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Design a solution to improve wheelchair efficiency by identifying and reducing the factors that have effect

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ABSTRACT

There have been many improvements made to self-propelled wheelchairs (SPWCs) in recent years. Such improvements have brought lighter, stronger, more tailored products to market. This has been driven by the growing demands and popularity of wheelchair sports such as basketball, rugby and racing. Today’s SPWCs are designed and manufactured using modern materials and techniques with greater thought given to the end user than ever before. However, even after all these innovations, the basic layout remains the same demonstrating testament that the original design where the use of push rims mounted to the rear wheels is still the preferred method of propulsion. This solution has the advantage of being lightweight, simple, requiring minimal maintenance and provides an ideal gearing for normal use.

It has been documented that a problem with push rims is that long term use causes fatigue and places excessive repetitive strain on the upper limbs and shoulders of the SPWC user. Also, in comparison to walking, a wheelchair has a gross energy efficiency of 10% or lower. Demonstrating more can be done to improve the existing designs.

This report identifies the shortcomings of existing generic SPWC designs, defining their impact on wheelchair users. The findings significantly contributed towards the creation of a detailed design brief and specification for concept development, with the ambition to construct a prototype for testing, so that a new product may be developed to launch.


INTRODUCTION

The author has been a SPWC user since 2009 following a spinal cord injury (SCI) and is aware of the fatigue and upper limb strain suffered due to the lack of efficiency inherent in generic SPWC design.

There is little variety of SWPC suited to prolonged self-propulsion methods over rough terrain as the push rim remains a popular staple. This lack of choice for the customer exposes a gap in the market. There are currently around 1.2 million wheelchair users in the UK. (NHS England, 2018)

This paper researches: the reasons for fatigue and upper limb injury from SPWC use; causes of low wheelchair efficiency; ideas, designs and patents that claim to address the issues. A critical review of these issues will provide a better understanding of the problems and lead to compiling a
concise design brief so that a more ideal solution can be identified.

**METHODOLOGY**
To achieve a fundamental understanding of the cause of upper limb fatigue & injury from using a SPWC an investigation into kinematics, biomechanics and musculoskeletal movements was made. Data that highlights the factors effecting the efficiency of a wheelchair were also considered. However, anecdotal evidence from other wheelchair users, carers, retailers and health professionals has also proven insightful.

With this knowledge a critical review of any existing ideas, patent applications and products that use lever propulsion was made. These evaluations allowed a detailed design brief to be generated using a recognised procedure so that preliminary design ideas may be explored initially as a desk top study.

**FATIGUE AND REPETITIVE STRAIN PROBLEMS FOR WHEELCHAIR USERS**
Pain and fatigue mediate the relationship between usage of certain mobility aids and depressive symptomatology. The use of people to assist in ambulation is associated with greater odds of moderate-to-severe depressive symptomatology, while always using a wheelchair is associated with lower odds (DiPiro, et al., 2014).

This demonstrates that the more independent a person can be without reliance on others, the less likelihood of developing depressive symptoms. The use of a wheelchair is one such way of gaining independence. However, this independence may have its price: wheelchair propulsion plays a significant role in the development of shoulder pain in manual wheelchair users…the more variation in hand/wrist placement at the start and end of the recovery phase the more likelihood of shoulder pain from wheelchair propulsion (Jayaraman, et al., 2014).

However, it may be more likely that the pain causes the variance: with fatigue, joint power shifts from the shoulder joint to the elbow and wrist joints (Rodgers, 2003). The forces that upper limbs (ULs) are required to generate and pushing frequency both increase substantially with propulsion up a steeper slope (Gagnon et al., 2014).

When quantifying the effects of incline on trunk and shoulder kinematics Gagnon, et al., (2015) found that: forward trunk flexion and shoulder flexion increased as the slope became steeper, whilst shoulder flexion, adduction, and internal rotation moments along with the muscular demand also increased as the slope became steeper. The results confirm that forward trunk flexion and shoulder flexion movement amplitudes, along with shoulder mechanical and muscular demands, generally increase when the slope of the treadmill increases.

This could be assumed to be a natural response to deliver more power to the wheels while maintaining balance. However, some wheelchair users with a higher level SCI would find trunk flexion movement difficult if not impossible. Since most wheelchair users may not be able to use the trunk muscles to generate propulsion power as fatigue occurs, they may have increased susceptibility to injury at the wrist as the shoulder muscles fatigue (Rodgers, 2003).

Further study is needed to understand better the effects of long-term ambulation on secondary conditions including pain, fatigue and depressive symptoms after traumatic

Hand cycling induces significantly less strain at a moderate sub maximal level of 35W and shows noticeably higher maximal exercise responses than wheelchair propulsion, which is consistent in subjects with paraplegia and able-bodied controls. These results demonstrate that hand cycling is beneficial for mobility in daily life of wheelchair users (Dallmeijer, et al., 2004).

Hand cycles may prove too large and cumbersome for alternative everyday use, but this study gives credence to a hybrid design idea incorporating the superior efficiency of a hand cycle with the compact manoeuvrability of a wheelchair. Some efforts have been made into replacing the push rim with an alternative method of self propulsion for wheelchairs, but many ideas have not made it to market or been successful.

Conventional SPWCs are designed with hand rims for manual propulsion. However, hand rim propulsion is energetically inefficient, where the ratio of work to energy expenditure, or mechanical efficiency (ME), is often found to be less than 10%. This contrasts with walking, running, or cycling, which typically have an ME of 20% to 30% (Lui, et al., 2013). That study investigated the ME of lever propulsion and reinforces the findings of other studies quoted its text. However, no firm details of the overall ratio of the gear train mechanisms were disclosed. Although, it is assumed that there is a reduction ratio (greater mechanical advantage) as the lever propulsion was more efficient when climbing a slope than push rims.

PRODUCT ANALYSIS
All Patents searches have shown nothing new or novel in the concept of lever propelled wheelchairs. Applications with relevance to this topic were either withdrawn or refused. Those that were of interest often offered an overly complex solution that would be expensive to manufacture and difficult to service or repair.

The majority of the few existing products that are commercially available on the market today include:

Figure 1. NuDrive

A detachable lever mounted on a retrofit hub that is fixed to a framework mounted on the outside of the rear wheels of the wheelchair. The hub contains a ratchet to allow forward freewheeling and a braking system operated by transverse pressure on the lever. The brake engages with the wheel to allow backward travel.

This design is simple in operation, requires very little work to install onto almost any wheelchair and is relatively cheap. However, it adds significant width to the wheelchair making navigating through gaps and doorways more difficult and the 1:1 gear ratio is fixed. It is suggested that for
higher speeds the lever should be gripped nearer the fulcrum at the centre of the wheel bringing the operators fingers near to the fast moving spokes.

Figure 2. Mountain Trike

A modified SPWC design that has a steered (via cables from the right lever hand grip) wheel to the rear, levers mounted to small gearboxes drive short chains to the driving wheels. Disc brakes are mounted to the wheel hubs. Small wheels mounted off the ground at the front serve as anti-tips.

The three wheeled design provides grip and stability on uneven surfaces, the rear wheel position creates a modest wheelbase so that stability ascending steep inclines is assured. The presence of a steering system allows turning while both wheels are being propelled and improves efficiency as changes in direction are made without braking.

This is a refreshing evolution in wheelchair design. Although it is not marketed as a wheelchair for obvious reasons: At 20kg it is very heavy for everyday use as a wheelchair; the levers will not propel the wheels backwards limiting manoeuvrability; the protrusion of the rear wheel increases the footprint size and is low to the floor presenting a trip hazard to others; the angle of the seat base provides a lower centre of gravity but may be uncomfortable for prolonged use and could prove difficult for transferring.

Figure 3. Desino Radius

A conventional looking SPWC with levers connected to a gearbox under the seat which drives the rear wheels. Currently there is little information other than marketing images and a short video. The main features are an adaptive seat design that moves with the operator and the lever propulsion. The gearbox has a selection of ratios for inclines and the levers fold out of the way for transferring and so that the push rims can be used in a conventional manner when desired.

Figure 4. Grit Freedom Chair

A basic three wheeled SPWC designed for outdoor use, with large levers that drive the rear wheels via chains. Short stubs welded
to the levers provide brakes when the levers are pulled backwards. The brief for this design was for use in the third world so it had to be cheap, suitable for unpaved surfaces, simple and strong with very little maintenance required. With no specialist or unique components so that it could be repaired with bicycle parts and basic tools.

The levers and the cantilever that accommodates the front wheel would make transferring difficult. This long protrusion at the front will also make using a table awkward and impinge manoeuvrability in small spaces.

CONCLUSIONS & RECOMMENDATIONS
Clearly there is a need to improve the efficiency of a SPWC to help avoid fatigue and long-term damage to the upper limbs. One way to do this is to avoid the use of push rims as a method of propulsion.

Lever propulsion allows the use of large muscle groups in the upper body that are stronger with more endurance than those that would be employed with push rims. A more natural movement of the upper limbs exerts less strain on the upper limb joints reducing the likelihood of injury.

The products examined above, have their merits but a lot of disadvantages are obvious. With so few products on the market there is an opportunity for alternative designs that draw on the merits of existing systems and mitigate any disadvantages.

A detailed design brief that states what properties and features are both required and not desired has been generated. Although there may not be a sustainable ‘one size fits all’ design a more focused brief may yield a more refined result.

A Product Design Specification, Opportunity Specification, Risk Management Plan and Financial Justification have been made as part of a draft Business Case Portfolio and Integrated Management Plan. These documents set the pathway for the Development-to-Production phase of a potential new product and may be used to support a patent application.

At this stage the factors effecting SPWC efficiency have been identified and design ideas and concepts are being developed.

REFERENCES


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