Permobil White Paper

A systematic review of the evidence for power assist devices

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LIST OF ABBREVIATIONS (ALPHABETICAL)

ADL: Activity of daily living

CP: Cerebral Palsy

CPG: Clinical Practice Guidelines

ICF: International Classification of Function, Disability & Health

MD: Muscular Dystrophy

MET: Metabolic equivalent of task

MS: Multiple Sclerosis

MWC: Manual wheelchair

PAD: Power assist device

PAPAW: Pushrim-activated power assist wheelchair

RSI: Repetitive strain injuries (also known as overuse injuries)

SCI: Spinal cord injury

WHO: World Health Organization

Abstract

AIM:

To describe the impact a power assist device (PAD) can have on the life of an individual who uses a manual wheelchair for mobility. Another unique aim of this study is to compare the impact between different types of PAD: front, main wheel, and rear.

METHODS:

The primary source was a systematic literature review. A total of 84 scientific publications were identified, of which 35 were included.

Other sources were:
- A user survey amongst 125 participants with a PAD
- Five interviews with individuals using different types of PAD
- Supporting articles; total of 32 publications, including guidelines and position papers

RESULTS:

Identified evidence-based benefits for using any type of PAD:

- Reduces repetitive strain, contributing to reduced risk of upper extremity pain and dysfunction
- Enables wheelchair propulsion over longer distances
- Decreases demand with activities requiring a higher force
- Supports performing activities easier and faster
- Provide energy conservation
- Increases the possibility of navigating a wider range of environments
- Can increase overall independence

Considerations when matching the needs of a person to the type of PAD (front, main wheel, rear):

- Propel on more challenging surfaces
- Perform activities such as door negotiation and wheelies
- Have access with PAD to home, school, work and on transportation
- Carry items on lap
- Transport the device in a vehicle
- Independently manage and use the device

CONCLUSION:

The Impact that a PAD has can extend beyond the relief of repetitive strain and energy conservation into what activities people can participate in, the environments they can access and navigate in and how independent they are. Understanding the benefits and the differences of the available variety of PADs will help determine which solution will best meet the needs and goals of an individual.

IMPLICATIONS FOR CLINICAL PRACTICE:

When assisting an individual with the complex task of selecting a PAD, there are many solutions and options to consider. This white paper intends to tie together existing evidence with lived experience so that the reader can determine how best to apply it to the unique needs of an individual. This allows increased understanding how power assist technology can not only impact the physical health of a person, but also that independence and quality of life are multi-factorial. In addition, this document represents how evidenced-based practice can be used to a support document for advocacy, funding, or market access, contribute to informed clinical-decision making, supplement to educational curriculum or even to support client education.

1. Introduction

BACKGROUND

It is well documented that manual wheelchair propulsion is a significant contributing factor to repetitive strain injuries (RSI) of the upper extremities[1]. In their daily interventions, healthcare and assistive technology professionals strive to reduce complications such as pain and dysfunction as much as possible. To achieve this, topics for behavior change related to ergonomics, overhead reaching, transfers and pressure management behaviors, as well as wheelchair configuration and propulsion are addressed in the Clinical Practice Guidelines (CPG)[2] "Preservation of Upper Limb Function Following Spinal Cord Injury: A Practice Guideline for Healthcare professionals." Primary recommendations from the CPG related to propulsion are to limit the number of propulsive strokes that a person must complete as well as the forces generated to create the movement[2].

The goal of using a Power Assist Device (PAD) is to reduce the physical demand experienced when propelling a manual wheelchair while providing improved function over a lifetime of wheeled mobility. This is achieved through the benefit of decreased number of propulsion cycles and decreasing the amount of force of effort required to propel[3]. There is an increasing body of evidence, with multiple recent scientific publications, describing a wide range of benefits of the use of a PAD on health, activities, participation, and quality of life.

There are an estimated 65 million people worldwide who need to use wheelchairs for mobility; however, not all have access to the necessary devices[4]. It is currently unknown how many people have or would benefit from the use of power assist devices in addition to their manual wheelchair; however, in a survey of almost 500 people who have a spinal cord injury and reside in Switzerland, 47% of participants felt that they had an unmet need related to being provided a power assist device[5].

METHODOLOGY

Aim of this white paper

To describe the impact a power assist device can have on the life of an individual who uses a manual wheelchair for mobility. A broad impact was assessed on body functions and structures, activity, participation, quality of life and independence. Furthermore, environmental and personal considerations were discussed. Another unique aim of this paper is to describe the differences in impact between different types of PAD (front, main wheel, rear). The intention of this white paper is to serve as a resource to inform clinical practice.

International Classification of Functioning, Disability and Health (ICF)

This white paper will use the ICF framework when describing the overview of the evidence (Figure 1). This framework maps an extensive set of considerations with regards to body functions and structures, activities, and participation, and how these interact with environmental and personal factors[6]. In a modified version, quality of life was added as a concept that encircles all the individual aspects of the framework[7]. The ICF framework was developed by the World Health Organization (WHO) to shift discussions from a medical model focused on diagnosis and disability to one highlighting the social model with function as its primary purpose. According to the WHO, ICF creates a standard language to describe health and health-related states. The ICF framework can be used in many different ways, but the main purpose is as a tool when making decisions around health plans and health policies[6]. For those who want to read more about the ICF framework, additional information is provided in Appendix A.

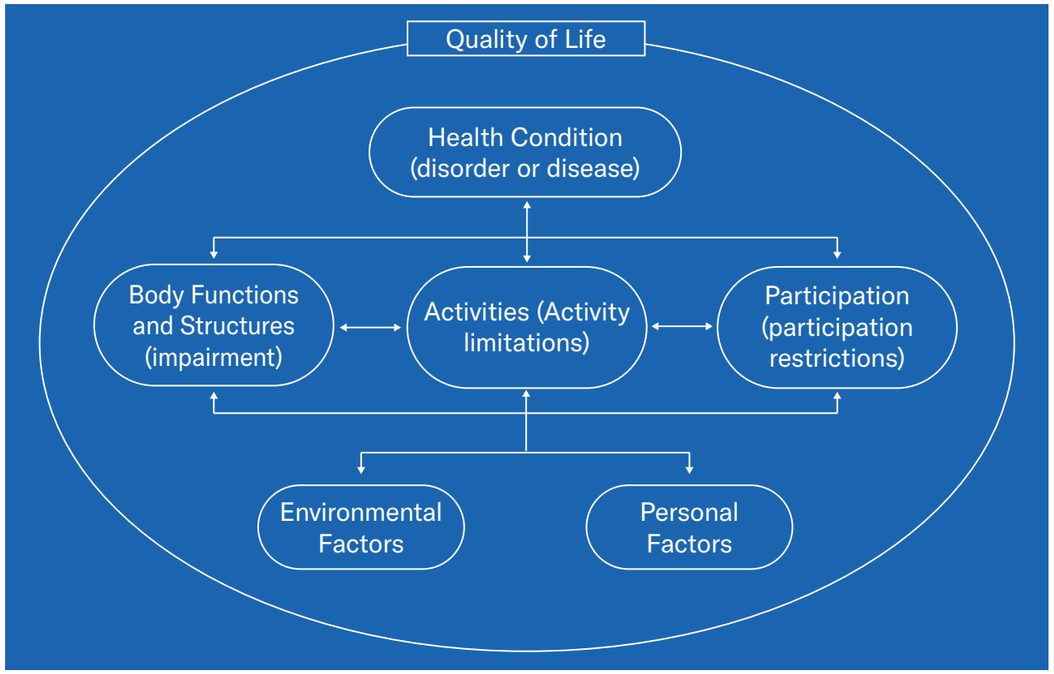

Figure 1. ICF model including Quality of Life[7]

Sources

1. Systematic literature review

The primary source of this white paper is a systematic literature review, which was performed to identify the impact of PAD on all outcomes of the ICF model. A search was performed using PubMed/Medline identifying publications without any time restriction. The PICO (Population, Intervention, Control, Outcomes) framework was used to define the search and used the following key words. For PAD, key words included: power assist*, add-on, propelling aid, and power support; for population, the key word added was wheelchair. The search was not limited to any Comparison or Outcome.

As shown in Figure 2, this search identified 84 publications, which were systematically reviewed by title, abstract, and full text, after which 35 publications were included. These 35 publications included three systematic reviews and 32 studies with quantitative or qualitative findings on the impact of PAD. All references used are listed at the end of this white paper.

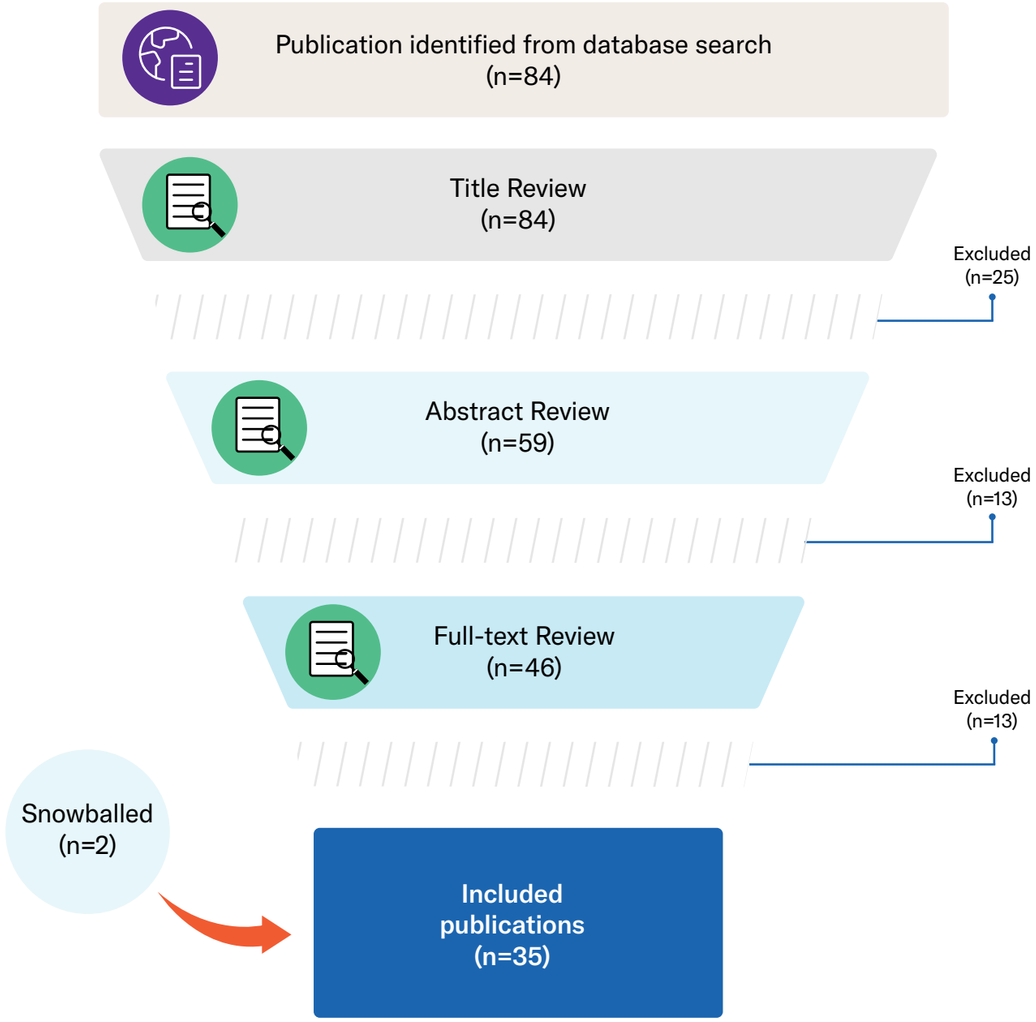

Figure 2. Overview of the search process

2. User survey

Results of a user survey will be presented as an addition to the findings from the systematic literature review. In the beginning of 2022, Permobil performed a web-based survey of wheelchair users to get a better understanding of their needs associated with PAD. An invitation to the survey was shared via email lists and social media and reached wheelchair users worldwide. A total of 334 participants started filling out the survey and 288 persons answered at least 25% of the survey which was set as the minimum amount to be included in the analysis. From the group of 288, eight were excluded because they were under 18 and 21 participants were excluded because they did not currently have a manual wheelchair. Of the 259 remaining participants, 125 were currently using PAD, 25 had PAD experience but were currently not using one, 13 had a PAD but were not using it, and 96 had no experience with PAD.

Regional distribution of participants included: North America (59%), Asia Pacific (22%), Europe/Middle East (18%), and other (1%). A majority identified as male (64%). There was a wide range of ages with 9% between 18-30 years old, 34% between 31-50, 21% between 51-60, 25% between 61-70, 8% between 71-80, and 2% more than 80 years old. Most participants were experienced using a manual wheelchair, with 50% having more than 20 years' experience and 38% with at least 5 years' experience.


Keith navigating his vehicle ramp with a rear power assist device, representative of the 51+ age group participating in the user study.

3. Anecdotal

Pictures and quotes from individuals using a variety of PADs are used to visualize and explain the scientific evidence provided. Clinical applications compiled based on interviews with users of different devices are presented in appendix B.

4. Supporting articles

In addition to the systematic review, survey and anecdotal evidence, supplemental publications have been utilized for areas such as background information and considerations, and clinical support has been added from practice guidelines and position papers. Supporting articles are indicated with an * in the reference list.

Health conditions

PADs may be useful for people with a variety of mobility impairments, which would be determined by an evaluation performed by a care team. This may include a person with upper and/or lower extremity impairments, coordination difficulties and energy conservations requirements. Some devices can even be used by an attendant or caregiver (carer).

All health conditions are considered in this white paper. Some health conditions, such as spinal cord injury (SCI) have been more extensively studied than others. When there is limited or unavailable research available related to a specific mobility impairment, it does not automatically mean that a power assist device (PAD) may not be beneficial. If there are specific differences between populations or types of mobility impairments, this will be discussed when appropriate.

Evolution of power assist

When the concepts of power assisted wheelchair propulsion was first developed and investigated, the need came out of the lack of suitable options for people who wanted to self-propel a manual wheelchair but could not do so efficiently, effectively, or without upper extremity pain[8]. The initial power assist solution was a pushrim-activation system that would sense when torque was applied to trigger a motor that was attached to the hub of a wheel. Results of some of the first studies evaluated the safety and usability of a pushrim-activated power assist wheelchair (PAPAW), the participants demonstrated lower oxygen consumption and a lower heartrate when using the power assistance compared with propulsion without power assistance. Some of the initial barriers were based upon the size, weight, and transportability of the original devices. These results indicated that providing powered assistance can reduce the energy required to propel a manual wheelchair and "may provide manual wheelchairs with less physiologically stressful means of mobility with few adaptations to the vehicle or home environment"[8].

PAD is the description of a general category and there are a wide variety of control methods that can be matched with each specific power assist technology. While some devices have technology that relies on the pushrim as the activation and control method, other devices use a combination of pushrims and external controls such as wearable technologies, dials, and switches. This has also been referred to as partial assist where manual propulsion is still required but is "augmented or sustained"[9]. In addition, control methods may include a power add-on, a term that is used in some settings and regions to describe when a proportional joystick or steering tiller is added. The idea of a power add-on is to control start, stop, acceleration, deceleration, and directional control. This has also been referred to as "full-assist" where the PAD supports all propulsion requirements with electrical power and no manual propulsion is required[9].

Over the last 20 years, power assist solutions have become more diverse in how they are activated and controlled, where the drive wheel and components are located, how much they weigh, how they are transported and even which activities they are best suited for. Results from the user study show that over 10 different types of PADs were identified by 163 people with PAD experience. With this much variability, a skilled assessment for each individual evaluating their needs, requirements and environment is critical to the PAD selection process. A systematic review from 2013 summarized the impact of PAPAW for manual or power wheelchair users[10]. This current white paper can be seen as a necessary update of that review, as there is a considerable amount of new research publications over the last decade which are not limited to PAPAW but include a wide variety of PADs.

Definitions

A wide variety of terms have been used to describe PAD throughout clinical practice and published studies. Terms such as rear-mounted, hub-mounted, front-mounted vs pushrim activated vs power add-ons can all be identified and typically used interchangeably. Recently, researchers identified that because newer PAD systems provide assistance by adding an actual wheel to a chair compared to just providing push assistance, categorizing the type of PAD by "how they drive the MW [Manual Wheelchair]: front-wheel drive power, mid-wheel drive power and rear-wheel drive power"[11]. In this white paper, it was determined to identify the type of PAD based on the location of the motor or wheel that is included in the PAD. When a motor or wheel is added to the front of the chair, it can be referred to as a front PAD. When the power is generated from a motor in the large propelling wheel or "hub", this can be referred to as a main wheel PAD. When the motor or wheel is added to the back of the wheelchair, this will be referred to as a rear PAD.

TYPES OF POWER ASSIST DEVICES

Assessing differences between types of PAD is a unique aim of this white paper.

Front PAD

Front PAD are typically characterized by a motorized wheel that is located in front of the footplate or footrest of a manual wheelchair. The system attaches or clamps on to the front frame of the MWC and elevates the front caster wheels off the ground. It is then controlled by a tiller or handle-bar style system with an external motor and external battery. The front PAD also lifts the front casters off the ground to improve navigation on uneven terrain.

Main wheel PAD

Main wheel PAD is typically identified by motorized drive wheels that take the place of the large rear wheels. Main wheel PADs are typically characterized by using accelerometers which provide the assistance based on push rim input. This type of PAD can have either one motor in each wheel or a single motor that is controlled by an added joystick. When a main wheel PAD has a motor in each wheel it allows for the ability to adjust input or sensitivity for right or left differences in strength or motor control. In addition, some main wheel PADs have individual batteries per wheel, and some have a singular battery that powers both wheels.

Rear PAD

A rear PAD typically attaches underneath the wheelchair. For example, on a rigid manual wheelchair it would attach to a clamp on the camber tube and on a folding chair it attaches with a bar between the axles of the rear wheels. Depending on the manufacturer, there may be a single rear caster or a rear wheel with omni-directional rollers.

Clinical considerations

The style or type of PAD requires individual consideration by a multi-disciplinary team to understand the needs and preferences of the individual who will be using the device. There are perceived benefits and drawbacks to every type of PAD[3,9].

Furthermore, when assessing which PAD matches each individual, evaluate carefully the maximum body weight that can be accommodated. It may be helpful to know not only the weight of the individual, but also the total weight of the wheelchair and seating system as well. The total weight a PAD can support varies extensively by manufacturer and by model or version.

Figure 3 shows the results of the user survey on a question to understand the frequency that someone uses a PAD in their everyday lives. The results show that 73% of people use their device daily (40%) or weekly (34%) which may help to understand the usefulness of the device and the impact it might have on one's life.

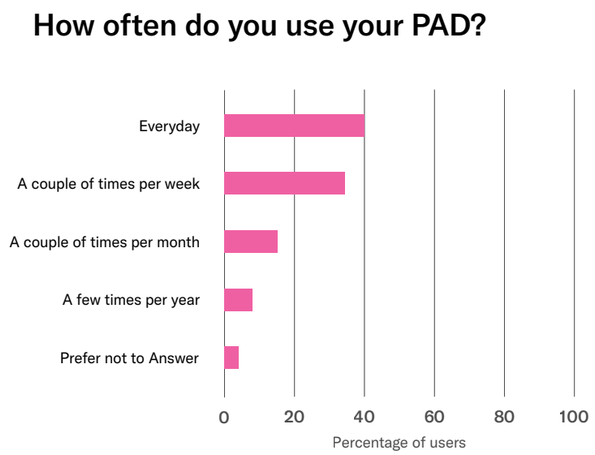

Figure 3. Results of user survey on question: How often do you use your PAD (n=125)

MWC considerations

Prior to introducing PAD to an individual's wheeled mobility solution, best practice is to complete a thorough evaluation and assessment to address the wheelchair configuration as well as secondary supports that would be needed. Secondary supports may include, but are not limited to, seat cushion, back support, pelvic positioning belt, or lateral trunk support. In addition, the care team should take all necessary steps to ensure that a PAD can be safely used by the individual, which can include but are not limited to cognition and vision assessment, as well as manual wheelchair skills testing.

Related to wheelchair configuration, appropriate manual wheelchair set-up and individual configuration have been well established as priorities when trying to optimize propulsion and decrease limb strain[2,12]. To uphold these recommendations, prescribing practitioners need to take into consideration the impact the addition of a PAD would have on the set-up and configuration of the manual wheelchair. In addition, clinicians should always check compatibility of the device and chair with appropriate manufacturers.

There are devices where the center of gravity of the rear wheel is required to be in a specific position or seat-to-floor height may have to be adjusted to accommodate the PAD. In addition, devices such as a front PAD lift the front casters off the ground which changes the entire orientation in space by raising the front seat-to-floor height which may impact overall back angle and postural stability.

MWC skills

The use of a PAD can be optimized when a person understands basic manual wheelchair skills. Every PAD is different in the way it attaches to the MWC, as well as the activation and operation method. It is recommended individual have a core understanding and training of MWC skills independent of the PAD.

It is well established that wheelchair skills training is a critical step of the equipment provision process, and wheelchair skills are necessary to fulfil functional mobility at home and in the community. Researchers have also demonstrated that skills training is required for individuals using PADs to increase safety and confidence[13]. Specifically, for rear PADs, skills training was found to be successful in 1-2 sessions with a PAD to maintain an individual's skill capacity and confidence[13]. Out of 11 participants, there were some that could complete tasks faster and more quickly and could even complete tasks they were unable to do with manual propulsion without a PAD such as completing obstacle course activities and negotiating slopes. The researchers did identify that learning to stop a PAD by a means other than simply grabbing the push rims does take a longer time to learn due to the fact that this is an instinctual action by a skilled rider[13].

2. OVERVIEW OF THE EVIDENCE

Figure 4 represents the summary of the research review findings as to the influence of PAD use on all aspects of the ICF and ultimately on independence and quality of life. Each category is color coded to describe what evidence was found; whether results showed a positive effect or whether no conclusions could be drawn because evidence was limited. In addition, where there is a difference in the effect shown by the evidence based on the type of PAD (front, main wheel, rear), this will be in blue. To follow, Table 1 below will compare details regarding how this evidence varies by type of PAD (front, main wheel, rear).

In the sections that follow, the evidence will be described for each of the boxes of the ICF model: Body functions and structures, Activities, Participation, and Quality of life and independence. Each section will be organized using the same structure:

Background: Provides an introduction with supporting literature on the importance and evidence of each part.

Summary statements: Summary of all available evidence per topic. Concluding statements are printed in bold dark blue, and differences between different types of PAD are highlighted in light blue.

Considerations: Positive and negative factors that can be important to consider for the implication of the findings.

Detailed study descriptions: More detailed summary of available trials reporting on quantitative and qualitative results, linked to each summary statement.

After that, the evidence on environmental factors and personal factors will be discussed.

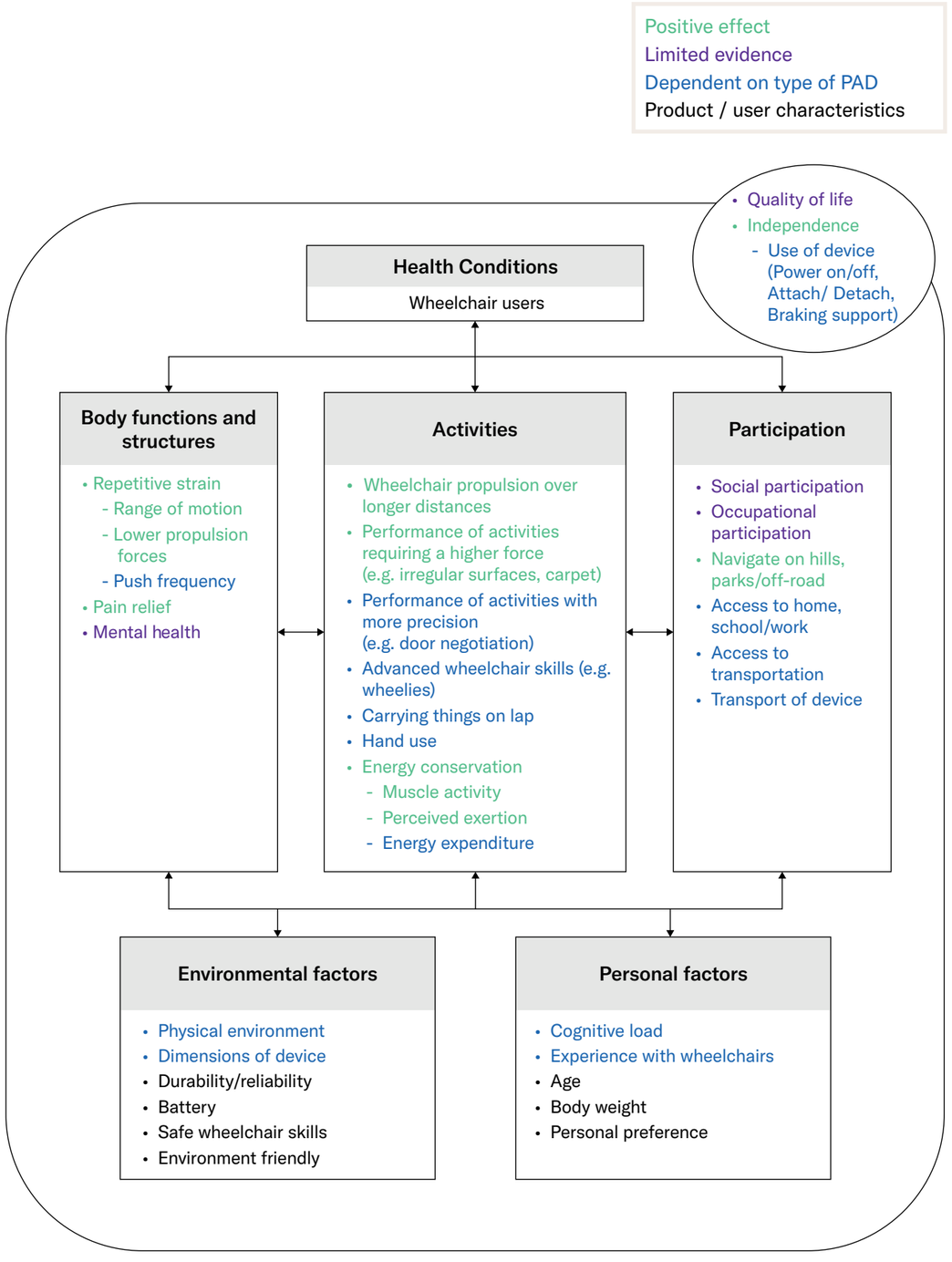

Figure 4. ICF as it relates to PADs

Table 1 represents the summary of the evidence regarding differences between front, main wheel and rear PAD*

	Front PAD	Main wheel PAD	Rear PAD
Body functions and structures			
Push frequency	Typically no pushing is required	Reduced frequency dependent on environment and health condition	Reduced frequency dependent on environment and health condition
Activities			
Performance of activities requiring a higher force (e.g. irregular surfaces)	Better performance than main wheel and rear PAD (when casters lifted of ground) and compared to without PAD	Better performance compared to without PAD	Better performance compared to without PAD
Performance of activities with more precision (e.g. door negotiation)	May be more difficult than without PAD	May be more difficult than without PAD	May not be impacted
Advanced manual wheelchair skills (e.g. wheelies)	More difficult than without PAD	More difficult than without PAD	Minimal change compared to without PAD
Carrying things on lap	Compromised compared to without PAD	Not compromised compared to without PAD	Not compromised compared to without PAD
Hand use	Always requiring a hand on the tiller/handlebar	Some devices can accommodate for differences in hand function	Pushrim input required to steer; start and stop may not, depending on input method
Energy expenditure	No pushes required = no energy expenditure	Less energy expenditure than manual propulsion	Less energy expenditure than manual propulsion
Participation			
Access to home, school/work	May be more difficult than without PAD	May not be impacted	May not be impacted
Access to transportation	May be difficult (related to transport of device)	May be difficult (related to transport of device)	Easier compared to other PADs
Transport of device	May be difficult because of size and weight	May be difficult because of size and weight and related to difficulty to attach/detach	Easier compared to other PADs
Independent use of device			
Power on/off	Easy to turn on/off	Easy to turn on/off	May be dependent on functional reach
Attach/detach	Requires significant upper body function and strength to install and remove but can be installed/removed while sitting in the wheelchair	Challenging to install and remove	Flexibility in being able to install and remove while sitting in the wheelchair
Braking support	Lever for active braking	Some pushrim activated PADs may provide braking for downhill and/or hill holding for anti-roll back	No active braking
Environmental factors			
Physical environment (soft terrain)	Better performance than main wheel and rear PAD (when casters lifted of ground) and compared to without PAD	Good performance compared to without PAD	Good performance compared to without PAD
Dimensions of device	Increases length compared to main wheel and rear PAD and without PAD	Increases width compared to main wheel and rear PAD and without PAD	Limited impact to length (often located under chair) compared to front PAD and without PAD
Personal factors			
Cognitive load/experience with wheelchairs	Most intuitive solution, start/stop, turn on/off	Easy to turn on/off; sensitivity might take time to get used to	May be more difficult to start/stop
Quality of Life: Insufficient evidence to determine			

*This table does not consider PAD with joystick control.

BODY FUNCTIONS AND STRUCTURES

BACKGROUND

Manual wheelchair propulsion is an activity that is both highly repetitive and requires strain, in particular for the shoulder, elbow, and wrist[14]. Studies reporting on prevalence of pain in manual wheelchair users are generally with small and heterogenous samples, and therefore the literature reports on a wide range of pain prevalence. A recent meta-analysis summarized findings of studies reporting on pain prevalence in manual wheelchair users and reported on an overall 50% prevalence of any musculoskeletal pain[1]. The summarized prevalence of pain was: shoulder (44%), elbow (21%), wrist (23%), hand (18%). In fact, people who self-propel manual wheelchairs are six times more likely to develop shoulder pain than those without mobility impairments[1].

The most frequently reported type of shoulder pain in wheelchair users are related to rotator cuff injuries, for which possible causes include joint inflammation, rotator cuff tears, and subsequent instability of the glenohumeral joint and tendinopathies[1]. A recent longitudinal study amongst adult wheelchair users with SCI used MRI to show pathology progression of the rotator cuff tendon over a one-year period in manual wheelchair users, while findings were stable in able-bodied controls[15]. Main causes of shoulder pain amongst wheelchair users are upper extremity propulsion forces and weight-bearing tasks such as transfers[1]. Furthermore, chronic overuse, repetitive traumas, instability of the joint, adductor muscle weakness, reaching, and overhead tasks have all been found to be able to cause shoulder pain[1,16]. Elbow, wrist, and hand pain can also be caused by overuse during manual wheelchair propulsion[1]. The type of health condition is also likely to be an explanation for the large, variation in pain reported, with the risks of developing shoulder pain being dependent on e.g., whether persons have impaired upper extremity strength or spasticity. Increased duration of wheelchair use has been identified as a risk factor for upper extremity pain[1]. In individuals with an acquired SCI and more than 20 years since injury, 20% have described their shoulder pain as unbearable[17].

Besides the strain of the upper extremities, using a wheelchair for mobility can come with additional health challenges. One third of persons with SCI are known to have moderate to severe mental health problems[18]. Mental health disorders are also prevalent in individuals with cerebral palsy (CP) as well as amongst those with multiple sclerosis (MS)[19,20]. The high prevalence of these disorders amongst wheelchair users also stresses the importance of studying the potential impact of mobility devices on a person's mental health.

SUMMARY STATEMENTS

PAD can reduce repetitive strain and thereby contribute to reducing the risk on upper extremity pain and dysfunction.

Repetitive strain is lower propelling with PAD compared to propelling without as supported by findings on range of motion and propulsion forces.

With regard to range of motion, research findings consistently show that the range of the upper extremity joints is more favorable when propelling with PAD compared to without PAD[21,22,23,24,25] . These findings are in line with the Clinical Practice Guidelines which recommend wheelchair users to minimize extreme and vulnerable positions of the shoulder and wrist[2].

Studies on propulsion forces show that the propulsion force needed to propel with PAD is lower compared to without PAD. Three studies showed a lower propulsion force in wheelchair users[11,21,26], and one study in able-bodied individuals[22]. Another study amongst wheelchair users found that a start-up movement performed with PAD has lower shoulder load compared to without[23], and a study amongst able-bodied showed that force when stopping with PAD is significantly lower compared to without PAD[27].

Qualitative research adds that wheelchair users experience the reduced strain when propelling with PAD compared to without PAD and indicate that this could help to reduce the risk on upper extremity pain and dysfunction[3,28].

Push frequency dependent on type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Body functions and structures			
Push frequency	Typically no pushing is required	Reduced frequency dependent on environment and health condition	Reduced frequency dependent on environment and health condition

The effect of PAD on push frequency showed mixed results across studies. In three studies push-frequency was lower with PAD propulsion compared to without [24, 29,30]. In one study push frequency was higher during PAD propulsion compared to without[21], whereas no difference in push frequency was found in three other studies[8, 22, 25]. Two studies measuring push frequency during overground propulsion showed mixed results in different conditions: lower push frequency with PAD during an outdoor course and during 100m propulsion but no differences in push frequency during an indoor course and on carpet and incline[31,32]. Explanation for the mixed results might be the study environments (treadmill, overground, different resistances and surfaces) or health condition[10,31]. All of these studies were on main wheel PADs, of which different control mechanisms and settings might have influenced these results[10]. Although none of the studies reported on rear PAD push frequency, it seems reasonable to assume that push frequency with rear PAD is also dependent on environment and health condition. With front PAD one typically does not push at all.

> *"My RSI [repetitive strain injury]at the level of the shoulders disappeared, symptoms of infection at Pectoralis insertion reduced significantly. " – H.D., when asked about how power assist has impacted his general health.*

CONSIDERATIONS

Consideration needs to be made for those who have difficulties or are unable to propel manual wheelchairs with one or both upper extremities[33,34]. These people may propel a manual wheelchair with one or two feet. For example, persons with hemiplegia typically use their unaffected arm and leg to propel, and frail elderly or those with central-cord syndrome may propel their wheelchair with two feet. The evidence of repetitive strain of wheelchair propulsion focuses primarily on the upper extremities, but in the case of foot propulsion the same considerations on pain and injuries as a result of repetitive strain might apply to the lower extremities.

Rolling resistance with a main wheel PAD measured on a treadmill was found to be higher compared to the rolling resistance of a manual wheelchair. Furthermore, deflated tires increased rolling resistance in both manual and with PAD. This could thus impose unnecessary physiological effort when propelling[35].

Another consideration with regards to providing PAD for prevention of upper extremity injuries is from a cost-effectiveness perspective. The costs of the PAD need to be outweighed against the costs of upper extremity injuries. The costs of these injuries are very high and include direct costs, such as pre-operative surgical interventions, the surgery costs itself, and post-operative rehabilitation as well as indirect costs experienced by the person such as increased assistance with activities of daily living, increased caregiver hours and fees, time off work, power wheelchair rental and increased transportation costs during the healing phase[36].

Mal ascending a long drive in Italy with rear PAD

Figure 5 shows the results from the user survey on the reported impact of PAD on reduced pain. A majority of participants, 69%, reported a positive impact (45% extremely positive and 24% somewhat positive). When asked an open-ended question about situations where using a PAD is helpful, participants reported: shoulder preservation, not damaging the shoulders, reducing shoulder pain wrist preservation and relief of back pain.

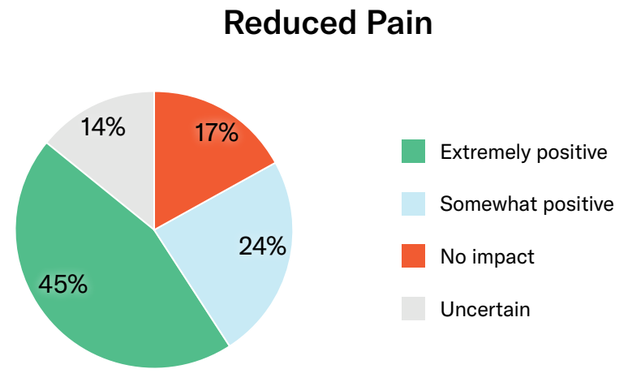

Figure 5. User survey results on impact of PAD on pain (n=125)

SUMMARY STATEMENTS

Very little evidence of impact PAD on mental health.

Very few studies reported on mental health. One study reported on overall perceived health[37] and three studies[38,39,40] reported on mental health, using a variety of outcome measures. More research is necessary to be able to conclude what the impact of PAD is on mental health.

Khamila on the playground with her sister using her rear PAD

Runar and his family having time in the outdoors together

ACTIVITIES

BACKGROUND

A wheelchair provides mobility for people with physical impairments, and thereby provides a way to perform activities of daily living. As propelling a wheelchair is a straining activity, often people are limited in the activities that they can do, how long they can do them for and how fast they can complete them. Furthermore, manual wheelchair propulsion might not be possible when someone has an upper extremity injury, severe pain, arm strength impairments, low cardiorespiratory function or inability to maintain posture[10,41]. If wheelchair propulsion was less straining, this might keep users in their manual wheelchairs for longer instead of transitioning to a power wheelchair[14].

Perceived exertion during daily activities is found to be relatively high amongst wheelchair users compared to the able-bodied population[42]. While this indicates that daily activities are more straining, energy expenditure of manual wheelchair users during daily activities is found to be around 25% lower[43]. This can be explained by the dependency on the upper body, which can make it more strained but also causes less energy expenditure because of the smaller skeletal muscle mass activated[43]. Furthermore, health condition is known to influence the response of the heart rate on physical activity, with findings showing that persons with spastic cerebral palsy (CP) have higher heart rate responses to physical activity compared to those with cervical SCI and muscular dystrophy (MD)[44]. In persons with high level SCI heart rate response to physical activity is known to be impacted both by the extent of the paralysis as well as by a reduced sympathetic control[45].

SUMMARY STATEMENTS

PAD can enable wheelchair propulsion over longer distances.

Two lab-based studies showed that PAD enables users to travel over longer distances[11,46]. These findings were confirmed in two studies in a community setting in which participants used the PAD for longer time periods[39,47]. Two other studies in which persons used the PAD for no more than two weeks, found no difference in distances travelled with or without PAD which indicates that longer evaluation times may be necessary to see the impact of PAD on distance[38,48].

PAD can enable activities requiring a higher force, and can make performance easier and faster.

Multiple studies showed that there are activities requiring a higher force (e.g. irregular surfaces) which wheelchair users can only perform with PAD and not without[13,49], and are easier and faster to perform with PAD compared to without PAD[24,29,30,32,38,48,50].

Mal carrying an item on luggage carriers with a rear PAD on a long trek to the park

Qualitative research findings further strengthen this evidence showing that persons experience a better performance of these type of activities with PAD compared to without PAD[28,38,51].

Performance of activities with more precision, advanced wheelchair skills, carrying things on lap, and hand use are all dependent on type of PAD.

	Front PAD	Main wheel PAD	Rear PAD
Activities			
Performance of activities requiring a higher force (e.g. irregular surfaces)	Better performance than main wheel and rear PAD (when casters lifted of ground) and compared to without PAD	Better performance compared to without PAD	Better performance compared to without PAD
Performance of activities with more precision (e.g. door negotiation)	May be more difficult than without PAD	May be more difficult than without PAD	May not be impacted
Advanced manual wheelchair skills (e.g. wheelies)	More difficult than without PAD	More difficult than without PAD	Minimal change compared to without PAD
Carrying things on lap	Compromised compared to without PAD	Not compromised compared to without PAD	Not compromised compared to without PAD
Hand use	Always requiring a hand on the tiller/handlebar	Some devices can accommodate for differences in hand function	Pushrim input required to steer; start and stop may not, depending on input method

When attaching a front PAD to the manual wheelchair, casters of the wheelchair are typically lifted off the ground[52]. As casters are known to impact mobility on more difficult terrain, propelling without the casters might make navigation on these terrains easier[53]. Furthermore, speed of main wheel and rear PAD have been discussed to meet users' needs, and to exceed users' need for front PAD[3].

Studies on main wheel PAD showed that activities which require

Demonstration of wheels lifted off the ground with front PAD

more precision (e.g. door negotiation) were easier to perform with compared to without PAD[31,49]. The difficulty of the performance of these precision activities is dependent on the type of PAD[3,52]. With front PAD precision activities may be more difficult because of a larger footprint and turning radius, whereas a rear PAD may be more valuable indoors and in tight spaces because of the smaller footprint and turning radius[52]. Furthermore, advanced manual wheelchair skills such as wheelies are found to be more difficult to perform with a front PAD or a main wheel PAD compared to without PAD[3,49,52]. For rear PAD, minimal change on advanced activities were reported compared to without PAD[13,52].

Another activity which may be impacted by the type of PAD is the ability to transport things on your lap. This is compromised when using a front PAD because of the place where the PAD is mounted, but not compromised with main wheel or rear PAD[3,28]. Another factor that can influence activities is hand use, with front PAD always requiring a hand on the tiller/handlebar[3]. Technical product information can help us to understand that some main wheel PAD devices can accommodate for differences in hand function and for rear PAD push rim input is required to steer, but start and stop may not, depending on the input method.

Matt using his rear PAD to assist with luggage with rear PAD

Chanda carrying coffee cup while using rear PAD

> *"Before I got my [rear PAD], I found that I had to really make hard decisions as to how I was going to spend my energy. With my [rear PAD] there is no downside for going out for walks with my family. I am definitely doing more activities now than I would have before I got my [rear PAD]". – Matt*

Figure 6 shows the results from the user survey on the reported impact of PAD on the ability to complete daily tasks. A majority of 71% reported a positive impact of the ability to complete daily tasks (43% extremely positive and 28% somewhat positive).

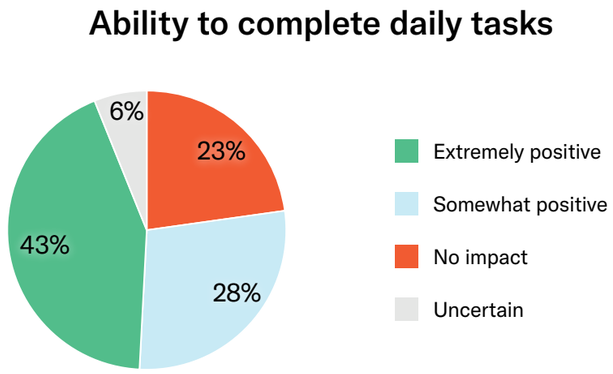

Figure 6. User survey results on impact of PAD on ability to complete daily tasks (n=125)

Figure 7 shows the results from the user survey on the reported impact of PAD on the ability to complete desired activities in a timely manner. A majority of 79% reported a positive impact on the ability to complete activities in a timely manner (47% extremely positive and 32% somewhat positive).

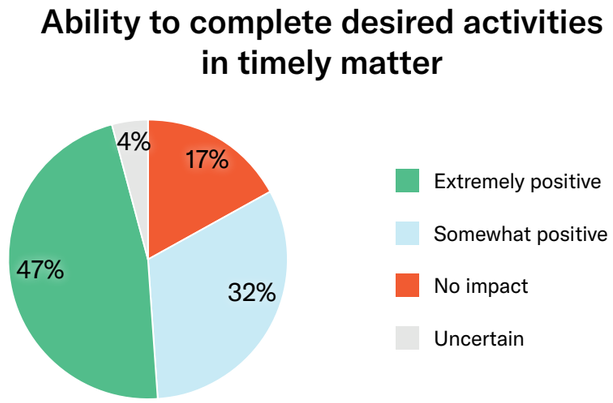

Figure 7. User survey results on impact of PAD on ability to complete desired activities in a timely manner (n=125)

SUMMARY STATEMENTS

PAD can be used for energy conservation.

The effort needed to propel a wheelchair with PAD is lower compared to without PAD, shown by a significant decrease in muscle activity, heart rate, energy expenditure and perceived exertion. This indicates that PAD can be used for energy conservation.

Findings on muscle activity showed decreases in activity when propelling with PAD. The most consistent finding was for a decreased activity of the pectoralis major and anterior deltoid[21,22,30,32].

Heart rate and energy expenditure as measured by oxygen consumption were found to be consistently lower with PAD compared to without PAD during a variety of tests; from tests on treadmill to activities of daily living[8,11,24,26,31,32,35,46,50].

Perceived exertion during daily activities was reported to be lower with PAD and mentioned as a reason for using PAD[3,10,28,29,32,46,48].

Energy expenditure dependent on type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Energy expenditure	No pushes required = no energy expenditure	Less energy expenditure than manual propulsion	Less energy expenditure than manual propulsion

With front PAD one typically does not push at all and therefore does not require any energy expenditure. Main wheel PAD and rear PAD requires or has the possibility to self-propel assisted by the PAD, and in that case does require energy expenditure but lower than compared to propulsion without PAD. The amount of energy expenditure may depend on the control method of the PAD. For example, some devices provide the addition of a proportional joystick which should not require energy expenditure compared to types of PAD that do require handrim activation or involvement.

”With MS, managing my fatigue and still be able to have some type of activity is a difficult balance. This allows me to still do things and manage my fatigue.”- Michael

Michael uses his rear PAD to save energy for his hobbies such as scuba diving

CONSIDERATIONS

An important consideration around energy expenditure is that many wheelchair users are known to be physically inactive, which may contribute to developing obesity and a negative cycle of deconditioning[54,55,56]. If travelling with PAD, and thus with less energy expenditure, is not compensated for by other types of activities or exercise this might increase the risk of becoming overweight and deconditioning. Increased weight is known to contribute to upper extremity overuse injuries of the upper extremity in those with SCI, resulting in limitations in mobility and activities of daily living[57]. On the other hand, if PAD means that a user can stay physically active or that the transition to a power wheelchair can be postponed, the benefits of moderate physical activity of wheelchair propulsion can remain over a longer period[10]. In a recent study, users reported that PAD is a way to conserve energy and that way the continued engagement in exercise[3]. Furthermore, conserving energy during straining tasks, such as propelling uphill or across a carpeted hallway, might allow a manual wheelchair user to maintain function while performing other necessary activities[50].

PADs for wheelchair users can be compared with e-cycling in the able-bodied population. E-cycling with moderate electrical assistance results in a greater heart rate and oxygen consumption response compared to walking[58]. This means that e-cycling leads to increased physiological responses that can confer health benefits related to physical activity. It was further noted that e-cycling is known to encourage people to travel further and for longer periods of time, perceived as easier to ride and reduce concerns about distance and inclines.

For new users, energy expenditure with PAD can be lowered with practice. This indicates that users should be able to practice with a PAD before evaluating whether the user can benefit from the technology regarding energy expenditure. There were also indications that perceived exertion might be influenced by the experience of the user, which should also be taken into consideration when interpreting these findings for new users[59].

The last consideration is that energy expenditure might be influenced by the health condition, as shown in a study evaluating three main wheel PADs amongst 46 wheelchair users on indoor and outdoor courses[31]. During an outdoor driving test, maximal heart rate was significantly higher with compared to without PAD, but it was also found that this difference was not as large for persons with tetraplegia.

Shimakawa using a rear PAD in between sessions of physical activity

Yasmine navigating public restroom with her main wheel PAD

PARTICIPATION

BACKGROUND

Limitations related to mobility can impact the ability to participate in a wide range of activities of daily living, the ability to socialize and to go to school or work. Providing wheeled mobility is known to increase participation[41]. Although the wheelchair is the most important mobility device for many, it is at the same time mentioned to be the most limiting factor of participation[61]. Other factors limiting participation were the individuals' physical impairment and the built and natural environment in which activities take place[61]. There are several environments with limited or absent wheelchair accessibility, including physically challenging environments such as carpets and inclines[41].

SUMMARY STATEMENTS

PAD increases the possibility to navigate a wider range of environments.

Only three studies reported on the impact of PAD on overall participation and therefore no conclusions can be drawn on whether PAD has an influence on social and occupational participation. Studies did report a positive impact of PAD on participation, by showing an increased possibility to navigate a wider range of environments[3,31,37,38,50,51].

Related to the discussion on the performance of activities with more force vs more precision (see page 25-26), activities requiring more force are typically outside activities and those requiring more precision typically reflect inside activities. PADs seem to have a continuous positive impact on access to outdoor environment such as on hills and in parks/off-road[3,31,37,38,50,51].

Use of front PAD in outdoor environment

Access to home, school/work dependent on type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Participation			
Access to home, school/work	May be more difficult than without PAD	May not be impacted	May not be impacted

Contrary to access to outdoor environment, the accessibility to indoor environments such as home, school/work, is dependent on the type of PAD[3]. Access to indoor environments may be more difficult with front PAD[52]. Related to this are the dimensions of the different types of PAD, which is further discussed under environmental factors (page 37).

Access to transportation and transport of device dependent on type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Participation			
Access to transportation	May be difficult (related to transport of device)	May be difficult (related to transport of device)	Easier compared to other PADs
Transport of device	May be difficult because of size and weight	May be difficult because of size and weight and related to difficulty to attach/detach	Easier compared to other PADs

Compared to power wheelchair/scooter users, portability of a PAD is better[37]. However, transporting a PAD may also be challenging, depending on the type of PAD. Difficulties with the transport of a PAD, e.g. taking it in and out of a vehicle, are dependent on the weight and size of the PAD[3]. For that reason, a rear PAD was found to be easier to transport than a front PAD[52]. In addition to the size and weight of a main wheel PAD contributing to the difficulty to transport the device, attaching and detaching the wheels is expressed to be difficult[3,8,28,31,38,51].

Access to transportation may be dependent on how easy it is to transport the device. Better possibilities for transportation of the device might contribute to removing barriers of inaccessibility. One example here is the access to public transportation, which might be easiest with a PAD that is more manageable to transport and easier to attach and detach. Accessible transportation is known to increase the likelihood for wheelchair users to participate in the community[61].

> *"I can move around without having to use the car and any public transport. It's 100% helpful at any moment, for example to an official invitation to City Hall or to a party in the city with friends". Elisabeth, when asked about how the use of a PAD increases participation and socialization."*

CONSIDERATIONS

One important consideration with regard to transportation is that chair transfers are associated with increased risk of shoulder pain[62]. The positive impact of PAD on repetitive strain and thereby decreasing the risk on

shoulder pain as discussed in the chapter on body functions and structures (pages 20-22) should therefore be considered together with a potential increased risk of shoulder pain regarding an individual lifting, loading and transportating larger and heavier PADs.
Figure 8 shows the results from the user survey on the reported impact of PAD on the ability to socialize. A total of 66% reported a positive impact on the ability to socialize (44% extremely positive and 22% somewhat positive).

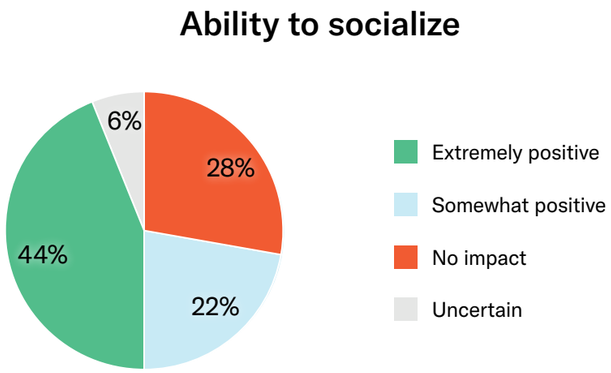

Figure 8. User survey results on impact of PAD on ability to socialize (n=125)

Figure 9 shows the results from the user survey on typical situations during which they use PAD. Most rated activities were outdoor activities in the community, outdoors around home and when travelling. Travelling and transport were also frequently mentioned with respectively 55 and 37 mentions (of 125 users). Examples of activities that were mentioned under other useful situations include camping, hospital appointments, and longer distances when parking is a problem. In an open-ended question asking for situations in which users felt really helped by PAD the most frequently answered included: inclines, ramps, hills and rough terrain when extra strength is needed. The second and third mentioned theme were long distances and daily activities outdoor.

Amanda enjoying outdoor activities with her partner with use of Front PAD

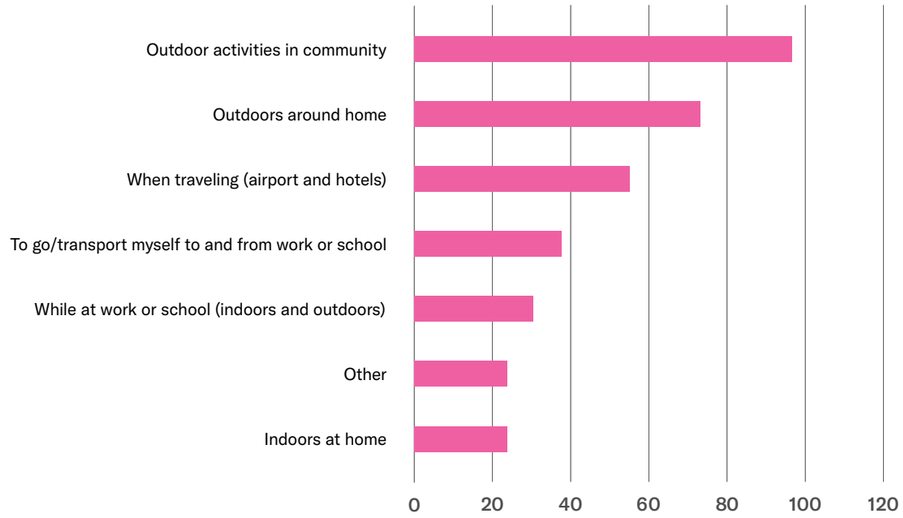

Figure 9. User survey results on typical situations PAD is being used (n=125). Participants selected all that applied.

Figure 10 shows results from the user survey on typical surfaces, with most frequent being concrete, asphalt and tiles. Thick carpets and grass were also mentioned by around 50 out of 125 users

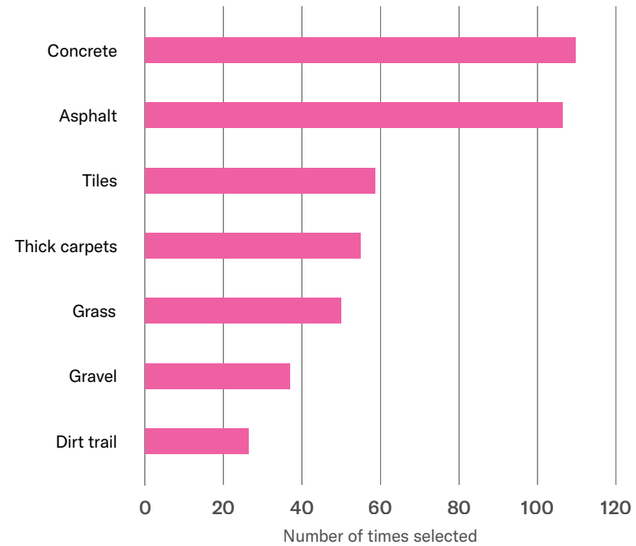

Figure 10. User survey results on typical surfaces PAD is being used (n=125). Participants selected all that applied.

QUALITY OF LIFE AND INDEPENDENCE

BACKGROUND

Provision of wheeled mobility has been found to improve quality of life[64]. Furthermore, pain associated with wheelchair propulsion has also been found to lead to a decline in function, independence and quality of life. Wheeled mobility that is less straining than manual wheelchair propulsion has the potential to improve quality of life by increasing the number of accessible environments, reducing pain and increasing independence along the age spectrum[14].

SUMMARY STATEMENTS

PAD can increase independence

Although enhancing quality of life is often seen as the ultimate outcome of mobility interventions, there was only one study commenting on quality of life and therefore it is not possible to draw conclusions.

Independence has been studied more frequently and it has been consistently shown that PAD can increase one's independence[3,28,37,38,51].

Independent use of the device is dependent on the type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Independent use			
Power on/off	Easy to turn on/off	Easy to turn on/off	May be dependent on functional reach
Attach/detach	Requires significant upper body function and strength to install and remove but can be installed/removed while sitting in the wheelchair	Challenging to install and remove	Flexibility in being able to install and remove while sitting in the wheelchair
Braking support	Lever for active braking	Some pushrim activated PADs may provide braking for downhill and/or hill holding for anti-roll back	No active braking

> *"My wife doesn't have to worry about me falling, I can manage by getting my wheelchair and [rear PAD] so I don't need help and assistance". – Michael when asked about how his independence is impacted*

One important consideration with regards to independence is the ability to independently use the device. Both front PAD and main wheel PAD are known to be easy to turn on and off, whereas for rear PAD this may be dependent on the functional reach[3,52]. For attaching and detaching a front PAD requires significant upper body function and strength to install and remove but can be installed/removed while sitting in the wheelchair. Whereas a rear PAD has flexibility in being able to install and remove while sitting in the wheelchair[3]. A main wheel PAD is known to be challenging to install and remove[3]. With regard to braking support technical product information helps us to understand that a front PAD has a lever for active breaking, main wheel PAD that is pushrim activated may provide braking downhill and/or hill holding or anti-roll back, and with a rear PAD there is no active breaking.

Michael enjoying travels in the western United States with his wife

CONSIDERATIONS

Amongst manual users with a progressive disease or with increasing needs because of aging or injuries, there might be a stigma associated with transitioning to a power wheelchair[21,52]. A PAD might allow manual wheelchair users to delay this transition, and thereby the stigma. Manual wheelchair users can use the PAD when they want or need but can choose to propel without as well.

Another consideration is cost-effectiveness of PAD for which we did not identify any research publications. This lack of research is not limited to PAD but there is unfortunately overall very little research available on the cost-effectives of providing wheelchairs[65]. From clinical experience, it can be discussed that PAD may be cost-effective when it would mean that home and transportation modifications will not be needed[66]. Furthermore, if providing PAD could help to delay or change the introduction of a power wheelchair, this could for example also prevent costs on changes in functional routine and the training of it.

> *"The device draws positive attention...I am no longer considered as a disabled individual but as an active and able person." – H.D., when asked about how power assist changed his mobility and impacted his quality of life.*

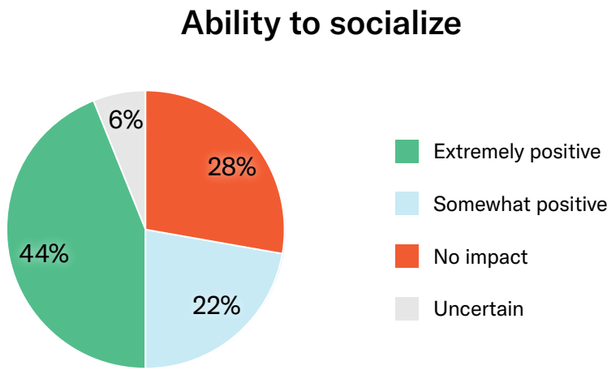

Figure 11. User survey results on impact of PAD on independence (n=125)

Figure 11 shows the results from the user survey on independence, with 87% (69% extremely positive and 18% somewhat positive) reporting that PAD has a positive impact on independence. Results from an open-ended question on the benefits of PAD include reporting that it included not needing someone to push, being able to use a manual wheelchair instead of a power wheelchair and being able to move side by side with companion.

ENVIRONMENTAL AND PERSONAL FACTORS

BACKGROUND

There is limited knowledge on environmental and personal factors related to PAD[10]. Factors described in the literature and which have come up in the survey will be described below. Several of these factors are also related to the type of PAD (front, main wheel or rear) and will be discussed if applicable.

ENVIRONMENTAL FACTORS

Physical environment

The interaction with the physical environment is dependent on the type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Environmental factors			
Physical environment (soft terrain)	Better performance than main wheel and rear PAD (when casters lifted of ground) and compared to without PAD	Good performance compared to without PAD	Good performance compared to without PAD

Considerations around the physical environment have been discussed when presenting the impact on activities (requiring higher force such as on irregular surfaces, pages 25-26) and participation (navigation on hills, parks/off-road, pages 30-31). As also discussed previously, lifting casters off the ground, as is the case with a front PAD, might make navigation on difficult terrains easier, including soft terrain[53]. From clinical experience, it can also be noted that in snowy environments, hand rims typically get wet and cold, and this discomfort can be prevented by using a front PAD or PAD with joystick control which eliminates the need to touch the hand rims.

Mal navigating unpaved trail with his front PAD in Australia

Dimensions of device

The wide variety of PADs has differences in overall size dimensions

	Front PAD	Main wheel PAD	Rear PAD
Environmental factors			
Dimensions of device	Increases length compared to main wheel and rear PAD and without PAD	Increases width compared to main wheel and rear PAD and without PAD	Limited impact to length (often located under chair) compared to front PAD and without PAD

When propelling in smaller environments, front PADs typically add the most to the length while main wheel PAD adds to the width of the MWC[3]. Rear PADs are typically placed under the wheelchair and may have the least impact on dimensions of the overall MWC[3].

Dislikes about the additional width, weight and transportability of main wheel PAD, and how this limits access to indoor environments has been mentioned in qualitative studies[28,48,51].

Durability/reliability

Durability and reliability are important considerations with regards to the selection of all assistive technology, and thus also for PAD.

Compared to manual wheelchair users and power wheelchair users, those using a PAD have been reported to have lover satisfaction with autonomy regarding the durability and reliability of their device[37]. Being compliant with standard technical testing is an important requirement with regards to durability and reliability[8,67].

Battery

It is important that the battery capacity of the PAD meets the user needs, and that there are no concerns about the reliability of the battery.

The most important concern of main wheel PAD users mentioned was being stranded after the battery charge was exhausted, because with the added weight of the PAD wheels the wheelchair was hard to push without the push assistance from the PAD available[28,51].

Safe wheelchair skills

The use of PAD should not impact the ability to safely complete wheelchairs skills. When performing wheelchair skills with and without main wheel PAD, a similar proportion experienced the manual wheelchair as safer as the proportion that found the PAD safer[49]. Another study reported several safety issues with a rear PAD during the performance of an obstacle course[13]. In particular by having the PAD in the right mode, forgetting or having difficulty turning off the PAD when going downhill, and unexpected PAD acceleration.

> *"The [front] PAD has reduced the need to use [my] car and significantly reduced how many times I have to transfer. I go to a small grocery or baker shop 4 km/2.5 miles away, which I used to use my car. Now I don't have to worry about finding city parking." – H. when asked about how using a PAD influenced transportation and activities*

Environment friendly

In the user survey a comment was made by a PAD user that one of the benefits of using PAD is that it can limit the need of a vehicle and therefore is beneficial to the environment. This is an argument which is also heard by those using an e-bike, as using an e-bike increases the distances traveled cycling compared to using a conventional bike, which therefore can provide the opportunity to e.g. commute to work using the e-bike instead of taking the car[58].

PERSONAL FACTORS

The needed cognitive load and experience with wheelchairs is dependent on type of PAD

	Front PAD	Main wheel PAD	Rear PAD
Personal factors			
Cognitive load / experience with wheelchairs	Most intuitive solution, start/stop, turn on(off	Easy to turn on/off. Sensitivity might take time to get used to	May be more difficult to start/stop

Cognitive load

Cognitive load is a consideration related to safe use of PAD Front PAD was found to be an intuitive solution, for start/stop and turning on/off[52]. Rear PAD was mentioned to have a higher cognitive demand required to operate, which was often associated with concerns for safety. People reported that they had to be focused or else they thought they would crash. An overview of manual wheelchair users perceptions about different type of PADs (front, main wheel, and rear)[3] support these findings. It further adds for main wheel PAD that it is easy to turn on/off and reports on the consideration of the adjustments of sensitivity and responsiveness.

Experience with wheelchairs

Wheelchair propulsion with different types of PADs can be more or less intuitive and experience with wheelchairs and the mastering of wheelchair skills might be a consideration that needs to be made when choosing a PAD. Front PAD was found to be more intuitive and easier to learn than rear PAD by able-bodied persons[52]. Main wheel PAD is somewhat easy to learn[52].

Age

PADs are used by people of all ages, where both younger and older people have different considerations. As age is known to be a risk factor for shoulder pain, the need of power-assisted propulsion might increase with age[1]. For the younger age range, there is very limited evidence related to long-term outcomes.

Adolescent manual wheelchair users have commented on the appearance and the relative importance of the functionality of wheelchairs compared to how they look, but also admitting that they wouldn't get an ugly wheelchair. These users also considered the attitudes and priorities of friends without disabilities and the value of their opinions[63].
Due to limited evidence for the younger age groups, manufacturer recommendations should be followed along with.

Body weight

All PADs have weight capacity limitations, which can be a consideration that needs to be made for those with a higher body weight.

Personal preference

Personal preferences for a certain type of PAD are an important consideration[3] and related to the different characteristics as extensively discussed in this white paper. Another factor to consider here is the liking of the appearance of the PAD[8 28].

Aroha enjoying the outdoors with her pup

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*Supporting articles (those not identified as part of the systematic literature review) are indicated with an **

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Appendix A: International Classification of Functioning, Disability and Health (ICF)

When matching the right power assist device to the person who will be using it, there are a multitude of factors that can influence the decision. Factors may include the person's previous experience, the device that fits best with their transportation, or how it improves the ability to complete daily activities with less pain. There is a comprehensive way to include such considerations, which is from the International Classification of Functioning, Disability and Health (ICF) framework[6]. The ICF was developed by the World Health Organization (WHO) to shift discussions from a medical model focused on diagnosis and disability to one highlighting the social model with function as its primary purpose. According to the WHO, ICF creates a standard language to describe health and health-related states.

In "ICF: A Hands-On Approach for Clinicians and Families", the editors state "The ICF framework is a tool to expand our thinking and actions across all dimensions on the field of healthcare providing more rich opportunities to rethink and improve". The ICF framework can be used in many different ways, but the main purpose is as a tool when making decisions around health plans and health policies[6].

This white paper will utilize the terminology of the ICF along with supportive evidence as the structure relates to important areas of a person's everyday life related to body functions and structures, activities, participation, environment, and personal factors.

Figure 12 represents one of the models that is often used when describing the basis of the ICF where the arrows are a visual representation of how health conditions interact and intersect with contextual factors to make up functional outcomes. And they can overlap depending on everyone.

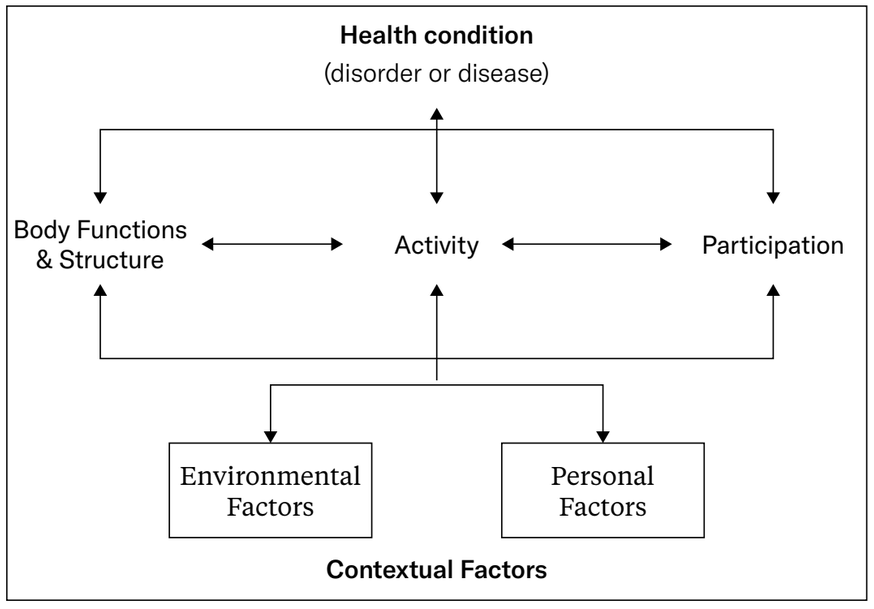

Figure 12. ICF model from "How to use the ICF: A Practical Manual for using the International Classification of Functioning, Disability and Health (ICF)[6]

Body Functions & Structures:

Body functions are physiological and psychological processes that occur within the body systems while the structures serve as the "anatomical support". Body functions can include memory and language, sensation and pain, cardiorespiratory functions, neurological and neuromuscular functions of movement as well as integumentary functions of the skin, hair, and nails. Body structures parallel the functions but are related to the actual anatomical body segment. For example, the body function of vision and seeing is followed by the body structures of the musculature, nerves, blood supply for example. Another example as it relates to power assist would be when a person has pain in a body part such as the shoulder or wrist, the sensation of pain is the body function while the body structure would be nervous system, nerve endings, as well as the muscles, ligaments, tendons of the shoulder joint.

Activities:

An activity is anything that is the execution or completion of an action or task. This can vary from basic, everyday required activities such as self-care activities of brushing teeth, combing hair, to mobility related activities such as transferring from the bed to a wheelchair, maintaining body position, or using a wheelchair. An activity is also inclusive of communication, whether verbal or non-verbal, expressive, or receptive. For this white paper, a PAD may assist someone with completing activities such as making the bed, as seen in the image below.

Participation:

Participation is defined as "involvement in a life situation" which often include the social world around the person such as being a student in a classroom or pursuing a vocation. Participation also often includes community, social and civic life, as well as interpersonal relationships.

Contextual factors:

Environment and internal personal characteristics make up the contextual factors. For environment it is not only the physical environment but the social and attitudinal environment such as social and legal structures. Personal factors are influencers on how a person perceives their disability such as their age, gender, coping style, education, and past experiences.

Appendix B: Clinical applications

CLINICAL APPLICATION 1:

Matt

Background

Matt is a 39-year-old, father of two with a background in environmental engineering. He has utilized a manual wheelchair for mobility following an incomplete spinal cord injury at the C6 level in 2005 as a result of a climbing accident. At the time of the interview Matt has utilized a rear PAD for two years with the primary goals to conserve his energy for required and desired activities, to reduce soreness reported in his arms, shoulders, and neck and to increase functional tasks such as carrying items when propelling his MWC.

In addition to being a husband, a father, Matt is also the Chief Operating Officer for a Medical Equipment provider and a member of the Canadian National Para Cycling team. As he began training and competing with his cycling team, he was able to see how the use of a rear PAD could impact some of his teammate's ability to travel and reduce expended energy.

Type of device: Rear PAD

Matt chose a rear PAD solution after observing peers using that during travels. *"In terms of which type of PAD to use and why I chose it, I was lucky in seeing my teammates use of the rear PAD and how it affected their energy expenditures while travelling e.g., mobilizing in large airports, carpeted hotels etc. Plus, seeing how using the [rear PAD] they could manage their luggage and bikes independently (for travelling – [our bikes are] packed in a box to get to competitions)."*

Main goals of PAD:

He states that the energy preservation and independent handling of luggage during travels were two key decisive factors for his choice. Matt also states that being able to travel and preserve his energy were also desired benefits that he saw his peers benefiting from.
He also would like to be able to hike with his family and go mountain biking with *"able bodied friends and keep up"*. In addition, portability was important to Matt so that he can just *"throw it in the car"*. He also feels a rear [PAD] would provide the most flexibility to take it with him and use it if and when he needs to.

Main activities with PAD

When discussing how he selected the type of PAD that would work best for him, Matt states *"Because of my work in the medical field I saw different types of PAD at the store where I work. Plus, as a member of the Para Cycling team I see how my teammates use different types of PAD. For example, one of my teammates has a front PAD that he uses very successfully around his rural home, but he would never use it while travelling as it is heavy and cumbersome to bring on a plane."*

Aside from traveling Matt states it allows him to be hands-free when managing his luggage or bike and that he can *"push a cart and carry more than just what fits on sidewalks"*. He feels that city sidewalks are also a wonderful use of his rear PAD, especially that when pushing on *"a canted sidewalk is very fatiguing without my [rear PAD] and I would typically not bother going out for those kind of outings if I needed to use the side walk for longer distances"*.

Experienced PAD benefits

Matt describes some of the critical life moments when he really relies on his PAD. He describes not only is it integral in his independence when traveling, but also when he is out with his family. Matt states: *"Before I got my [rear PAD], I found that I had to really make hard decisions as to how I was going to spend my energy. With my [rear PAD] there is no downside for going out for walks with my family. I am definitely doing more activities now than I would have before I got my [rear PAD]"*. Regarding his overall functional mobility, he states that when traveling alone, *"I don't need for people to rescue me. I use it with my family when we go camping and I can keep up with my girls. Before [having a rear PAD] I would likely just stay at the campsite if my girls went off to play. With the [rear PAD] I will go down to the playground with my girls and participate."*

Experienced PAD Limitations

When asked about any limitations as to when and how he uses his rear PAD, two themes emerged. He has difficulty placing it on his wheelchair while he is seated in it and that the way he controls the PAD was connecting inconsistently. Regarding placing the device on his chair, he has a manual wheelchair set-up that places his device in an awkward position, requiring him to transfer out of his wheelchair to place the device. This not only increases the effort to use the device but also takes up time in his day. Regarding the technology limitations, an issue was identified with his device and this is in the process of being addressed in an attempt to limit this as a barrier to its everyday use.

Impact on Quality of life

Matt states *"it gives me more opportunities to participate"* and *"it changes the number of times [for the positive] I participate. It is a great tool to have in my toolbox"*. He also claims that he will go out with his family more now that he has his PAD. He recalls a time when he knew he would be at the mall Christmas shopping for three hours, it was helpful that he knew he had the option to use his PAD so he could participate more.

CLINICAL APPLICATION 2:

H.D.

Background

H is a 59-year-old male who is married with one daughter. He lives in a residential area about 12 km/7.5 miles from the main city. His primary interests include gardening, socializing, and going into the city to meet with family and friends. H began using a manual wheelchair in 1987 following a motorcycle accident. He presents with a T12-L1 incomplete SCI.
Approximately 9 years ago, H was diagnosed with a repetitive strain injury (RSI) involving his shoulder with chronic inflammation of the pectoralis muscle where it attaches to the sternum. This was attributed to the number of years he has been propelling a MWC as well as other repetitive tasks such as transfers.

Type of device: Front PAD

For the past nine years, the device that has best met his needs and goals has been a front PAD. This allows him to traveling into the city, go out into the forest, complete his gardening tasks, as well as allows him to take the device along in his personal vehicle. It is of interest to note that when H talks about his gardening, this takes place over an 8000m2/ 2-acre distance which is all grass and uneven terrain.

He has utilized a front PAD and obtained the newer model of the same device four years ago. He also has supportive funding to be able to have a second battery available as needed. At this time, both devices are functional; however, he keeps one for environments where the device may get dirty such as gardening or going into the forest and the newer device for his city travels. His utilization of the front PAD varies by the activities heh as planned but he does report using the device daily, sometimes between 8-10 hours and an average of 20 km/12.5miles per day. He also reports that the device is *“easy to attach and detach in a matter of just seconds so it is much more user friendly”*.

Goals of PAD:

H reports he needed a device that would reduce his shoulder stain, be easy to use, have a high speed, and allow him to improve his accessibility on different types of outdoor terrain.

Activities with PAD:

H reports that he started to use a manual hand-cycle attachment for his manual wheelchair; however, this was only further contributing to the RSI issues in his shoulder. In addition, he underwent a surgical flap closure of a wound on his ischial tuberosity approximately 10 years ago and reports that the load and friction he experienced with the hand bike was not helpful in limiting his risk for skin impairment.

Experienced benefits

When asked about how using the front PAD has impacted his health, H states: “*RSI at the level of the shoulders disappeared and symptoms of infection at the pectoralis insertion reduced significantly.”* He also states that with the use of the PAD, *“no more pushes [are] required outdoors.”* Regarding functional mobility, H states that the front PAD “makes propelling the wheelchair redundant” which is why it was critical to relieve the pain and dysfunction he had with his shoulder. In addition to propulsion, using the front PAD has increased his perceived level of safety because he does not have to worry about tipping over backwards. H also reports that the use of a front PAD has reduced the amount he has to use his personal vehicle, which also reduces the number of transfers he has to perform. This is critical since both propulsion and transfers were a contributing factor to his shoulder pain and dysfunction.

Experienced limitations

Regarding potential limitations of using a front PAD, H reports that there are times he feels a little bit passive or lazy. In addition, when he has to ascend a curbstone or curb, the front PAD contacts first limiting his ability to navigate that obstacle. Due to the distances, he travels, he is always sure to take his extra battery.

Impact on quality of life & independence

Finally, when discussing the impact the device has had for his participation and socialization, H provides unique insight: [the front PAD] *“is a really important aid to maintain or make new contacts, visit friends, or visit a bar. The device draws positive attention and reduces the stigma of a wheelchair user that is not capable of doing things. You’re no longer considered as a disabled individual but as an active and able person.”* Individuals frequently start a conversation with H (which he doesn’t mind at all) about how impressed they are of how the device makes things possible for a wheelchair user. Besides the positive perception of the outside world, the device really fits well in the culture where he resides to use more electric vehicles, lower CO2 emission, and use more environmentally friendly transportation.

CLINICAL APPLICATION 3:

Mal

Background

Mal and his wife are an adventurous outdoor couple who have travelled worldwide, love to kayak, and go on “bush walks” (or hikes). They live close to a lake and love to play outdoors with their pets, which include a dog and birds. Professionally, he has been involved with assistive technology as an equipment provider or manufacturer ambassador since 1990. Mal is also very involved in his community where he serves in a counseling role for those recovering from drug addiction.

Mal has utilized a manual wheelchair for mobility since 1980 due to a complete spinal cord injury at the T5 level. Mal reports that he is *“some 42 years post injury”* and his shoulders and elbows are *“not as good as they used to be”*. This impacts his ability to be outdoors and kayak as much as he used to be able to in the past.

Type of device: Front and rear PAD

There are two different types of PADs that Mal is able to integrate into his life, both which he began using about 10 years ago. He uses both a front and rear PAD depending on the activity, the terrain he may encounter, as well as transportation and the destination ahead. He states *“the front attachment is quite different to the way I use the [rear PAD]”*.

As Mal has been able to use a wide variety of technology, he was one of the first to use a rear PAD. He states: *“the [PAD] surprised me when it first came out. I had an idea that it was really really great and was such a simple [solution].”* He states that some of the benefits of the front PAD are that it *“required minimal hardware and a small adaptor and you can stay in the same chair”.*

He also notes that when going on walks with his wife, the rear PAD allows him to set a pace and he can *“do a little bit of exercise pushing on the flats but combines it with using the assistance on the hills”*.

Goals of PAD: Shoulder preservation and avoid activity limitations

Mal has propelled a manual wheelchair for over 40 years, so his main goals are to protect his body and create longevity of his activities. Mal determined using a variety of PADs is the solution to preserve his body and sustain his independence. He also feels that using a PAD meets his lifestyle needs so that he does not feel limited by where he can go, what he can do, or how long he can participate in a desired or required activity.

Activities with PAD

Mal has many uses for power assist in his life, navigating through the land around his home, for going on walks with his wife, community activities and supporting his travels. He reports using one of his two options for PAD at least five times per week. Due to his shoulders and elbows being *“not as good as they once were”*, Mal also utilizes his PAD when *“going up to the shops [as]”* he *“does not have to transfer himself or his chair in/out of the car multiple times or worry about finding a car park”.*

He also uses his front PAD for environments that he knows he needs to go at a faster speed, such as navigating busy streets in London or heading into his city for shopping. He also uses a front PAD for *“something a bit more off road”* now that he lives in a more rural area. Mal also lives close to a beach reserve with cleared paths for

access, so between the grass and the sand, the front PAD is very useful.
For airline travel, Mal states that his [rear PAD] is easier as you can *“stick it away inside the plane”*. He reports it is especially useful for places like the mountains in northern Thailand and the Dolomite Mountains” where it is much easier to take with you because it is lighter weight.

Experienced benefits

Related to how using a PAD has impacted his general health, Mal states “*positive, particularly mental health! I can go somewhere and I can get anywhere. Just knowing that I can do stuff without it being painful.”* He also feels that from a mental health standpoint it’s great to *“just get out and blow the cobwebs out”*. Mal states that he has seen a change in his activities using a PAD. He reports: *“increased participation in all activities. Increased distance and increased exploration”*. He also says that using his PADs help him preserve his energy throughout the day and not have to think about where to park his car or if he can get back home at the end of the day. All of these contribute to his independence in that he *“isn’t reliant on others to go places without driving as the wheelchair can go farther”.*

Experienced limitations

The biggest limitations he reports relate to the weight and portability of the front PAD. He feels that it is “*just really hard, particularly if I am on my own. So the biggest barrier is being able to lift it and put it in the car”*. Mal also remarks that his front PAD loses traction when he is on uneven terrain which is also wet. He feels that the front PAD gets *“a bit of a slippery front wheel”* where he doesn’t experience that as much with his rear PAD.

Impact on overall quality of life & independence

Mal offers insight and reflection stating: *“We’re living a lot longer than we did back in the 1980s. You got a long life ahead. I think it’s much better to have a PAD earlier…rather than lose your abilities [due to injury] and quality of life.”* He closes with *“it’s hard to believe when you’re young that things will become more difficult,”* but by the time transfers get harder *“it’s too late then”*. Mal also shares that using a PAD allows him the opportunity to explore and using a PAD has *“opened up a world of difference”*.

CLINICAL APPLICATION 4:

Michael

Background

Michael is a US Army Veteran who has also worked as a paramedic. He is married and and has two grandchildren. He loves to travel using his recreational vehicle (RV) and he has a passion for scuba diving. Michael is currently 55 years old and was diagnosed in 2003 with Multiple Sclerosis (MS). He does recall symptoms beginning prior to his diagnosis he had some lower extremity weakness and started "tripping", but when he lost his vision in his right eye that confirmed his MS diagnosis. Michael also states that he has torn the labrum in his hips because of his walking pattern as a result of the spinal cord impairments that are associated with MS.

Type of device: Rear PAD

Michael uses a rear PAD on a manual folding wheelchair. Based on the recommendations of his therapists they felt it was the best option for him to retain his function and fitness, but to prevent the fatigue that comes with MS. His treatment team did discuss a scooter but he feels that propelling a chair with his [rear PAD] is easy to *"transport and take in a ride share to have it with me if I need it"*.

Goals of PAD

Michael states that his mobility issues included falling while walking as well as fatigue. His main priority was energy conservation so he can *"use my legs when I can, but have a wheelchair and [PAD] when I need."*

Activities

The primary role the rear PAD has for Michael is to allow him to reduce the fatigue that interrupts his daily activities. He feels he is still able to *"go there, be part of things, participate in things"*. The activities he does vary daily and weekly as he is very involved with his children and grandchildren who have busy schedules. For example *"when I am doing an errand with my wife, if it is a big shopping trip I use my [rear PAD]. I am slowly taking the advice of my medical team to use it more often even for shorter bouts so that I don't get tired."* He also reports that living in Florida and being in the heat allows him to get out and go to parks with his grandkids.

Experienced benefits

Transportation was a benefit to selecting a rear PAD over another PAD or scooter. Michael states *"It is easier for me to use the [rear PAD] because I can fold up the wheelchair rand have it in the car when I need, so I can do as much as I can before needing the assistance."*

Experienced limitations

Due to Michael's extensive travel, he would like updates to his device allowing it to be able to manage longer and steeper hills more consistently.

Overall quality of life & independence

The use of the PAD has increased Michael's overall independence because when he feels himself getting weaker or losing energy to propel himself or walk, he is able to use his power assist device without asking for help and assistance.

Michael also states that he is a lot happier now that he has his [rear PAD] because he had *"a lot of depression because of losing my ability to walk as my legs got weaker. I feel like I am included again. I am losing my ability to walk but I am not left behind. My spirits are a lot better. This allows me to have that freedom again and the ability to still do things."*

CLINICAL APPLICATION 5:

Yasmine

Background

Yasmin is a 38-year-old, journalist, podcaster and author. She is married and has a little dog, and they all live together in a house in the southern part of Stockholm. She enjoys long walks either with her dog or by herself to get some exercise. She also likes spending time in the city environment getting a coffee with friends . Yasmin likes to travel frequently with her husband.

Yasmin wrote a book about her experiences around her accident entitled “When life took a dive”, published in 2012. She is also an awardwinning podcaster for her previous podcast ‘Timglaset’ in she which was focusing on interviewing people about their experiences from living with disabilities.

She utilizes a manual wheelchair for mobility following a complete spinal cord injury at C4/C5 level in 1999 as a result of a diving accident. Due to the incomplete nature of her injury, she has motor and sensory imbalance between her right and left side of her body. Her right hand does not have sensation whereas her left has sensory sparing in her thumb and forefinger. Regarding her muscle strength, her left arm is stronger than her right.

Type of device: Main wheel PAD

Yasmin has utilized a main wheel PAD solution for about 10 years. Her latest pair of power wheels were acquired in 2017. She reports it was challenging to find a device that could accommodate her upper extremity paralysis but also the strength difference between her arms and hands. She did have tendon transfer surgery to compensate for this imbalance so at this time it is not as much of a concern as it was when she first began using a PAD.

She had to consider what type of device would work with the additional equipment she had on her chair that was used in her adaptive vehicle. In addition, she did not feel comfortable with a front PAD as it was difficult for her to maintain two hands on the steering tiller.

Goals of PAD

The primary goal was to increase her independence and to be able to do more activities on her own and with more self-esteem. Shoulder preservation was also a goal, she was struggling with pain in her shoulders which limited her ability to exercise and in the number of activities she could participate in.

She was also concerned looking at peers who have been using a wheelchair for many years and how they were suffering from shoulder tear from years of pushing and ending up having surgery.

“The main reason for getting a PAD was simply to make me able to roll as much as possible by myself.”

“I was always suffering more or less from pain because I don’t have all the shoulder muscles, I only have a few small ones which means I have to work very hard to push. I had to be careful with how much I trained and used them [the muscles], and I couldn’t do too much without getting in pain. So, this has absolutely simplified a lot for me.”

Activities with PAD

Yasmin uses her main wheel PAD solution every day for all her mobility needs indoors as well as outdoors. She estimates that she has an average daily driving range of 4 km/2.5 mi. With her main wheel PAD, she is able to independently take her dog for walks even in more variated terrain like trails without an assistant joining, which she truly appreciates.. She also goes into the city for work or a coffee with friends without having to worry about her shoulders or energy levels. She also uses the PAD to exercise by taking fast and long trips around the neighborhood.

“An important thing for me with these is that I keep fit, even if I get extra help with the wheels. I will still get my pulse up in a different way when I can roll faster and longer distances... ...I consider this as exercise, that I get fitter. It is the best training for me.”

Yasmin says that with increased independence comes self-esteem, and with self-esteem comes courage to do more activities. There are more opportunities to socialize because you have the self-esteem to trust that you will manage to get around, especially without asking for help.

” Asking for help is difficult, you want to avoid that as much as possible. I think it is about integrity and dignity, that instinct that you want to be able to manage by yourself as much as possible.”

Experienced benefits

“It was an enormous freedom to be able to roll everywhere by myself. I was doing okay indoors on plain surfaces, but as soon as I got on asphalt or the tiniest little slope, I used to need help. With this [the main wheel PAD] I can basically manage completely by my own outdoors as well.”

Getting in and out of the car independently is also an important aspect. She would not be able to get up on the ramp without her PAD solution.

The most valued benefit it the increased independence,self-esteem, and courage which has helped her overcome and do more. She has access to assistance 16 hour per day but with the PAD she can do more things of her own for a few hours and have the assistants as back up if needed to come if something would happen.

Shoulder preservation is also a consideration, she has concern about having pain but also an injury. With the use of a PAD, she can avoid constantly thinking about the amount of time she can propel. She does not have to plan activities around the potential for feeling tired or being in pain.

“Above all is the independence, I feel freer and get increased self-esteem from that. Prevention of shoulder issues is also a very important aspect. When you know, you are going to spend the rest of your life in a wheelchair and be rolling everyday, then it is extremely important aspect to save on your shoulders as much as possible.”

The utilization of the main wheel PAD lets Yasmin have a more equal distribution of the force when rolling. Even if she no longer needs to have the two wheels programmed differently it is a significant difference compared to her manual wheelchair because of the difference of strength that she has in her arms. This becomes more evident when self-propelling as soon as she needs to add extra force which makes the overall ride less smooth.

Experienced limitations

Main concerns relate to if something would happen to the wheels during a trip or during transport to a travel destination because of the sensitivity of the product. If they would get damaged during transport or if something would happen with the electronics when away, she would be stranded because the chair would be too heavy to self-propel manually and cumbersome for someone else to carry. When going to places where she is not fully familiar with the surroundings and infrastructure, she prefers to use her manual chair without PAD on for peace of mind.

“The disadvantage with these is the impractical part of them being heavy and that the fact that the electronics need to work, if something would happen with them, if they break then they are really heavy, so I guess that is the disadvantage.”

The lithium battery is an additional cause for stress or frustration for travel purposes she has to when explain to airport staff.

“On trips to new places or like to Tokyo or London I bring my manual chair, just because I want to minimize the risk of something happening when I am away or during transportation. You are so dependent of your device and how they treat it during transport, and these wheels are quite sensitive.. I am just more vulnerable on trips compared to home.”

Maneuvering in tight spaces like driving through tight doorways or in the car can be challenging. The PAD solution is sensitive for touch and activation so if the rim is touched unintentionally the chair can make a jump and drive forward or may drive over someone’s toe. Yasmin says she is always watching out when someone is standing too close her especially if in a club or where it is really crowded. It is important to remember to change the drive mode when being indoors to avoid unintentional activation.

At home, she has a door that is smaller than standard width where she needs to pay attention to when passing through. However, the additional width that her main wheel PAD solution adds to the wheelchair is seldom a problem since it is not affecting the possibility to pass through any standard door openings.

Lack of automatic brake is an issue in combination with the weight when going down steeper slopes. It gets heavy and it is difficult to get enough strength to regulate the speed with her hands. If too steep she needs help from her assistant.
“When I need a little extra help by someone, even if the wheels are working, to get over curbs it is heavy; or when going down a steep hill or slope it does not have automatic brake function and it is heavy. I brake with my hands and it burns and I get chafed on my right hand, that is a quite big disadvantage actually. I can brake independently, but since it does not have automatic brake assistance I need some extra help, but otherwise I brake by holding my hands against the rims.”

Quality of life & independence

The freedom of independence is affecting Yasmin’s perceived quality of life in various ways. Emotionally it has increased her self-esteem and courage to do more things, to trust her capability to cope with more situations and environments. Also the fact that she can exercise by using her PAD she becomes more fit both physically and increases her emotional well-being as well.

“It has increased my quality of life. The ability to be able to roll independently is huge. Now I don’t even consider being pushed around. That feeling of having to be pushed around, I don’t ever want to have that feeling again. My freedom and my dignity in being able to cope by myself, not feeling helpless.”

“I think this has critical for me in so many ways, both the independence and thinking about the psychological aspect. If you suffer from a lot of pain, you will feel bad by that and you will feel frustrated because you cannot always do what you want to do, you always have to hold back. So, with these wheels, the aspect of independence they provide makes you feel so much better. It is a feeling of freedom- you feel freer. The emotional suffering from feeling helpless and less able affects you deeply, so the aspect of being independent is so very important.”

Appendix C: Detailed study descriptions

C.1 BODY FUNCTIONS AND STRUCTURES

Detailed study descriptions on range of motion

Amongst 11 wheelchair users, shoulder kinematics and force during propulsion were studied while on a treadmill during 1-minute bouts of propulsion with and without main wheel PAD[21]. When propelling with the PAD, the stroke angle, maximal shoulder flexion, extension, abduction and internal rotation angles were significantly lower than without PAD. The peak resultant force was lower and earlier in the propulsion cycle with less abduction and internal rotation at the shoulder. At the glenohumeral joint the anterior directed force was significantly lower during PAD propulsion while the posterior directed force was significantly higher. No superior directed force occurred; however, the minimum inferior directed force was significantly higher with PAD. Internal rotation and flexion moment were significantly lower during propulsion with PAD while the external rotation moments were significantly higher.

The same research group reported on the same participants when performing a start-up movement, with and without main wheel PAD[23]. No difference was found on stroke angle, but the start-up movement was performed with significantly less shoulder internal rotation with PAD compared to without. At the handrim, the start movement with PAD was performed with a lower propulsion moment and less downward force. The peak resultant force was also lower and performed with more extension and less abduction. At the shoulder, there was also less anterior, posterior, and interior force, as well as lower abduction and extension moments.

One study measured biomechanical outcomes during 3-minute-long propulsion trials on a wheelchair dynamometer which is a stationary roller system that measures work, power, torque and speed. Researchers compared three different resistances (slight, moderate and high) with and without main wheel PAD in 15 persons with tetraplegia[24]. During propulsion at the slight and moderate resistance, range of motion was lower when using PAD for shoulder flexion and extension, internal and external rotation, horizontal flexion and extension, and wrist ulnar and radial deviation. Furthermore, at moderate resistance, range of motion was also lower with PAD for forearm supination and pronation, and at the highest resistance, range of motion was lower with PAD for all joints except shoulder abduction and adduction.

Findings in 10 persons with SCI performing a standardized propulsion protocol on different speed and resistance levels with and without main wheel PAD on a dynamometer, showed that with PAD maximum range of motion was lower for shoulder flexion/extension, horizontal flexion/extension, wrist flexion/extension, and ulnar/radial deviation[25].

In a study amongst nine able-bodied, shoulder biomechanics were assessed while propelling with and without main wheel PAD on a treadmill[22]. Results show that with PAD maximum shoulder flexion and internal rotation angles were lower. No differences were found in shoulder extension and abduction.

Detailed study descriptions on propulsion force

A recent study assessed upper limb propulsion effort during a 6-minute outdoor propulsion test with and without rear PAD in 21 adults with SCI propelling the wheelchair[11]. The mean mechanical load and propulsion cycle parameters recorded during the first 150 m (492 ft) of each test were significantly lower with compared to without PAD. Furthermore, peak mechanical effort during the propulsion phase was significantly lower compared to those without PAD. The forces applied on the handrim were 34% lower, and this did not result in a concomitant loss of performance; the distance covered with the PAD during the 6 minutes was greater with than without.

A study amongst 11 wheelchair users evaluated force during propulsion on a treadmill during 1-minute bouts with and without a main wheel PAD[21]. The peak forward force applied during the push on the rim was lower with PAD compared to without. The same research group reported on the same participants when performing a start movement, with and without main wheel PAD[23]. At the handrim, the start movement with PAD was performed with a lower propulsion moment and less downward force. With PAD, power output was significantly lower during the start movement.

In another study, ten manual wheelchair users (majority with a SCI), performed five-minute tests on five different resistances with and without a main wheel PAD[26]. Power was significantly lower and mechanical efficiency significantly higher compared to without PAD. Participants needed to generate on average 3.7 times more power without the PAD to achieve the same speed on the same resistance level. Mean mechanical efficiency over all trials was 80% higher with PAD.

In a study amongst nine able-bodied, shoulder biomechanics were assessed while propelling with and without main wheel PAD on a treadmill[22]. Horizontal and vertical forces exerted on the rim were significantly lower and the moments around the Z-axis were also significantly lower with PAD compared to without. Furthermore, during propulsion with PAD the peak resultant force was significantly lower and was reached earlier in the propulsion cycle and with less internal rotation at the glenohumeral joint.

Start and stop with-and without a rear PAD was analyzed in 24 able-bodied persons, and showed no significant differences in starting force or speed[27]. Although it was thought that the added weight of the rear PAD would increase stopping force, the force was instead 10% less using PAD. Furthermore, stopping distances (normalized to body weight) were about 20% shorter with PAD compared to without. The authors discuss that the reduction in stopping force may have been due to the inertia and rolling resistance of the rear PAD wheel. As the wheel of the studied PAD consist of several omniwheel rollers and is knobby and solid, and because of its footprint, this might have increased the rolling resistance of the wheelchair, thereby increasing the drag which resulted in a shorter stopping distance with the same amount of force. Coming to a complete stop in a shorter distance with less force could be beneficial to prevent shoulder injuries.

Detailed study descriptions on push frequency

Lower push frequency

A recent study amongst three able-bodied and one person with SCI analyzed push frequency during common daily life wheelchair maneuvers performed with a manual wheelchair only and combined with a main wheel PAD[29]. For all maneuvers, the push frequency was lower when using PAD. Although the effects of PAD use varied across all maneuvers and between different participants, on average, participants applied less torque and the average number of pushes on each wheel was significantly lower when using PAD compared to without.

Another study amongst 14 wheelchair users with SCI evaluated main wheel PAD propulsion on different resistance levels on a treadmill[30]. Cycle length was significantly longer and push frequency lower during fast PAD propulsion, but not on self-selected speed or in graded conditions.

One more study found significantly lower push frequency with main wheel PAD, during 3-minute-long propulsion trials with different resistances (slight, moderate and high) on a dynamometer, in 15 persons with tetraplegia[24].

Higher push frequency

A study amongst 11 wheelchair users (SCI or coordination impairments) examined shoulder kinematics and force during propulsion on a treadmill during 1-minute bouts of propulsion with and without main wheel PAD[21]. When propelling with PAD the push frequency was higher compared to without.

No difference in push frequency

A study in 10 manual wheelchair users with SCI performing a standardized propulsion protocol on different speed and resistance levels with and without main wheel PAD on a dynamometer, showed unaltered push frequency in all conditions[25]. Findings in 11 persons with SCI or MS (multiple sclerosis) performing ADL activities with a main wheel PAD and without, also showed no difference in number of pushes[8]. In another study amongst nine able-bodied, shoulder biomechanics were assessed while propelling with and without main wheel PAD on a treadmill and push frequency was found to be comparable with and without PAD[22].

Dependent on environment

Three main wheel PADs were evaluated by 46 wheelchair users on indoor and outdoor courses[31]. During the test on the outdoor course the number of handrim pushes was significantly lower with two out of the three PADs, compared to without PAD. During the test on the indoor course, the number of handrim pushes was overall comparable, but subgroup analyses showed that for those with lower lesion levels number of pushes were significantly higher with one of the PAD compared to without, while no effect was found for the other PADs.

In another study amongst eleven elderly wheelchair users, push frequency was lower during 100-meter propulsion test with a main wheel PAD compared to without, but on carpet and incline no differences were found in push frequency with and without PAD[32].

Detailed study descriptions on perceived upper extremity pain and prevention of injuries

A qualitative study amongst 16 experienced independent manual wheelchair users (mostly with SCI) explored the perceived impact of PAD (mix of front, main wheel and rear)[3]. All users expressed that PADs helped to maintain physical health, and in particular help manage existing overuse injuries of upper extremities and prevent potential injuries as they age. Some participants noted that the risk of overuse injuries was a learning process that required them to change their mindsets which involved a process of shifting their attitudes towards PAD.
A qualitative study asked 20 wheelchair users about their experiences after both four- and eight-weeks of using a main wheel PAD. Six out of 14 participants with reported pain, commented that they experienced less pain after four and eight weeks of using the PAD. This included pain in the back, hands and shoulder[28].

Detailed study descriptions on experienced health

A survey study amongst 123 wheeled mobility device users reported that those using a manual wheelchair with an add-on (non-powered front-end attachments or front/rear PAD) had higher satisfaction with their health conditions compared to manual wheelchair, power wheelchairs and scooter users[37].

Detailed study descriptions on mental health

Fifteen manual wheelchair users with tetraplegia evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. Psychosocial impact, as measured by adaptability, competency, and self-esteem, did not differ with and without PAD. Four out of 15 participants gave negative ratings to their own wheelchair, but positive ratings to the PAD on adaptability, competency as well as self-esteem. One person reported that PAD had a negative psychosocial impact. Those who needed assistance with PAD had lower scores.

A study in 38 children with physical disabilities (6-13 years old) performed a randomized control trial to assess the effects of a behavioral activation in tandem with the installment of a main wheel PAD, compared to only receiving the PAD[39]. Although the main aim of this study was to determine the effect of the addition of behavioral activation it was interesting to note that the group receiving PAD showed a decrease on the children's depression inventory (12.32 to 7.37) and a decrease on avoidance/rumination of the behavioral activation for depression scale (from 16 to 10) comparing assessments before they received the PAD to 8 weeks after receiving it.

In another study, eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks and comparisons were made to a similar time period in which they used their power wheelchair[40]. A questionnaire on psychosocial impact of assistive devices, comparing manual wheelchair with main wheel PAD and power wheelchair use, showed large variability between the users on the different items including competence, adaptability, and self-esteem. Participants scored higher on self-esteem with the power wheelchair compared to the manual wheelchair with main wheel PAD.

C.2 ACTIVITIES

Detailed study descriptions of wheelchair propulsion over longer distances

Lab-based studies

A study comparing the use of a rear PAD vs using a manual wheelchair only during a 6-minute outdoor propulsion test in 21 adults with SCI[11], showed that the distance covered in 6 min was 16% more propelling with compared to without the PAD. In another study, eighteen persons with SCI and shoulder pain performed a 6-minute steady-state and 12-minute intensity graded wheelchair propulsion test on stationary rollers with and without a main wheel PAD[46]. Distances travelled were significantly greater in both those with paraplegia and tetraplegia for the PAD condition.

Studies evaluation longer time periods

Twenty manual wheelchair users (mostly SCI) participated in a 16-week study, of which they used a main wheel PAD for eight weeks. With PAD, the participants traveled significantly greater distances than without PAD[47].

A study in 38 children with physical disabilities (6-13 years old) performed a randomized control trial to assess the effects of a behavioral activation (a skill in cognitive behavior therapy) in tandem with the installment of a main wheel PAD, compared to only receiving the PAD[39]. Although the main aim of this study was to determine the effect of the addition of behavioral activation it was interesting to note that the group receiving PAD showed improvements over time in the distance that they travelled, from 27 km/17 miles before receiving the PAD to 4 weeks later to 41 km/25 miles between 4 to 8 weeks after receiving the PAD.

Studies evaluation shorter time periods

Fifteen manual wheelchair users with tetraplegia evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. Distances travelled with or without PAD were not significantly different. In another study seven manual wheelchair users with paraplegia were followed for a 2-week period with and without main wheel PAD. There were no differences in average distance and total distance[48].

Detailed study descriptions performance of activities

Quantitative outcomes

Performance of an obstacle course was studied amongst 11 wheelchair users (mostly SCI), comparing performance with and without a rear PAD[13]. It was found that participants could go up a long hill and up a 200 m indoor ramp significantly quicker with PAD. One older participant with a high cervical lesion could not do most of the outdoor wheeling tasks (such as grass, gravel, ramp) without PAD, but was able to do it with PAD. Two persons were able to ascend an incline only with PAD and not without, and two other reported that descending a steeping ramp was easier with the PAD because of the drag when turned off. Performing wheelies was not impacted. No significant differences were found on wheelchair confidence or on the wheelchair skill tests scores.

Wheelchair skills with and without main wheel PAD were compared amongst 30-able bodied participants[49]. It was shown that the score on a wheelchair skills test was similar with and without PAD. However, it was noted from observations that skills requiring a higher force on the push rim (e.g. gravel or irregular surface), were performed more easily with the PAD whereas skills requiring greater control of the wheelchair (e.g. door negotiation or wheelie) were performed easier without PAD. Participants often bumped into barriers during completion of skills requiring greater control with PAD. It took participants generally longer to fold the wheelchair with the PAD wheels and it seemed to be more difficult because of the weight of the wheels. Participants self-reported to find it more effective without PAD to move turns, role backwards, turn in place, make three-point turns, do parallel parking, pass a doorway, and make a wheelie. On the other hand, participants seemed to find the low-curb, high-curb, gravel, irregular surface, incline-ascent/descent and rolling-forward skills easier with PAD.

Fifteen manual wheelchair users with tetraplegia performed tests on an ADL (activities of daily living) course in their own manual wheelchair, with or without main wheel PAD[50]. The following four obstacles were rated as significantly easier to complete with PAD compared to without: carpet, dimple strips, propelling up the ramp, up the curb cut. The amount of assistance that the users needed to complete all the obstacles did not differ with and without PAD. Results of the study indicate that PAD has the potential to significantly improve function when propelling over thick carpet and ascending hills. Users reported that it was significantly easier to propel and that the pushrim was more comfortable with PAD compared to without.

Seven manual wheelchair users with paraplegia were followed for a 2-week period with and without main wheel PAD)[48]. There were no differences in mean speed. However, people reported that they liked the ease of use. With regards to climbing hills, 43% stated that they were able to do this better with PAD and 29% reported travelling quicker and further with PAD. Propulsion was reported to be easier (8.8 with PAD compared to 5.9 without on a 10-point scale.

Eleven elderly wheelchair users propelled in their manual wheelchair and with the addition of a main wheel PAD on level surface, carpet and an incline[32]. Eight participants rated that with PAD it was really easy to propel.

Furthermore, ten participants rated it very easy or easy to propel on the level and inclined surfaces, and nine found it very easy or easy to navigate on carpet.

Speed was compared with and without main wheel PAD in a study in 3-able bodied and one person with SCI during common daily life wheelchair maneuvers[29]. All participants ranked the physical demand and effort of PAD propulsion lower than without PAD. For all maneuvers, the task completion time was lower when using PAD. Although the effects of PAD varied across all maneuvers and between different participants, on average, participants travelled at a higher speed when using PAD compared to without. It has to be noted that while velocity increased in a linear direction to help with efficiency, velocity also increased in an angular direction which could contribute to difficulty controlling the desired direction or path.

A study amongst fifteen manual wheelchair users with tetraplegia who evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38], showed that participants traveled faster with PAD compared to without. Another study amongst 14 wheelchair users with SCI studied main wheel PAD propulsion on different resistance levels on a treadmill[30]. When propelling with PAD on the higher resistance levels, speed was significantly higher compared to propelling without PAD. One more study measuring speed during 3-minute-long propulsion trials with different resistances (slight, moderate and high) comparing conditions with and without main wheel PAD in 15 persons with tetraplegia[24] found that in the highest resistance trial, the participants had significantly higher velocity with PAD compared to without.

Three main wheel PADs were evaluated by 46 wheelchair users on indoor and outdoor courses[31]. During an outdoor driving test, no difference was found in completion time of an outdoor driving test comparing with and without a PAD. During the indoor driving test, completion time was significantly slower with one of the PADs compared to without PAD, while no effect was found for the other PADs. Furthermore, during the outdoor driving tests, 8 to 10 persons needed help with each of the PADs, while without PAD 12 persons needed help. There was no significant difference in overall satisfaction comparing with and without PAD. During an indoor driving test, the number of collisions during the test was significantly lower without PAD compared to one of the PADs, but not for the other ones. Satisfaction was significantly lower with PAD for two of the PADs. For door management, no significant differences were found in overall completion time, but subgroup analyses showed that those with thoracic lesions were significantly faster without PAD. For the indoor driving test, satisfaction was generally higher without PAD, in particular in those with thoracal level of injury.

Findings in 11 people with SCI or MS studying an extensive battery of different ADL tasks showed no differences in completion time of an ADL driving course and traversing down and up a long ramp comparing the performance with and without main wheel PAD[8].

Qualitative outcomes

An overview of manual wheelchair users perceptions about different type of PADs (front, main wheel and rear)[3] include the perception that speed of front PAD exceeds users' needs whereas it meets users' needs for rear and main wheel PAD. It further includes a discussion and overview of different type of activities that are easier or more difficult to do in each type of device.

A qualitative study asked 20 wheelchair users about their experiences after four and eight weeks of using a main wheel PAD[28]. Thirteen out of twenty participants reported that PAD enabled them to complete novel activities. This included activities such as going to the mall, going out with the dog. One participant also reported that this enabled her to have her daughter sit on her lap while wheeling.

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks and comparisons were made to a similar time period in which they used their power wheelchair, and participant's experiences were captured in focus groups[51]. Persons described that the use of the PAD was much easier than their manual chairs, allowing them to go faster and further. Several participants identified difficulty coordinating pushes of equal force on each wheel resulting in the PAD turning or moving in other directions than planned. This was in particular the case during braking or when negotiating a decline and led to safety concerns amongst some of the participants.

Fifteen manual wheelchair users with tetraplegia evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. In a qualitative part of the study, eleven out of 15 participants reported that PAD increased ease of propulsion.

In a mixed-method study, two PADs were compared: one rear and one front, with 11 able-bodied persons performing an obstacle course and participating in an interview[52]. The front PAD was mentioned to be most useful for longer trips outside and on off-road terrains because this PAD had easier speed control, higher maximum speed and a simpler braking system. The rear PAD was found to be more valuable indoors and in tight spaces because of the smaller footprint and a better turning radius.

A survey study amongst 123 wheeled mobility device users reported that those using a manual wheelchair with an add-on (non-powered front-end attachments or front/rear PAD) reported that there can be path deviations, intentionally having to slow down to maintain stability or that there could be too much torque being applied to specific tasks[37].

Detailed study descriptions on muscle activity

A study amongst 11 wheelchair users studied EMG during main wheel PAD propulsion on a treadmill and without PAD, during 1 minute propulsion[21], and results showed significantly less activity for the anterior deltoid and pectoralis major with PAD compared to without.

In a study amongst nine able-bodied, shoulder biomechanics were assessed while propelling with and without main wheel PAD on a treadmill[22]. Muscle activity of the pectoralis major, posterior deltoid and triceps was lower with PAD compared to without PAD. No significant differences were found for the anterior deltoid, middle deltoid, trapezius and biceps.

Another study amongst 14 wheelchair users with SCI measured EMG during main wheel PAD propulsion on different resistance levels on a treadmill[30]. On self-selected comfortable speed, in fast and graded conditions muscle activity of the pectoralis major and anterior deltoid was significantly lower with PAD compared to without. In fast and graded conditions, muscle activity was also lower for the supraspinatus and infraspinatus with PAD compared to without.

Eleven elderly wheelchair users propelled in their manual wheelchair and with the addition of a main wheel PAD on level surface, carpet and an incline[32]. Across all surfaces, muscle activity of the extensor carpi radialus, triceps, pectoralis major and latissimus dorsi was significantly lower with PAD compared to without. On the incline, there was significantly less muscle activity of the anterior deltoid.

Detailed study descriptions on energy expenditure

Lab-based studies

Physiological outcomes were measured during a 6-minute outdoor propulsion test with and without rear PAD in 21 adults with SCI propelling the wheelchair[11]. Cardio-respiratory outcomes were lower with compared to without PAD, with oxygen consumption (VO2) being 45% lower with compared to without the PAD. Other significant differences were found for heart rate, METs (metabolic equivalent of tasks), tidal volume, and minute volume.

Three main wheel PADs were evaluated by 10 wheelchair users while propelling on a dynamometer, and their oxygen uptake was compared to propelling without PAD[31]. It was shown that when using PAD, oxygen consumption and heart rate when propelling at different resistances was significantly lower compared to propelling without PAD. No differences were found between the three different PAD devices.

Energy expenditure was evaluated while propelling on a treadmill with two main wheel PAD devices in 10 able-bodied participants[35]. Results showed that energy expenditure was significantly lower and propulsion efficiency significantly higher for one of the PADs compared to propelling without PAD. For the other PAD only tendencies for lower energy expenditure and higher propulsion efficiency were found but no significant differences.

Eighteen persons with SCI and shoulder pain performed a 6-minute steady-state and 12-minute intensity graded wheelchair propulsion test on stationary rollers with and without a main wheel PAD[46]. Oxygen uptake and heart rate were significantly lower with PAD during both tests.

Physiological outcomes were measured during 3-minute-long propulsion trials with different resistances (slight, moderate and high) comparing conditions with and without main wheel PAD in 15 persons with tetraplegia[24]. With the PAD, participants had a significantly lower mean oxygen consumption and ventilation throughout all trials. Furthermore, mean heart rate was also significantly lower in the high resistance trial, but not for the light and moderate resistance conditions. Results indicate that PAD has the potential to reduce metabolic energy expenditure. For people with decreased physical capacity, conserving energy during routine tasks, such as propelling uphill or across a carpeted hallway, might allow a person to maintain function while performing other necessary activities, such as transferring to a different surface.

In a study with ten manual wheelchair users (majority SCI) who performed five-minute tests on five different resistances with and without a main wheel PAD[26] metabolic energy was significantly lower when propelling with compared to without PAD.

Findings in 11 persons with SCI or MS studying a main wheel PAD showed that compared to manual wheelchair only, propulsion with PAD had significantly lower oxygen consumption at different speeds. Furthermore, heart rate was significantly lower with PAD whereas no overall significant difference was found for ventilation comparing propulsion with and without PAD[8].

Activities of daily living

Fifteen manual wheelchair users with tetraplegia performed tests on an ADL (activities of daily living) course in their own manual wheelchair, with or without main wheel PAD[50]. The course was completed in the same amount of time, but the mean heart rate was significantly lower when using the PAD compared to without.

Eleven elderly wheelchair users propelled in their manual wheelchair and with the addition of a main wheel PAD on level surface, carpet and an incline[32]. With PAD heart rate was lower compared to without PAD.

Energy expenditure was compared amongst five persons with SCI propelling their own wheelchair and a wheelchair with main wheel PAD on an outdoor cement track for twenty minutes[60]. With PAD, heart rate and oxygen consumption were lower in three persons and higher in two persons. It has to be noted that this variation can be caused because by participants being allowed to propel at comfortable and efficient velocity with and without each of the PADs.

Detailed study descriptions on perceived exertion

In a recent study amongst three able-bodied and one person with SCI during common daily life wheelchair maneuvers performing with and without main wheel PAD[29], all participants ranked the physical demand and effort of propelling with PAD lower than without.

A qualitative study amongst 16 experienced independent manual wheelchair users (mostly with SCI) explored the perceived impact of PAD devices (mix of front , main wheel and rear)[3]. All users mentioned that they wanted to use a PAD to conserve energy, and some reported that they preferred PAD devices over power wheelchairs because PAD allows for continued opportunity to engage in physical exercise through manual propulsion. Although PAD decreased the overall need for manual wheelchair propulsion, participants valued how using PAD could preserve their ability to exercise or be physically active in their wheelchairs.

A qualitative study asked 20 wheelchair users about their experiences after four and eight weeks of using a main wheel PAD[28]. Sixteen of the 20 participants reported less fatigue after using the PAD. Participants commented that this made it possible to do more activities that they wanted to be involved in, because they did not have to consider if they had the energy for it.

Eighteen persons with SCI and shoulder pain performed a 6-minute steady-state and 12-minute intensity graded wheelchair propulsion test on stationary rollers with and without a main wheel PAD[46]. Perceived exertion was found to be significantly lower with PAD during both tests.

Eleven elderly wheelchair users propelled in their manual wheelchair and with the addition of a main wheel PAD on level surface, carpet and an incline[32]. With PAD perceived exertion was lower than without PAD.

Seven manual wheelchair users with paraplegia were followed for a 2-week period with and without main wheel PAD. The PAD was reported to provide relief when tired and persons reported that they were able to get more things done in a day[48].

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks, and their experiences were captured in focus groups[51]. Several participants noted that compared to using their power wheelchair, the main wheel PAD still required some degree of upper extremity strength it caused fatigue at times.

C.3 PARTICIPATION

Detailed study descriptions on social and occupational participation

Fifteen manual wheelchair users with tetraplegia evaluated their mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. No differences in overall participation were found: participants visited a similar amount and type of places, such as grocery store, bank, work, school, museum, during the weeks with and without PAD.

Seven manual wheelchair users with paraplegia were followed for a 2-week period with and without main wheel PAD[48]. There were no differences in number of times persons left the house. Although not significant, persons reported that they were more likely to use their wheelchair with PAD compared to without, when leaving the house.

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks and comparisons were made to a similar time period in which they used their power wheelchair[40]. There were no differences in time spend using the power wheelchair and the manual wheelchair with main wheel PAD. The authors concluded that participants were thus able to maintain participation in community-based activities using their PAD instead of their power wheelchair. Users that already used their manual wheelchair more frequently might be better candidates for PAD.

Detailed study descriptions on navigation and access

A qualitative study amongst 16 experienced independent manual wheelchair users (mostly with SCI) explored the perceived impact of PAD devices (mix of front, main and rear)[3]. Participants expressed that the use of a PAD provided access to new environments and enabled to explore environments that were more difficult to access with a manual wheelchair. Several participants praised PAD devices for helping them wheel more effortlessly on inclines and side slopes in an urban environment. Users also noted that the device enabled them to travel longer distances and for longer periods. In addition, a PAD helped to overcome difficult terrains found in the outdoor natural environment.

A survey study amongst 123 wheeled mobility device users reported that those using a manual wheelchair with an add-on (non-powered front-end attachments or front/rear PAD) had higher satisfaction with their autonomy in buildings outside of the home environment compared to power wheelchair/scooter users, with the exception of maneuverability on different terrains[37]. In the outdoor built environment (e.g., inner-city), higher satisfaction with speed was rated for manual wheelchair users with an add-on. In the outdoor natural environment (e.g., green spaces), autonomy satisfaction scores were the lowest, with manual wheelchair users having lower scores compared to manual wheelchair users with an add-on and power wheelchair/scooter users.

In a qualitative study amongst 6 adolescent manual wheelchair users, trying out a main wheel PAD, the practicality of the PAD and its functional advantages in different contexts were discussed[63]. The users articulated the advantages of the PAD, that it can help to climb hills easily and to get over obstacles, which can make life easier. It was noted that it is more difficult to have control with the main wheel PAD when trying to go straight and having to put the right amount of pressure on each wheel. To be noted that this might no longer be an issue depending on the technologies in use which may allow to program the sensitivity.

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks and comparisons were made to a similar time period in which they used their power wheelchair[40]. Most participants had higher participation scores on the performance of community-based activities with their power wheelchair compared to manual wheelchair with main wheel PAD. With regard to satisfaction with participation, the differences between the two devices were more scattered between participants. Another publication reported on the experiences of the same participants which were captured in focus groups[51]. Participants noted that with the PAD they were able to propel at a sufficient speed to keep up with colleagues and friends who were walking, when that would have been impossible with their manual wheelchairs. PAD enabled participants

to increase their level of community mobility and access new environments compared with using their manual wheelchairs. Access to inclines and ramps as well as propelling over softer surfaces (grass, carpet) were reported as important achievements. However, compared to their power wheelchair some outdoor environments were more challenging, including extended inclines and unpaved surfaces. Furthermore, persons noted that indoor environments were more accessible with the manual wheelchair with PAD compared to a power wheelchair.

A qualitative study asked 20 wheelchair users about their experiences after four- and eight-weeks of using a main wheel PAD[28]. Eighteen of 20 participants reported the PAD allowed greater access to diverse terrains including sand, gravel, and grass. Eighteen participants also reported about positive experiences on abilities to go up hills with the PAD.

Fifteen manual wheelchair users with tetraplegia evaluated their mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. Accessibility with and without PAD were rated similarly. In a qualitative part of the study, three participants reported that PAD increased performance in difficult terrain, while three participants reported difficulty in maneuvering in small rooms and inside the house.

Detailed study descriptions on transport of device

In a mixed-method study, two PADs were compared: one rear and one front, with 11 able-bodied persons performing an obstacle course and participating in an interview[52]. The front PAD was much larger and heavier and therefore more difficult to transport, most people would need someone to help them load it in their car. The rear was much more compact and lighter and described as that when not in use it would be possible to transport in your lap if you had to.

The ability to transfer three different types of main wheel PADs and wheelchairs into and out of the car was evaluated by 10 wheelchair users. Participants evaluated their ability to transfer themselves, their wheelchairs and PADs[31]. None required help with manual wheelchairs whereas two out of 10 persons required help with two of the main wheel PADs. The persons who successfully completed the transfers with all PADs had the shortest completion time without PAD. Satisfaction was also significantly higher without PAD.

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks, and their experiences were captured in focus group[51]. Participants commented on that the manual wheelchair with PAD was much easier to transport than their power wheelchair, particularly in a personal vehicle.

A qualitative study asked 20 wheelchair users about their experiences after four- and eight-weeks use of using a main wheel PAD. Findings with regard to transportation indicated that those with the possibility to transport the chair and PAD with ease, with a wheelchair lift, a spouse, public transportation, or other assistance, reported greater benefits from the PAD. Six out of twenty participants reported transport in and out of a vehicle as a concern due to the added weight[28].

Findings in 11 persons with SCI or MS studying an extensive battery of different ADL tasks with and without main wheel PAD. Five persons were not able to do one or more of the car transfer tasks with PAD while they were able to do it without. Comparing ratings of car transfer between main wheel PAD and with their manual wheelchair showed lower ratings for the PAD for taking the wheels off and putting the wheels back on. There were no significant differences in physical strain for all call transfer tasks[8].

C.4 QUALITY OF LIFE AND INDEPENDENCE

Detailed study descriptions on quality of life

Fifteen manual wheelchair users with tetraplegia evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. In a qualitative part of the study, four participants reported on increased quality of life.

Detailed study descriptions on independence

A qualitative study amongst 16 experienced independent manual wheelchair users (mostly with SCI) explored the perceived impact of PAD devices (mix of front, main wheel and rear)[3]. Participants expressed that PAD devices expanded one's world, and that it enabled them to gain a sense of autonomy, with most users feeling that PAD device provided them with an increased sense of belonging and autonomy, including being able to fully engage with others during social activities.

A survey study amongst 123 wheeled mobility device users reported that those using a manual wheelchair with an add-on (non-powered front-end attachments or front/rear PAD) had higher scores of autonomy compared to manual wheelchair users and power wheelchair or scooter users[37].

Eight persons using both a power and manual wheelchair (mostly MS or SCI) trialed a main wheel PAD for three weeks, and their experiences were captured in focus groups[51]. Persons described an increased independence, with PAD reducing or eliminating need for assistance.

A qualitative study asked 20 wheelchair users about their experiences after four- and eight-weeks use of using a main wheel PAD[28]. Thirteen out of twenty participants reported that using a PAD makes them feel more independent, have more freedom, and feel less of a burden to family and friends.

Fifteen manual wheelchair users with tetraplegia evaluated mobility for two weeks in their own wheelchairs and for two weeks with a main wheel PAD[38]. In a qualitative part of the study, six participants reported on increased independence when using the PAD.