Pushing Uphill? Clinical Considerations for Effective Self-Propulsion

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Abstract

Where effective self-propulsion for mobility is the primary goal of wheelchair prescription, clinicians must be clear about factors critical to both long and short term success. Perhaps more importantly, clinicians must also clearly recognise when prescription choices are likely to compromise effective self-propulsion, and educate wheelchairs users and carers accordingly. Propulsion biomechanics are an outcome of a multifactorial system, therefore it is essential that no single factor be considered in isolation. This paper examines some key issues related to wheelchair design, configuration and user technique that can be addressed to promote success in self-propulsion, and highlights common pitfalls that will sabotage this outcome. As quality if life and community participation is commonly correlated with mobility status, clinicians need to “keep it real” and promote equipment choices to support realistic mobility goals, and educate clients that this may include both parallel and alternative strategies to manual self-propulsion.

Keywords
wheelchair propulsion, wheelchair prescription, wheelchairs, biomechanics

Introduction

Where effective self-propulsion for mobility is the primary goal of wheelchair prescription, clinicians must be clear about factors critical to both long and short term success. Perhaps more importantly, clinicians must also clearly recognise when prescription choices are likely to compromise effective self-propulsion, and educate wheelchairs users and carers accordingly.

Objectives

This paper examines some key issues related to wheelchair design, configuration and user technique that can be addressed to promote success in self-propulsion, and highlights common pitfalls that will sabotage this outcome.

Method

Promoting the ability of a client to self-propel easily, effectively and without pain or injury is a commonly stated goal of wheelchair prescription. Suboptimal propulsion biomechanics result in inefficiency and undesirable loading patterns and have been repeatedly identified as the causative factor for the very high incidence of upper limb pain and injury associated with long-term wheelchair use (Boninger et al 2005). Prescribers who are seeking to optimise self-propulsion as outcome have well-established parameters to assist with appropriate wheelchair choices.

Firstly, wheelchair design characteristics have a great deal to do with how potentially easy a chair is to self-propel. Secondly, the wheelchair must be appropriately configured and set-up to realise this potential for the individual user. Lastly, the user must be educated about how to effectively use their wheelchair, and avoid unnecessary strain and injury.

Each of these factors will be discussed in turn, although it must be noted that propulsion biomechanics are an outcome of a multifactorial system: it is essential that no single factor be considered in isolation.
Results

1. Wheelchair Design:

A discussion of wheelchair design as relevant to self-propulsion generally focuses on three things: the weight of the frame, the shape of the frame and the way it is constructed, and the adjustability, size and components of the frame in terms of how it can potentially be individualised to suit each user.

a) Wheelchair Weight

Current clinical practice guidelines recommend prescribing the lightest chair possible for active users in order to help preserve upper limb function (Paralysed Veterans of America Consortium for Spinal Cord Medicine 2005).

The law of physics dictates that (all things being equal) a lighter chair will require less force to propel. A heavier chair tends to both result in slower push velocity and increase the effort required to generate forward motion (Cowan et al 2009).

However, for two key reasons, clinicians should however exercise great caution when using comparisons of frame weight as wheelchair selection criteria. Firstly, manufacturer’s published weights can be confusing in that they refer to the base product in a configuration which may or may not at all resemble that which will be selected to suit the individual user. Secondly, in propelling a wheelchair forward, the user must overcome resistance generated by the combined weight of both the chair and their own body weight. As body weight tends to represent 80% or more of the total system weight, small variations in chair weight will have minimal impact as a percentage of total system weight.

b) Frame Construction

Weight (and materials) is only part of the picture when it comes to wheelchair design. The way the frame is constructed is very influential in how potentially efficient the unit is to propel.

Springle (2009) points out that to move the system forward, the wheelchair occupant must overcome the rolling resistance generated by both friction and inertia, before input energy can be translated to forward motion.

A better quality chair with better machined and/or fewer moving components and quality wheels, castors and bearings, will tend to have reduced generate rolling resistance. More “play” in the frame and more interfaces between the push rim and the carriage translates to more input energy being “lost”, and relatively less available to propel the chair forward.

Because folding frame chairs are invariably heavier, and have relatively more moving parts, they are generally less efficient to push than their rigid frame counterparts. With either type of frame, the mechanism by which the axle and wheel interface with the chair will vary: the more direct the connection, the more potentially efficient can be the push.

c) Frame Adjustability, Size & Components

Frame adjustability and optional components are necessary to allow customised set-up for individual users. A salient point for the clinician is that both adjustable and optional components will generally add weight (and sometimes bulk) to the chair, which may be undesirable. Adjustable components may also provide a potential for energy leakage and reduced efficiency, especially if excessive play develops over time. Trade-offs should therefore be carefully considered.

One aspect of a wheelchair which is usually not adjustable is width. Width is a critical variable as it relates closely to shoulder biomechanics during pushing. Abduction and internal rotation in combination put the supraspinatus tendon at risk of impingement (Neer 1983). However the push cycle necessarily includes abduction and internal
rotation combined with shoulder flexion and extension (Collinger et al 2008). A wider chair forces additional abduction at the shoulder throughout the push cycle. Because abduction mechanically blocks shoulder extension, additional internal rotation also tends to occur as the user strives for a longer and more efficient stroke.

Core components of any wheelchair used for self-propulsion are wheels, tyres, handrims and castors. Sizing of wheels and castors can be important in determining the height of the seat from the floor, especially if particularly low or high heights are required for functional activities. Rear wheel size is critical to access. Smaller castors and shorter forks will generally offer less rolling resistance and be less prone to castor shimmy (Brubaker 1986, Kauzlarich 1986).

The new generation of ergonomic handrims increase the surface area of the handrim and helps to make pushing more efficient. Ergorims encourage the hand to stay in better contact with the rim and load more evenly throughout a longer stroke (Boninger & Dixon 2005). The shape and materials of the rim tend to allow more of the hand to contact with less grip force required to maintain that contact (Koontz et al 2006). As repetitive pinch gripping is associated with onset and severity of carpal tunnel syndrome (Keir et al 1998; Rempel et al 1997), it has been suggested that the reduced pinch is the mechanism responsible for a reported diminishment of wrist pain in long-term wheelchair users who use ergorims (Boninger & Dixon 2005; Koontz et al 2006).

2. Wheelchair Configuration & Set-Up:

How a wheelchair is set-up for each client will be critical to them realising success in self-propulsion (Collinger et al 2008, Louis & Gorce 2010). The best designed chair in the world will be a miserable failure if it is too big, too small, or simply set up wrong.

The most common parameters for consideration are as follows:

a) **Vertical Axle Position**

Van der Woude and colleagues (1989) reported that the ideal vertical axle position generates an elbow angle of approximately 100-120 degrees when the hand is resting on the top centre of the pushrim.

An alternative method for achieving appropriate vertical axle position is to position the user so that their fingertips are in the centre of the rear wheel when arms are extended and hanging at their side (Bonninger et al 2005).

A relatively lower seat position is generally associated with improved push efficiency. Decreasing the vertical distance between the shoulder joint and the wheel axle allows a larger portion of the rim to be accessible during the push cycle, which in turn tends to encourage both a longer stroke and decreased stroke frequency (Masse et al 1992; van der Woude et al 1989; Boninger, et al 2000).

b) **Horizontal Axle Position & Weight Distribution**

The position of the user relative to the drive wheel is critical to effective self-propulsion. Moving the rear axle as far forward as possible (that is, moving the centre of gravity of the chair rearward) without compromising the stability of the user is recommended (Boninger 2000, Cowan et al 2009, Freixes et al 2010). The forward axle position is effective for two primary reasons.

Firstly, a more rearward centre of gravity will reduce rolling resistance. As Brubaker (1986) points out: "rolling resistance is primarily a function of wheel (and caster) characteristics, laden weight, and weight distribution". Relatively more weight over the drive wheels is desirable: ideally, the castor is relatively unweighted compared to the rear wheels (DiGiovane et al 2006).

Secondly, the forward axle position is more biomechanically advantageous for the upper extremity (Boninger et al 2010), requiring less shoulder range of motion (Freixes et al 2010) and helping to prevent injury to upper extremity joints, especially the shoulder and wrist (Boninger et al 2005).

While much investigation has been done to demonstrate the benefits of a relatively forward axle position in the SCI population, evidence also exists to suggest that a rearward axle position adversely affects
proportion mechanics in the elderly population (Cowan et al 2009).

c) Seat Slope

Seat inclination also has a bearing on weight distribution as above, but has additionally been found to be influential in encouraging a stable upright sitting posture and improving balance and reach (Hastings, Fanucchi & Burns 2003; Bolin, Bodin & Kreuter 2000).

d) Backrest Height & Angle

If the seat is sloped, then the backrest angle should generally be adjusted to bring the user back to vertical (Hastings et al 2003). Failure to do so will tend to make the wheelchair less stable rearwards and will force the user to adopt a more kyphotic posture (Harms 1990, DiGiovane et al 2006). This kyphotic posture in turn both decreases push efficiency (because it effectively moves the centre of gravity forward again) and may contribute to neck, shoulder and low back pain (Greenfield et al 1995, Samuelsson et al 1996).

To unweight front castors, in order to traverse obstacles, the wheelchair user basically has to drive the wheelchair forward under the centre of gravity using the handrims, and simultaneously displace their mass rearward to allow the chair to react to gravity (Brubaker 1986). To high a backrest will sabotage the effectiveness of this manoeuvre, as well as potentially physically impede rearward motion of the upper arm during the push cycle.

e) Castor Adjustment

In a clinical setting, castor shimmy is frequently caused by the seat slope and/or axle position of the chair being adjusted without adjustment to the castor housing.

As Kauzlarich and colleagues explain (1984), castor shimmy is detrimental to effective propulsion because it significantly increases rolling resistance. Castor shimmy occurs because the castor is not positioned perpendicular to the direction of motion, is strongly correlated with speed and loading, and gets worse during turning. It tends to become a problem more quickly (at lower speeds) with larger castors and longer forks, which unfortunately tend to coexist with wheelchairs that offer little in the way of adjustment.

3. User Training and Technique:

The prescription process for a client who will manually self-propel to any degree should include education on how to most effectively push their chair, and therefore minimise risk of injury. Given that the chair is set-up optimally and is as light as possible, wheelchair propulsion training generally focuses on reducing cadence and optimising stroke technique (Betz 2007).

A long, smooth stroke that maximises contact with the pushrim is generally recommended as most appropriate to train (Paralysed Veterans of America Consortium for Spinal Cord Medicine 2005, Bonninger et al 2005). Bonninger (2002) identified the semicircular pattern (Figure 1) - where the user uses a relatively long stroke and lets the hand drift below the rim in the recovery phase - as most desirable for general pushing. Patterns where the user lifts their hand above the push rim during the recovery phase should be discouraged, as should contact with the push rim during the recovery phase.

![Figure 1: Semicircular (left) and Arcing (right) Propulsion Patterns (Source: PVA 2005)](image)

An arcing or pumping pattern (Figure 1) - where shorter, more frequent strokes are employed on the top front quadrant of the wheel and the hand follows the curve of the rim during recovery - can be more efficient than the semicircular technique when taking off from a standing start or where rolling resistance is increased (such as on carpet or going uphill) (Richter et al 2007).

Assisting wheelchair users to most optimally push generally requires some training, as push frequency and stroke length seem to somewhat habitual, and generally less affected by wheelchair weight, horizontal axle position and surface type than other parameters such as velocity (Cowan et al...
Clinicians should always invest time in this important aspect of wheelchair prescription, as push technique has been specifically identified in numerous studies as a prime contributor to the extremely high rate of pain and injury to the upper limb joints experienced by long term wheelchair users (PVA 2005).

CONCLUSIONS

Prescribing a manual wheelchair is an outcome-oriented activity for both therapists and clients, the success of which can only be judged against the predetermined goals and objectives on which the process is predicated. A single piece of equipment may not be available to promote all goals equally. Compromise is often necessary.

Quality of life and community participation is commonly correlated with mobility status (Aronson 1997, Scherer & Glueckauf 2005). Effective and independent mobility is an expressly desired goal for most wheelchair users.

For many users who possess a good physical ability to push their chair, achieving this goal via manual self-propulsion is clearly a primary objective. Where self-propulsion is accepted as primary, factors as discussed above related to wheelchair design, configuration and user technique must be carefully addressed during the prescription process to promote success. Equally, the prescriber must clearly identify, and strive to avoid, choices that will sabotage this outcome.

For many other users though, especially the elderly, it is unrealistic to expect that full mobility via self-propulsion can be achieved. Where self-propulsion is a secondary or even tertiary objective, clinicians need to recognise this reality, "keep it real", and promote realistic mobility goals for the manual wheelchair. Clients must be educated to form appropriate expectations, and encouraged to consider parallel or alternative mobility strategies to manual self-propulsion before final equipment decisions are made.

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