[15] identified no significant differences. However, the healthy participants ranked the hand-rim wheelchair as more effective for tasks which require greater control such as turns, moving through a doorway and wheelie skills. The power-assisted wheelchair seemed easier for tasks which required more force, such as curbs, irregular surface and ascent–descent.[15] Based on questionnaires, powered wheelchair users preferred the powered wheelchair for activities outdoors, whereas the power-assisted wheelchair was preferred for tasks performed in a confined space.[21]

Measurements in the home environment comparing power-assisted wheelchair use with hand-rim or powered wheelchair use reported no significant differences on activity (in example daily duration of wheelchair use, involvement in occupational activities), social participation and psychosocial impact,[18–21] except for faster traveling[18] and travelling longer distances with a power-assisted wheelchair.[22]

Qualitative analysis showed that subjects experienced increased ease of propulsion with a power-assisted wheelchair (respectively 73% ($n$ = 11/15;[18] $n$ = 8/11[23]); 85% ($n$ = 6/7) of the participants[19]). Mainly power-assisted propulsion on level and inclines (91% ($n$ = 10/11)) and carpet (82% ($n$ = 9/11)) were rated as (very) easy compared to hand-rim wheelchair propulsion.[23] In addition, 43% ($n$ = 3/7) reported an improved ability to climb hills.[19] Manoeuvring a power-assisted wheelchair in confined spaces was a limitation for 20% of the participants.[18] The additional width of the power-assisted wheelchair made it difficult to manoeuvre indoors.[18,19] Difficulties with taking the power-assisted wheelchair wheels in and out of a vehicle was also reported[18,20] The car transfer, which required taking off and putting on the wheels, was not possible for 50% ($n$ = 5/10) of the subjects when using the power-assisted wheelchair.[16] Individuals with the capacity to transport the chair with ease, for instance with a lift, spouse, public transport or other assistance, reported superior benefits from the power-assisted wheelchair.[20] Positive experiences with a power-assisted wheelchair, including access to new and different activities, was perceived in 65% ($n$ = 13/20) of the participants.[20] Also 65% ($n$ = 13/20) experienced the use of a power-assisted wheelchair as less burdensome and experienced greater independence.[20] More independence was also experienced in 40% ($n$ = 6/15) of the participants in the study by Ding et al.[18]

## Discussion

The main results of this systematic review imply that power-assisted propulsion reduced the strain on the arms and cardiovascular system compared to hand-rim wheelchair propulsion. Precision tasks seemed easier with a hand-rim wheelchair, while tasks which require more torque seemed easier with a power-assisted wheelchair. Social participation was not affected significantly by the use of a hand-rim, powered or power-assisted wheelchair.

This review was confounded by a number of factors. First, despite the extensive search we possibly failed to notice relevant publications because the initial selection was done by one of the authors only and four articles were excluded based on language or study design. Second, a meta-analysis was not possible. The relatively small research populations, small number of articles per outcome measure and the variety in methodology made it difficult to make an extensive comparison. Third, the methodological quality of all studies scored less than half of the maximum score on the checklist for measuring quality. The areas with the lowest scores were external validity, confounding and power, warranting caution with generalization of the results. Self-evidently, a first step in investigating a relatively new technology is done within an experimental setting and with a small study population. Also blinding is hardly possible. Hence, to our opinion a randomized controlled trial in which subjects are their own controls is the best feasible protocol to evaluate two different types of wheelchairs. Fourth, the results of this review must be generalized to other hand-rim wheelchair users with care. The majority of the studies assessed subjects with a spinal cord injury, which is a small part of the total hand-rim wheelchair population. The inclusion of studies with healthy subjects[12,15] as well as hand-rim wheelchair users[11,13,14,16–20,22–26] or dual users[21] with varying pathology resulted in the description of a population with a large variety in arm function and physical condition. The studies included in this review solved this problem by using a within-subject comparison. Therefore, personal variations such as lesion level and arm strength were tackled as confounders.

Transition from a hand-rim wheelchair to another type of mobility device, such as a powered wheelchair, is induced because of arm injury, pain, insufficient arm strength, low cardiopulmonary reserves or inability to maintain posture.[1] According to this systematic review, power-assisted wheelchair propulsion could have an effect on all these factors, except the inability to maintain posture.

Guidelines for lowering the risk of arm injury during hand-rim wheelchair propulsion focus on the spinal cord injury population.[4,27] These guidelines recommend minimizing extreme or potentially injurious positions at all joints, especially extreme wrist positions and positions where the shoulder is prone to impingement. The combination of extreme internal rotation with abduction or forward flexion, and maximum shoulder extension combined with internal rotation and abduction should be avoided.[4] The results of this review showed that the abovementioned angles decreased during power-assisted propulsion compared to hand-rim propulsion.[12,13,17] Two studies[13,17] reported slightly different results despite a comparable experimental setup. A plausible explanation for these differences might be that Algood et al.[13] measured subjects with a cervical spinal cord injury and Corfman et al.[17] mainly measured subjects with a thoracic spinal cord injury. The spinal cord lesion level influences the kinematics during hand-rim wheelchair propulsion.[24,28,29]

Another recommendation to lower the risk on arm injury is to reduce the push frequency as well as the amplitude of forces and moments exerted on the rim and acting on the shoulder. The results for push frequency yielded conflicting results, and only one study with healthy subjects investigated the force applied to the hand-rim during propulsion.[12] The results were promising, however the measurements should be repeated with hand-rim wheelchair users before generalization to the wheelchair user population is possible. With this review no long-term effects on shoulder injuries were identified.

For subjects with insufficient arm strength and low cardiopulmonary results the power-assisted wheelchair seems beneficial. The effort needed to propel a power-assisted wheelchair in comparison with a hand-rim wheelchair is reduced, based on significantly decreased: intensity of muscle activation of the majority of the measured shoulder and arm muscles,[12,23,24] heart rate,[11,13,16,23] metabolic costs[13,14,16,26] and perceived exertion.[23,26] On the other hand, physical inactivity occurs disproportionately among those with disabilities, contributing to obesity and a cycle of deconditioning and further decline.[22] It is plausible that the physical fitness further declines when travelling with less effort. However, if the transition from a hand-rim to a powered wheelchair can be postponed with a power-assisted wheelchair, subjects retain, at least to some extent, the benefits of exercise by hand-rim wheeling.[14,17,23] Currently the long-term effects of power-assisted propulsion on the cardiovascular system are unknown.

Power-assisted propulsion seemed beneficial for tasks which require more effort and seemed less convenient for tasks which require more control when compared to hand-rim wheelchair propulsion. Three different tests were used to determine wheelchair skills. The Wheelchair Skill Test[30,31] is a valid and reliable test. The outcome of this test is a series of pass or fail tests. Algood et al.[13] and Cooper et al.[16] both analysed an ADL course with a standardized but not validated test. Besides pass or fail, they did a more extensive examination by measuring time to complete the task, heart rate and a visual analogue scale (VAS) score to determine ease of completing the tasks. None of the protocols measured removing and replacing wheels. This is an important task because this is a prerequisite for a car transfer, for instance, and therefore for usability and independence. Because of the additional weight of approximately 10 kg per wheel, it is a challenging task. To increase comparability between studies investigating wheelchair skills, consensus about the included skills and standardization of measurements should be reached.[32,33]

Activity monitoring in the home environment of the subjects was investigated in four studies.[18–22] The only significant differences were faster[18] and further travelling with a power-assisted wheelchair compared to a hand-rim wheelchair.[22] Two findings are noteworthy because they might explain the lack of more significant differences. First, in two studies subjects could use their own wheelchair within the power-assisted trial.[18,19] In the study of Ding et al.[18] subjects in the power-assisted trial used their own hand-rim wheelchair at a similar frequency as the power-assisted wheelchair. For the study of Fitzgerald et al.[19] this factor was unknown. Second, Levy et al.[22] found that the first two weeks could be considered as an adjustment phase in which subjects are less active than in subsequent weeks.[22] Two of the studies measured only two weeks of power-assisted propulsion, and therefore possibly missed an increase in activity.

The number of involved activities[19,21] as well as occupational performance[19,21] and quality of life[18] did not change significantly using a power-assisted instead of a hand-rim wheelchair. A possible explanation is that daily activities are more related to changes in behavioural and social routines[19] than to change of wheels. Changing habits is not likely to occur within two weeks, especially when the subject is aware of the fact that the chair must be returned to the investigators.[19] In addition, habit change might also depend on factors such as transportability, social network and personal factors as force, fatigue or physical fitness.

Environmental and personal factors received limited attention in the included studies. Because a wheelchair is often the primary mode of daily mobility, it is essential to take these factors into account when choosing the designated type of wheelchair. Especially access to transportation and the home environment, and ability to transport the power-assisted wheelchair might be an issue due to the additional weight and width of the wheels.

In conclusion, the pros of power-assisted wheelchair propulsion are: reduction of load on the arm, decrease in cardiopulmonary demand, increase in propulsion efficiency, maintained benefit of exercise, easy access to challenging environments and – compared to a powered wheelchair – relatively lightweight and easy to transport. The cons of power-assisted wheelchair propulsion are: difficulty performing tasks which require greater control such as a wheelie, difficulty with car transfers and access to home environment due to additional weight and width compared to a hand-rim wheelchair, unknown long-term effects on physical fitness and repetitive motion injuries can still be present or have no time to heal.

Further research is needed to get insight into the influence of power-assisted propulsion on forces and moments exerted on the rim and acting on the shoulder. Furthermore, a longitudinal study would provide information about the long-term effects of power-assisted wheelchair use on arm injuries and physical fitness. Further research addressing the change of activity profiles after transition to a power-assisted wheelchair is important, because next to the (re)training of function, improvements in activity and social participation are also important focuses in the rehabilitation process.

### Clinical messages

- Power-assisted propulsion is promising in reducing load on the arm and cardiovascular system.
- Power-assisted propulsion is most beneficial for tasks that require high levels of effort and is less convenient for tasks requiring greater manoeuvrability.
- A large disadvantage is the weight of the power-assisted wheels.

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