

Improving wheelchair prescription: an analysis of user needs and existing tools

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Abstract. Wheelchair users experience many situations that affect the stability and associated performance of their wheelchair. Stability is affected by user characteristics and abilities, environmental features and conditions, and wheelchair modification and accessories. Wheelchair prescribers need effective tools and methods to provide quantitative evaluation and prediction of the behavior of the user-wheelchair system in a variety of static and dynamic situations. Such information is very important to guide efficient management of associated risks and adjust chairs accordingly. This project involves a user-centered approach for design and evaluation of a load cell based wheelchair stability assessment system (Wheel-SAS). Here, the current methods for assessing stability are described, and their shortcomings explained. The user-centered design approach being applied to the development of the associated Wheel-SAS hardware and software is described. Future work including semi-structured interviews and an online survey with wheelchair prescribers and associated healthcare professionals for deriving user requirements and a design specification for a load cell system for measuring dynamic wheelchair stability are detailed.

Keywords: wheelchair stability assessment, wheelchair prescription, Wheel-SAS

1. Introduction

Loss of wheelchair stability can lead to a chair tipping and potentially injury to the user. Sixteen fatalities and numerous injuries directly related to wheelchair stability were reported between 2005 and 2007 to the Medicines and Healthcare Products Regulatory Agency in the UK [1]. Canadian research indicates 12% of wheelchair users experience a tip per year [2]. This would translate to around 144,000 incidents per annum in England.

Accidents can result from loss of stability on ramps, slopes, steps, kerbs, soft ground or due to wheelchair modifications which change the wheelchair's centre of gravity [3, 4]. In addition, wheel-

chair performance may be adversely affected by the position of the centre of gravity causing slides and, particularly in the case of electric powered wheelchairs, a loss of traction. A wheelchair user fearing tips and slides is common, resulting in anxiety and reduced independence [5]. The problem is set to rise with increasing wheelchair usage, alongside specific patient conditions such as obesity affecting wheelchair performance [6]. As well as issues associated with poor stability, many wheelchairs have unnecessarily high levels of stability which can cause propulsion and maneuverability difficulties.

Through the prescription process, the risk of tipping needs to be balanced against the user's mobility goals, and the wheelchair adapted accordingly. These

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individual requirements are influenced by a user's physical characteristics, needs, capabilities, assistive technology requirements and the associated environmental conditions [7].

Currently there is a lack of a standardized method of assessing the stability and performance of the human-wheelchair system. It is the aim of the WheelSAS project to develop a novel system to support and enhance wheelchair prescription and in doing so, adopt a user-centered design approach.

2. Wheelchair performance and tuning

Wheelchair prescription involves selecting and reconfiguring the wheelchair to optimise it for specific user characteristics taking into account ability, competence, and behaviour (e.g. body movements and behavioural choices); as well as environmental features and conditions. Wheelchair modification, special seating systems and units, and accessories, for example the addition of ventilators, oxygen cylinders and communication devices, will affect performance [2].

Performance of the wheelchair includes its static and dynamic stability, rolling resistance, propulsion efficiency, downhill turning tendency, turning and maneuverability and barrier negotiation [8]. The wheelchair can be tuned in a number of ways to affect stability and performance more broadly, for example, moving the center of gravity of the chair towards the rear will improve the propulsion and maneuverability and allow easier tipping for climbing curbs [9]. There is a balance to be achieved between the risk of tipping and the user's mobility goals. It is important to reach a balance in order not to compromise, or substitute stability for performance [3, 9].

In order to safeguard the user before they are issued with their wheelchair, it is possible for the prescriber to assess the stability in a rudimentary way. Manufacturers and suppliers will also test the stability of wheelchairs in certain situations. One of the more frequent uses of stability testing is in Special Seating clinics, where bespoke seating systems are fitted to wheelchairs. Such systems may move the total system (wheelchair, seat and user) centre of gravity beyond the limits that the original manufacturer had intended and tested for, and therefore a stability test is usually performed.

3. Review of existing stability testing

3.1. ISO 7176

The ISO 7176 series are standards for wheelchair manufacturers to demonstrate meeting the essential requirements of the European Economic Union Council Directive of 14th June 1993 concerning Medical Devices. ISO 7176 is to assist the manufacturer to publish stability information about their wheelchair. Importantly the ISO 7176 test methods measure aspects of stability but do not specify any pass or fail criteria.

ISO 7176-1 covers static stability testing of wheelchairs [10]. It indicates testing by placing the wheelchair on a standardized tilting test surface with a reference load to simulate the occupant in the wheelchair. The wheelchair is tested at increasing angles of inclination facing uphill, downhill and sideways and the angles at which two of the wheels of the wheelchair lift off the test surface are recorded in degrees [11].

The dynamic stability section, ISO 7176-2 [12] addresses how stable a powered wheelchair is in the rearward, forward and lateral directions when it is driven. The wheelchair is tested in a variety of conditions such as 'starting uphill and 'braking downhill'. In the starting uphill test, for a wheelchair with rear wheel drive, the wheelchair is placed on the test surface and configured to its worst configuration for stability going up hill. For example if the wheelchair has a reclining back it is reclined to its maximum. A reference load is positioned in the wheelchair to simulate the occupant, as in the static test The surface is inclined to one of the standardised test angles, for example 6 or 10 degrees. The wheelchair is then driven at full power up the slope and scored according to a set of criteria, which includes whether the front wheels lift off the test surface, whether the chair rocks back momentarily onto an anti-tip device before returning to have all the wheels in contact with the test surface or whether the chair rocks back onto an anti-tip device and does not return to all the wheels being in contact with the test surface. The scoring determines whether the wheelchair has passed or failed the test at that standardised test angle. The test is repeated at the other standardised test angles as appropriate. The standard specifies similar criteria for downhill and lateral testing.

The dynamic tests employ a very large angle adjustable ramp that is long enough for the wheelchairs to be driven at full speed up and down its length.

Whilst the test equipment for the static test is not as large, the standard is unsuitable for application to clinical use and occupied chairs by patients. Furthermore the dynamic test refers only to powered chairs.

For the static test, the increasing angle of inclination is continuous and not in discrete increments, or at standardised angle, so the exact limit of static stability is determined. For the dynamic test, the test angles are standardised so the exact limits of dynamic stability are not determined, and the wheelchair is effectively placed into one of the predetermined categories of standardised test angles.

The ISO 7176 standards are useful in ensuring a level of quality [9] and to evaluate the safety and performance of both manual and powered wheelchairs [13]. However they are applicable for manufacturing and comparison purposes rather than for clinical use, as they make use of a test load rather than the client positioned within the chair during testing. Also the testing is conducted in the worst case scenario wheelchair configuration which may not be the case for the individual patient being assessed.

3.2. *Clinical stability testing*

As part of the prescription process within the NHS, stability is assessed predominantly through use of a fixed incline ramp. The initial research undertaken within the practising community suggests it is widely used but probably applied inconsistently.

Stability testing involves positioning a wheelchair and occupant on a fixed incline ramp. The ramp is set at 12 degrees for push chairs and 16 degrees for powered and self propelled wheelchairs. The wheelchair is then tested for a pass or fail of static stability against the relevant angle. This is illustrated in Figure 1 below.



Figure 1. Fixed ramp for checking wheelchair stability

This was a standardised test within UK NHS wheelchair provision prior to 1990. Since then the test has had no official status due to the re-organisation of the NHS provision of wheelchairs and

the relevant governing authorities in the UK. Despite this, the test and its pass/fail criterion is still in widespread use across the UK, by therapists and engineers, as there is no other criterion to refer to. The test is used particularly when specialised seating systems are fitted to a wheelchair, or for users whose wheelchairs are fitted with specific equipment, for example ventilators.

3.3. *Wheelchair stability platform*

A development of the fixed incline ramp is the wheelchair stability platform which allows the ramp position to be varied [14]. This offers advantages over the fixed incline ramp as it measures the actual angles of tipping in a similar way to the ISO 7176 standard. Furthermore, by raising the wheelchair in a controlled way from horizontal, it reduces the risk of manual handling issues and uncontrolled tipping. Several wheelchair services in the UK use this method and the 12 degree or 16 degree^o criterion is often applied.

3.4. *Problems with the existing systems used in clinical assessments*

There are no current standards for stability testing in clinical settings; therefore clinicians have adopted means of assessing stability that may have increased risk to users, carers and clinicians [3]. The fixed and variable ramps offer a crude assessment of static stability. They offer a demonstration of whether the chair will tip at specific angles, giving a pass / fail result. Such tests do not predict the exact angle at which the chair may become unstable in a real life setting.

They do not give indicative information as to how to tune the wheelchair to different situations. They are not able to give an indication of the position of the centre of gravity (used for product tuning) or indicate how the chair will behave in a dynamic situation (i.e. dynamic stability). Reliance on a test designed to ensure that the chair has greater stability than 12 or 16 degrees may lead to prescription of chairs that are excessively stable [5]. Alternatively for cases where a high level of stability is being sought (for instance where a patient habitually rocks in a wheelchair) neither of these tests is practical for angles in excess of 16 degrees.

Health and safety issues are presented to the prescribers when maneuvering and holding a wheelchair

and occupant on the ramp, and also moving around and assembling the ramp for use perhaps in a patient's home.

There is also potential risk to the wheelchair user positioned in a chair that may tip [3]. This can be disconcerting for the patients, many of which are unlikely to be able to give consent for the test (mental capacity, communication etc).

Despite the limitations of ramp based stability testing, the use of ramp-based systems has continued in the absence of an adequate alternative.

4. Wheel-SAS development

Over a 3 year period, the Wheel-SAS (Wheelchair Stability Assessment System) project aims to develop a system to support and enhance wheelchair prescription for use by wheelchair prescribers, manufacturers and suppliers.

4.1. User needs analysis

The involvement of wheelchair prescribers, the primary users of the system, will be maintained throughout the project as well as participation of wheelchair users, manufacturers and suppliers as appropriate.

Ongoing work includes semi-structured interviews and an online survey to explore user and market needs. Participants include wheelchair prescribers and associated healthcare professionals, wheelchair service managers, and wheelchair suppliers and manufacturers as the primary users of the proposed system.

The interviews will take place at the collaborating NHS Sites and involve service managers and prescribers. They will discuss advantages and disadvantages of the existing prescription mechanisms and areas for redesign and development, and collect data regarding the clinical and technical indicators used for stability testing and product tuning. The interviewees will be asked to complete a walkthrough, to demonstrate the prescription process and the associated wheelchair stability assessment equipment. The process will further consider the usability issues associated with the controls and displays, loading and portability.

It is anticipated that an online survey will enable Wheel-SAS development to be driven by a wider spectrum of views across the NHS and industry. It

will address similar areas to the interview: the advantages and disadvantages of the existing prescription mechanisms and areas for redesign and development, collecting data regarding the clinical and technical indicators used for stability testing and product tuning. Specific questions will also relate to attitudes, habits, interest and likelihood of purchase for potential customers. It will be distributed to all service managers in the UK and their prescription teams, wheelchair manufacturers in the UK and Europe and suppliers to the NHS and private market

The qualitative data from the interviews will provide a rich picture of user needs. The quantitative data will undergo graphical and statistical analysis to highlight key trends and differences in the user and market needs between different groups (i.e. prescribers, managers, suppliers, manufacturers). The data will be translated into a user requirements specification for Wheel-SAS.

4.2. Technical development

The current development of Wheel-SAS is based on the use of load cells. For some time the value of using load cells to weigh under each wheel of a vehicle to establish its centre of gravity has been known. Its application to wheelchairs has also been recognized [15]. Load cell technology has been worked on in isolated instances for wheelchair stability assessment within the NHS, but not along a developed program of user needs analysis research, nor developed to a point of distribution or commercialization.

Wheel-SAS will be a computer-based system incorporating load cell technology within a custom made rig. It will automatically measure the center of gravity, and map the stability points of a user-wheelchair system. This information will be provided to the prescriber to inform their tuning of the wheelchair, and be used predictively to model the effect of changes to the chair. The ongoing technical development of the system informed by the user requirements specification includes the following:

- Specification and development of the Wheel-SAS system based on load cell technology for determining the center of gravity of the human-wheelchair system
- Development of a mechanism for automated capture of wheelchair geometry to support wheelchair tuning. Subsequent generation of a database of the required wheelchair geometry for the majority of wheelchairs on the market

- Development of mathematical models to determine static stability and predict the dynamic stability of the human-wheelchair system
- Development and integration of usable software for wheelchair stability testing and assessment
- Development of a user-intuitive interface
- Packaging of the component parts and styling Wheel-SAS

4.3. Evaluation

The involvement of relevant users will facilitate iterative usability testing of the hardware and software elements throughout development. Users will take part in regular design workshops to ensure the system is usable at all levels including the software interface, data displays, assembly and portability of the rig, and calibration. The expertise of wheelchair prescribers across the retail, clinical and manufacturing sectors may vary significantly, and the system needs to cater for the whole group.

The final package of work will be a thorough evaluation and performance testing of the system with wheelchair prescribers and users. The accuracy and precision of Wheel-SAS measurements static and dynamic stability will be tested using ISO 7176 test equipment. The effect of Wheel-SAS on the prescription experience will be determined through an observational and interview study as the system is employed during clinical practice.

5. Conclusions

Wheel-SAS aims to support the clinical process of wheelchair prescription through the provision of enhanced information about the human-wheelchair system. In order for the information provided by wheel-SAS to have real benefits for the wheelchair user it is essential that the physical and software components of the system are easy to operate and interpret; and that the expert information given can be translated into the tuning of the wheelchair. Furthermore the experience of having the wheelchair prescribed, stability tested and tuned has to be a positive one with lasting benefits in terms of real world wheelchair performance.

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