Posture & Mobility Group

POSTURE AND MOBILITY GROUP BEST PRACTICE GUIDE 8: WHEELCHAIR STABILITY EVALUATION

The testing and impact of wheelchair stability

Abstract

Wheelchair stability is a key factor in the ability of the equipment to be used to its maximum potential, as well as to be used safely. This best practice guide will outline the nature of stability in relation to wheelchairs, as well as determining when and how to test wheelchair stability and how to interpret the results.

PMG Wheelchair Stability Evaluation BPG Group

Contents

Document summary

Posture and Mobility Group

The Posture and Mobility Group (PMG) is a membership organisation and Charitable Incorporated Organisation (CIO) which has the aim of sharing knowledge and promoting best practice in the field of posture and wheeled mobility. Currently, there are over 2000 members, mainly based in the UK, the majority of whom are professionals working in rehabilitation, focusing on the provision of wheelchairs and special seating.

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Introduction

Why we felt stability best practice guidelines were needed

The static and dynamic stability of a wheelchair is critical to both its safety and its performance. An overly *un*stable wheelchair can result in avoidable injury or death from tipping, whereas an overly *stable* wheelchair can result in avoidable long-term use challenges, inefficiencies or abandonment. We have a responsibility to optimise stability for mobility, specific to the user needs.

There is often a conflict between these two requirements, so a balance must be struck through careful and open-minded evaluation.

Wheelchair providers commonly adjust wheelbases, seating elements, or functions beyond typical usage expectations, as well as adding third-party accessories. Many of these changes affect the stability of the wheelchair system. Standards exist to guide manufacturers in their testing and governance, but providers are required to apply their own judgement in how to manage the risk and benefits of their adaptations.

Approaches vary across services in terms of *when* testing is carried out, *how* it is carried out, and what is done with the data, hence the need for best practice guidelines to consolidate and promote appropriate risk-benefit analysis for stability.

Despite there being several methods to test stability, the 'simple' numerical output of such a test (typically an angle between 5° and 20°) often leaves us with more questions: What do we do with the number? How do we relate this to the person? Crucially, how do we communicate something meaningful to both the user and assessor?

The intent of this guidance is to improve clinicians' awareness of stability evaluations by sharing variation in practice across the United Kingdom. The clinicians producing this document are volunteers. This document is not intended to be a comprehensive review of stability evaluation. It is offered in a spirit of curiosity and experience sharing rather than that of blame and fault finding.

Target audience

- Prescribers handing over equipment (wheelchairs, seating, wheelchair accessories, wheelchair- mounted devices)
- School staff
- End users
- Families and carers
- Healthcare professionals, e.g. community physiotherapists and occupational therapists
- Manufacturers
- Transport providers
- Other health and social care providers

Using this best practice guide

This best practice guide is intended to be accessible for both lay and professional audiences. To aid the reader, colour coding is used to help identify the nature of the information being presented in each section of the document.

Information presented in a turquoise-coloured box is intended as a summary for professionals with experience in the field of wheelchair stability.

Information in a teal-coloured frame is intended for professionals with experience in the field of wheelchair stability.

Information presented in a green-coloured box is intended as a summary for lay people or those new to the field of wheelchair stability.

Information in an apple-coloured frame is intended for all audiences.

When reading this document, it is important to remember that wheelchair stability is not a one-size-fits-all topic, and there may be scenarios, equipment setups, or user requirements which need to be discussed separately. Attempts have been made to indicate where this is the case and, where possible, to discuss those specific cases within their own sections of the document.

Glossary of terms

Term	Meaning
Active user / energy efficient manual wheelchair	A type of manual wheelchair used by people who lead an active lifestyle and can propel themselves. These wheelchairs require good trunk stability and upper body strength, and are intentionally less stable for manoeuvrability.
Anterior	Towards the front.
Back wheel balance	In an active user chair, the user intentionally tips the wheelchair onto its rear wheels, lifting the castors from the ground. This is often used to navigate a high edge such as a kerb.
Base of support	The points of contact between the wheelchair and the ground (or other surface supporting the wheelchair) through which the weight of the wheelchair acts.
Blocked	Refers to a stability test where the drive wheels are blocked to prevent the wheelchair from rolling and the tipping occurs around the pivot point of the wheel axle.
Braked	Refers to a stability test where the drive wheels are braked and therefore the tipping occurs around the pivot point where the wheel is in contact with the surface.
Centre of gravity (CoG) / Centre of mass (CoM)	The centre of gravity, or centre of mass, of an object is the point through which its weight can be considered to act. If the CoG is acting outside the base of support, the chair will become unstable and be at risk of tipping while the further inside the base of support it acts the more stable the chair will be.
Cross-slope Also “Cross-slope left”, “Cross-slope right”	Positional description of a wheelchair / buggy on a stability testing ramp; the user is facing across the incline of the testing ramp; “left” or “right” describe the direction faced by the user relative to “up-slope”.
Down-slope	Positional description of a wheelchair / buggy on stability testing ramp; the user is facing down the incline of the testing ramp.
Drive wheel	The wheel through which power is applied in order to move the wheelchair, either through a motor or human effort (i.e., self-propulsion)
Manual wheelchair	A wheelchair which is propelled primarily through the use of human force.
Posterior	Towards the rear.
Powered wheelchair / power chair	A wheelchair which is driven primarily by electric motors. Typically, these will be rear wheel driven (RWD), mid-wheel driven (MWD), or front wheel driven (FWD), according to where the drive wheel is located.

Recline	The angle of the backrest relative to the seat. It is generally described as the angle from the backrest being perpendicular to the seat. This will typically be either fixed or adjustable; fixed backrests tend to have between 0-10°, while adjustable backrests tend to allow between 0-50° of recline.
Tilt	The position of the seat relative to the wheelchair frame. The amount of tilt is generally described as the angle from the seat being parallel to the wheelchair frame. Negative angles are used to denote anterior tilt, while positive angles are used to denote posterior tilt, the latter being the most common. This will typically be either fixed or adjustable; fixed tilt wheelchairs tend to have between 0-10° of tilt, while adjustable tilt wheelchairs tend to allow between 0-30° of tilt. It is worth noting that 'standard' wheelchairs usually have a very small amount of fixed posterior tilt, around 3-5°; that is to say, the seat rail is not parallel to the ground.
Tilt in space wheelchair / "TIS" wheelchair	A wheelchair where the seating element can be tilted independently of the wheelchair frame without the need for tools (i.e., the angle of tilt can be changed using a trigger or similar).
Tipping angle	The angle of slope required for a wheelchair / buggy to transition from being stable to unstable.
Up-slope	Positional description of a wheelchair / buggy on stability testing ramp; the user is facing up the incline of the testing ramp.
Wheelchair / buggy system	The combined system formed by the user and their wheelchair / buggy.
Wheelbase	The area between the contact points of the wheelchair and the supporting surface, generally considered as the centres of the front and back wheels. N.B. 'Wheelbase' can also describe a manual wheelchair base designed to be fitted with a seating system.

Table 1 - Glossary of terms

Common myths/misconceptions

"Wheelchair instability doesn't cause problems these days"

Stability incidents do still occur, although they are sometimes sliding related rather than tipping related. It's also likely that incidents are largely unreported to agencies such as

"A stability test pass means the wheelchair is safe"

There are no pass / fail criteria. The test is designed to facilitate knowledge as part of the overall prescription and risk management.

"Wheelchair service rehabilitation engineers are solely responsible for stability"

Not necessarily. Any professional involved with wheelchair prescription has a responsibility to ensure the stability of the wheelchair is appropriate for use within the expected environment. Wheelchair users and carers also have responsibility for appropriate use.

"Greater stability is always better"

This will depend on how the wheelchair is being used. As an example, a manual wheelchair user climbing a kerb might want the wheelchair to be more "tippy" to make it easier, as well as being more energy efficient, and possibly safer.

"Stability testing is only needed for special seating"

Stability testing can be applicable to any situation, regardless of seating, and the attachment of other devices (such as communication aids or oxygen cylinders) also has an influence.

"If a wheelchair tips over it's the wheelchair stability that's at fault"

Not necessarily. It is possible it's being used in an unsafe manner, e.g., not ascending/descending a kerb correctly. It is also possible that it has been loaded with items additional to those with which it was intended or prescribed to be used.

What is stability, stability testing, and stability evaluation

Static and dynamic stability

There are two types of wheelchair stability:

1. Static stability – the stability of a wheelchair when it **is not moving**, e.g. when it is parked on a slope with the brakes on, or when the user is getting in/out of the chair
2. Dynamic stability – the stability of a wheelchair **while moving**, e.g. when rolling over bumps or stopping and starting movement

In either case, the following definition of stability may be applied: “Generally, for a wheelchair to remain stable, it must be upright on its wheels with the combined centre of mass of the wheelchair and user being within the wheelbase of the wheelchair." (MHRA Guidance on Stability of Wheelchairs, 2004)

Testing the stability of a wheelchair when stationary (static stability) does not necessarily predict how it will behave when moving (dynamic stability), but it provides a helpful baseline for a safety evaluation

Factors affecting stability

Factors affecting the stability of a wheelchair can be grouped into categories relating to the user, to the wheelchair, and to the environment in which the wheelchair is used. A wheelchair's stability will need to be tested if a specific risk of it tipping has been identified, or if modifications have resulted in significant changes in the setup of the wheelchair. The factors outlined below are not an exhaustive list, but will help to provide guidance for clinicians when making decisions on evaluating wheelchair stability. If there are concerns that a wheelchair could be at an increased risk of tipping for any reason, including those not stated here, it will be necessary to evaluate its stability before it is put into use.

User factors

User's body movements

A user's body movements may reduce the stability of a wheelchair by altering the location of the centre of gravity (CoG). Any movements that will reduce stability should be considered, e.g., involuntary movements, or spasms in the chair. The stability of a wheelchair should be tested if the user has:

- significant extensor patterns (movements that straighten or open a joint, for example the hip joint) that result in the user adopting a different posture and position in the chair
- involuntary movements in the wheelchair that result in the overall position of the CoG being shifted significantly
- involuntary backwards, forwards, or sideways movements that may result in some of the wheels being lifted off the floor

User's ability, lifestyle and goals

Consideration should be given to the client's needs as to whether they will need to use the chair in an 'unstable' configuration, e.g., driving in full rear tilt and recline, in full negative tilt, with a raised seat position, etc.

If the user is unable to adjust their position and perceive instability to reduce tipping risk, and it is not possible to provide training and increase awareness of the instability risk, there will be a need for evaluation for added safety.

The user may also be actively reaching for objects in front or adjacent to their chair, resulting in their body weight being shifted outside the footprint of the wheelchair and base of support, reducing the stability.

Posture and positioning

A significantly asymmetric posture and unusual seating position of the user in the chair may result in the CoG falling close to the edge of, or outside, the base of the wheelchair's support, thus decreasing its stability.

If the user's weight is close to the weight limit of the chair as recommended by the wheelchair manufacturer, it is important to carry out a risk assessment, part of which may involve testing for stability.

If the user has an amputation that results in significantly uneven/ asymmetric distribution of their weight in their wheelchair, e.g., amputee rugby players with broad shoulders.

Very open hip angles (i.e., a posture closer to lying than sitting): this is equivalent to recline, but in extreme cases could cause the person to be sited *between* the push handles, thus transferring a greater proportion of their weight rearwards; the effect of this must then be evaluated.

Wheelchair factors

Raised height of seating

- Some types of custom seat may raise the height of the seat and, as a result, the CoG. While it may have functional benefits to the user and enhance their interaction and independence, if the seat height is significantly raised without a corresponding increase in the base of support, this results in a reduced tipping angle and reduced stability in all directions.
- A raised seat height may also be due to incorrect selection of the front and rear wheel size or axle height position. Without the correct setup and adjustment to the frame, changing the wheel size or axle height can shift the wheelchair's CoG, increasing the risk of tipping in all directions, especially on uneven surfaces.

Tilt: broadly there are two types of tilt mechanism: fixed point, and floating.

- *Fixed:* where the seat unit pivots about a fixed point. This means that, as greater amounts of rearward tilt are applied, either (a) the more rearward stability is reduced; or (b) the more forward stability is improved; or (c) rearward stability is reduced *and* forward stability is improved, depending on the configuration of seating and weight of the person.
- *Floating:* a mechanism (usually a set of levers) is arranged to attempt to maintain the centre of mass relative to the wheels regardless of the angle of tilt, or at least to reduce the amount of variation experienced in a fixed pivot system.

With small children the functional outcome between the two can be negligible, because both their weight and that of the seating is small; with larger/older children and adults it is usually preferable to utilise a chassis with a floating tilt, if available.

Recline: As the recline is operated, the centre of mass of the person and system are transferred backward, which reduces rearward stability, and/or increases forward stability. Used in combination with a tilt having a fixed pivot, rearward stability can be significantly impaired.

Elevating leg rests: these have the effect of extending the knee, which moves the centre of mass of the person and wheelchair up and forward. The extent of the effect is governed by the length and weight of the leg, but can be significant; it may reduce forward stability and/or increase rearward stability, either of which may be helpful or unhelpful, depending on the circumstances.

Seat riser: this causes the centre of mass to be elevated, thereby reducing overall stability.

Evaluation of overall effect on stability: the above describes the effect of each feature on stability, but the presence of a particular feature does not necessarily mean it will be used, and so an evaluation of expected use is required, e.g., will the person use the full extent of recline, or attempt to drive the chair outdoors with the seat at maximum height elevation? If they will then action is required, either to dissuade them from doing so, or to explain the risks involved if they do.

Modifications

Any modification should be carefully considered with regard to its impact upon stability, and should ideally be carried out by a suitably qualified professional to ensure they do not compromise the wheelchair's safety. Stability evaluation should be carried out in the following situations:

- when changes have been made that result in a significant detriment to the stability of the wheelchair or in change from the manufacturers' guidelines for intended use. Examples include adapting the wheel position, extreme recline/ tilt range, and positioning of seating hardware or other accessories outside the wheelchair's footprint.
- when the seating modifications significantly increase the weight of the overall system and / or exceed the manufacturer's user weight limits.
- suspension system adjustments can also affect a wheelchair's stability, especially when the suspension is made too soft, causing the wheelchair to sway or lean excessively during turns.
- changes in the base of support, centre of mass of the overall system, and / or position of CoG by adjusting the axle too far forward / backward. This changes the turning radius or propulsion force and can make the wheelchair more prone to tipping, particularly during sharp turns or when navigating uneven terrain.
- if modifications have been made to remove or modify anti-tip devices.

Environmental factors

One of the most difficult things to consider is the environment that a wheelchair will be used in, due to the considerable number of different environments that exist. There can be an inclination to consider either the extreme worst case scenario, or only those common environments that the user will be facing. It is advised instead to consider the realistic use cases and also to prepare the wheelchair user with tools to enable them to assess for themselves the relative risks of any environment they find themselves in.

- If client's accommodation, or the driveway / pavement in their local environment, is on a slope, testing the wheelchair's performance in the actual environment may be useful to alleviate any risks or inform any adjustments to the equipment to make it safer. The risks may also be greater in wet or icy weather.
- The outdoor terrain in which the user may be using their wheelchair may require stability to be evaluated.
- Additionally, if the user will be driving the chair up a ramp to use their WAV without a lowered floor, the slope on the ramp can be steep.

Further, as part of the training that should be provided to the user, consideration should be given to factors such as the weather, ground cover (e.g., fallen leaves, mud, etc) and the material surface being driven over which may cause issues with, e.g., sliding.

Users ideally should be aware of the optimal ways of traversing different types of ramps or surfaces to maximise stability.

What is stability testing?

The stability of a wheelchair and its user is determined through stability testing. There are several tests that can be carried out, as well as different types of testing equipment available that can provide a range of information about the stability or instability of a given configuration.

The specific tests that should be carried out depend on what information is being sought, and how the equipment is intended to be used. In general, where stability is assessed, it will be the static stability rather than dynamic, but there is some scope to carry out subjective dynamic stability testing using slopes in the environment and requesting feedback from the wheelchair user on how the wheelchair handles while traversing them.

When is a stability test required?

The primary indicators for a stability test are as follows:

1) Where the person's weight distribution is atypical, e.g., a lower lib amputee
2) Where the person is not sitting in a conventional manner, e.g., very open hip angle
3) Where the equipment is being used outside the scope intended by the manufacturer, e.g., mounting of additional equipment

Other factors which may indicate the requirement for testing include:

- the physical ability of the occupant to control the wheelchair when in motion
- the ability of an attendant to push the chair, e.g., if they are finding it hard to push, it is worth considering a *reduction* in stability
- involuntary movements, e.g., strong extensor thrust, chorea
- atypical movements
- unconventional but intentional movements, i.e., what is sometimes termed "challenging behaviour"
- seating requirements, i.e., where the position of a seat moves the combined centre of mass of the person and seat away from that intended by the manufacturer; for example, a swap of the standard seat cushion for a different type of similar dimensions would be unlikely to have an effect, but a seating system might push the person (and therefore the centre of mass) upward and forward, thus changing the weight distribution of the combined system
- slopes in the person's home and environments accessed regularly
- terrain accessed beyond the broader community
- cognitive ability to evaluate risk and take appropriate action; this applies to both occupant and attendant
- size, context and competence of the care team

N.B. The outcome of a test is as likely to indicate the system is too stable as it is to indicate that it is not stable enough; this allows the balance to be fine-tuned to the needs of the individual and their particular circumstances.

Testing and Evaluation

History and prevalence of test methods

Current testing methods

- Manual tilting (on a level floor)
- Static angle ramp
- Adjustable / variable angle ramp
- Force plates
- Environmental testing

The Swansea Bay University Health Board conducted a National Stability Testing questionnaire in 2023. 16 responses to this questionnaire were received from around the UK, from NHS services / Trusts, private wheelchair providers, and wheelchair manufacturers.

The data is shown in *Appendix 5 – Swansea research into testing methods used*, and contains the responses to the question 'What equipment do you use for stability testing?'

At the PMG conference in 2024, a similar question was asked of workshop participants. The responses can be seen in *Appendix 4 – PMG 2024 responses to testing methods used*. A manual tilt or a test using the environment were the most commonly used stability test methods. This probably results from the lack of stability testing equipment available to wheelchair services.

Anecdotally, however, many wheelchair services rarely undertake any form of stability testing; nor do they have processes or procedures in place for determining whether stability testing is required or that stability has been assessed and aligned to the needs of users.

Testing equipment and methodologies for static stability

There are many ways of assessing static stability. Each test requires different equipment or techniques and can provide different information relating to the stability of a wheelchair. Due to the variation in available equipment and experience, not all wheelchair services will be able to carry out all of the different types of static stability testing.

Blocked vs braked stability

Both ramp-based and environmental stability testing can be undertaken with the wheels either being “blocked” or “braked”. Similarly, electronic testing systems may also provide information relating to the blocked or braked stability.

Each of these terms relate to how the wheelchair is prevented from rolling down an incline. The method chosen can have an impact on the tipping angle obtained, as well as on the implications and potential consequences of that tipping angle.

Blocked

The wheelchair’s brakes are not engaged, and a block is placed down-slope of the downhill wheels (i.e., if the wheelchair is facing up the slope, then the blocks would be placed behind the rear wheels); this block prevents the wheelchair from rolling or sliding down the slope.

In this scenario, the wheelchair will pivot around the downhill axle as the wheels are physically prevented from rotating or changing their contact point(s) with the ramp, but the wheel itself is free to spin relative to the wheelchair. The point of rotation may therefore be closer to the centre of gravity of the wheelchair.

The tipping point is considered to be when the uphill wheels lift off the slope.

Braked

The wheelchair’s brakes are engaged. There can be a flexible restraint fitted to the chair to prevent it from sliding down the slope.

In this scenario, the contact point with the ground on the downhill wheels may change as the chair tips backwards (since the wheels are physically prevented from rotating relative to the wheelchair, but as the chair starts to tip, the point of contact with the ground will shift slightly). The point of rotation is therefore on the edge of the downhill wheels.

the uphill wheels lift off the slope.

Fixed angle ramp

Fixed angle ramps are likely to be the most readily available piece of equipment for assessing wheelchair stability in wheelchair services. They usually comes in the form of a metal or wooden platform, approximately 1.2m (4ft) square; this is supported by blocks to provide a known angle. See Appendix 3 – Images and examples of stability testing ramps for further details.

These were a very common sight at NHS wheelchair services in the 1990s and early 2000s; however, over time, their availability has declined as old models deteriorate and are not replaced. At the same time, wheelchairs have tended to become larger and heavier, meaning that fixed ramps have also had to become larger and more substantial to accommodate them, which further disincentivises their use due to both manual handing considerations and the lack of space to store and use such equipment in many wheelchair services.

Protocol

This is a pass/fail test using a known angle. Such an angle may be determined using an inclinometer, which are available either as a specific tool, or on smartphones as an app. Bear in mind that with a phone there is greater margin for error because the measuring surface is short; this is less of an issue on a smooth, continuous surface, but may give false readings if attempting to measure a driveway, for example.

The test consists of three main steps:

1) Know the angle of ramp being used for the test (which should be conducted on level ground)
2) In its least stable configuration*, position the occupied wheelchair on the slope and apply the brakes**
3) Determine pass / fail, which is a simple matter of whether or not the assessor is required to intervene to prevent a tip

* The following conditions apply to achieve the least stable configuration:

i. Castor stems turned to position the point of contact with the ground at its highest point on the slope (applies when facing down or across the slope)
ii. Tilt and recline positioned in maximum tipped-back position (facing up slope)
iii. Tilt and / or recline positioned in maximum tipped-forward position (facing down and across the slope)
iv. Elevating leg rests positioned in the fully down position (facing up the slope)
v. Elevating leg rests positioned in the fully up position (facing down / across slope)
vi. Seat riser positioned at its highest (all orientations)

It may be decided that the wheelchair will not be used in certain configurations in certain environments, e.g., never in fully forward tilt, or never outside with the seat riser elevated. In these cases the test may be modified.

** Herein lies one of the challenges: facing up the slope, the wheelchair brakes should offer sufficient resistance to hold the chair on the slope without additional input. Facing down and / or across the slope is another matter, because the braked wheels are now taking a reduced load, with much more of the weight of the chair and person now passing through the castor wheels, which are not braked. Having turned the castor stems to make their contact point at the highest point on the slope, it will in all likelihood be necessary to prevent their rotation. First, an inspection should be made to ensure the castor wheel and spokes are intact and in good condition. Then a sturdy metal bar (thick screwdriver or spanner) should be placed through the spokes to jam against the castor forks. This is a crude method, but one which is effective unless the tyres slide on the slope. If this occurs, some other form of resistance to motion should be applied, probably by letting the chair slide in a controlled manner to the base of the slope in such a way that the tyres come into contact with the flat ground, acknowledging and accounting for the fact this will impair the test by making the chair more stable.

Clearly a manual test like this carries risks for the wheelchair user, and also for the assessor: for the former because if the assessor does not 'catch' a wheelchair which fails the test, their wheelchair will tip over; for the latter in terms of the manual handling involved with positioning the wheelchair on the slope, particularly facing sideways, and with 'catching' a wheelchair which is failing the test.

Making a record

The results may be recorded as follows:

OPTION 1: A static stability test of the occupied system was undertaken in the least stable configurations / in the following configuration (X/Y/Z) on a fixed angle ramp:

- Facing up the slope the system was stable / unstable at an angle of 12/16°.
- Facing down the slope the system was stable / unstable at an angle of 12/16°.
- Facing across the slope with the left side lower the system was stable / unstable at an angle of 12/16°.
- Facing across the slope with the right side lower the system was stable / unstable at an angle of 12/16°.
- (or) Facing across the slope with * side lower was not tested as facing across the slope in the opposite direction was the less stable configuration and was found to be stable at 12/16°.
- (or) Lateral stability was not tested as the centre of mass was placed centrally and low in the wheelchair base.

OPTION 2: A static stability test of the occupied system was undertaken in the least stable configurations on a ramp at 12/16° to the horizontal and was found to be stable in all four directions.

OPTION 3: There was no reason to suspect that stability of the occupied system would be impaired as the chair had been set up for use as the manufacturer intended.

OPTION 4: There was no reason to suspect that stability of the occupied system would be impaired as the centre of gravity was placed well within the wheelbase of the chair.

Adjustable angle ramp

Adjustable angle ramps are a development of fixed ramps, allowing the top deck of the ramp to have its angle relative to the ground adjusted. This allows for greater understanding of the tipping angle at which a chair becomes unstable.

Methods used to achieve this include, but are not limited to: a manual jack or powered actuator attached to a platform, varied size and / or geometry blocks, or an inflatable bag acting on a hinged slope. Some adjustable ramps are able to have the angle of slope altered while the wheelchair remains on the ramp; this can reduce the number of manual handling operations.

Protocol

This is much the same as for a fixed angle ramp, except that the wheelchair may be positioned on the platform with it level, before being elevated to the point of tip.

Making a record

The results may be recorded as for a fixed angle ramp, but with the following adaptation to option 1:

OPTION 1: A static stability test of the occupied system was undertaken in the least stable configurations / in the following configuration (X/Y/Z) on a variable angle ramp:

- Facing up the slope the system was stable up to * degrees
- Facing down the slope the system was stable up to * degrees
- Facing across the slope with the left side lower the system was stable up to * degrees
- Facing across the slope with the right side lower the system was stable up to * degrees
- (or) Facing across the slope with * side lower was not tested as facing across the slope in the opposite direction was the less stable configuration
- (or) Lateral stability was not tested as the centre of mass was placed centrally and low in the wheelchair base

OPTION 2/3/4: as for the fixed angle ramp.

Electronic force plates

A set of four force platforms and related software used to calculate expected tipping angles. This can be a modular arrangement or an integrated system and typically looks like either a single platform with a small ramp at one end to allow the wheelchair access to it, or two separate long platforms (which look like skis) that can be adjusted to the width of the wheelchair to be tested.

While most platforms will be able to work with wheelchairs with four wheels, some are able to work with chairs with six wheels (i.e. mid-wheel drive powered wheelchairs).

Typically these force plates will provide the most comprehensive and quickest method of testing stability and may require the wheelchair and user to drive onto and off the plates but no actual tipping of the wheelchair.

Obtaining force plate systems

Some centres have developed their own system using go-karting scales, a data acquisition card, and bespoke software using published mathematical formulae. However, at this time, there are limited opportunities to purchase force plate based systems. Enquiries could be made to services known to have force plate systems.

Protocol

The specific testing protocol will vary depending on the nature of the force plates and the underlying mathematical models. Reference should therefore be made to the operating instructions of the force plate that is being used.

In most instances, however, the wheelchair is manoeuvred via a small ramp onto the scales (force platforms). A number of measurements are input into the model, such as the height of the scales and wheel diameters. Differential mathematics is used to calculate centre of mass and base of support position in these scenarios. This data is triangulated and extrapolated to provide an estimate of tipping angle in all directions. The software can also provide results based on assumptions of braked and or unbraked wheels.

Manual tip test

There are two ways to carry out a manual tip test; attendant or user-initiated.

For attendant-initiated tests, an assessor standing behind the occupied wheelchair pushes down on the push handles to lift the castors off the floor to evaluate rearward stability. Similarly, they may attempt to lift the rear wheels from the ground to evaluate forward stability. Clearly there are some manual handling matters to consider for the assessor. One could in theory attempt to assess sideways stability, but this is inadvisable because of the free movement of the castor wheel, which cannot be controlled since it might be on a ramp, and which may lead to a complete tip.

User-initiated tests are typically carried out for active wheelchair users to assess rearward stability. In this case the wheelchair user may attempt to rear wheel balance; it is usually advised that an assessor stand behind the user with a safety strap to prevent the user from over-balancing and tipping backwards. At a minimum, the area behind the wheelchair user should be clear of obstructions.

Protocol

Using this method, one can quickly and subjectively establish if a wheelchair is profoundly unstable in either forward or rearward directions; in either of these cases it will require little effort for the assessor to lift either the front or rear wheels from the ground.

In attempting to evaluate stability closer to a reference angle (such as 12°), subjectivity introduces a much higher chance of error, unless some form of measurement is used. There are a range of magnetic or other “stick on” angle indicators, as well as smartphone apps which can be used to measure the angle of a wheelchair – in most cases these will require a second assessor or assistant to observe the measurement device during the test and record the appropriate information throughout the test (i.e., the tipping angle).

The next problem faced in this type of test is that it does not assess stability in the same way as the other test methodologies. In the other test methodologies presented here, the contact point of the wheelchair with the ground remains the same when approaching the tipping point (i.e., directly under the axle position on the rear wheel), while, during a manual tip test, the contact point moves around the wheel as the chair is tipped. This is potentially significant, with the impact being that the wheelchair will be less stable than measured.

In theory, it would be possible to apply a corrective factor to the measurement taken with the wheels on a level surface, but this is complicated by wheel diameter, which itself is impacted by tyre distortion and inflation pressure.

Nonetheless, it is better to perform some sort of evaluation than none, and the test can yield semi-meaningful results if its limitations are understood. It can certainly be used as a comparative ‘measure’.

Due to inter-assessor variability, the tip test cannot provide quantifiable results but can identify whether further testing is necessary without any equipment.

Attendant tipped

The attendant pushes down on the push handles to allow a sense of where the tipping point is. This can be done either with or without the brakes applied; however, it is often done unbraked.

User tipped

Active users can tip themselves onto their rear wheels to assess their stability. They are much more likely to favour an ‘unstable’ set up, particularly in the rearwards position as this is helpful for function.

Risk can be minimised in this instance by standing behind the user should they become unbalanced, or using a strap to prevent completely tipping over. Alternatively, ensure that the area behind the chair is adequately cleared of items and the test is conducted sufficiently far away from walls. A crash mat can also be used for added safety.

Environmental testing using inclines

Environmental testing of stability using inclines can give an indication of a wider range of information such as dynamic stability, pushing efficiency, etc., and generally requires using ramps and slopes with a known incline to determine whether a chair is stable in a given configuration.

Ideally, safe areas to carry out stability testing using the environment will have been identified in the area surrounding the wheelchair service; however, they may also elect to test in the user's environment (e.g., using their wheelchair accessible vehicle ramp, the access ramp into the property, etc.) where there may be a specific concern as to where a piece of equipment is to be used.

Test site selection

Testing inclines should be selected using the following criteria:

- Ideally located indoors and in an area which is controlled by the organisation carrying out the stability testing
- Located in low traffic areas (i.e., not the ramp into the main entrance of the building)
- Should align, where possible, with the standard testing angles from literature (12° and 16°)
- Should be clear of obstructions
- If using a build ramp it should comply with part M of the building regulations, particularly with respect to surfacing and handrails
- Should be appropriately lit
- The routes to and from the testing inclines should be well mapped and checked for any hazards and appropriate risk reduction measures should be put into place and agreed with the owning organisation
- Incline should be fixed or otherwise secured correctly to prevent movement during the test (for example if using access ramp into a WAV)
- There should be alternative routes if using an incline in a public area
- The testing protocol should account for the unique environment of the site

Where inclines are outdoors, further considerations should be made:

- Criteria for use in different weather, lighting and other conditions (such as presence of blow detritus including leaves, presence of standing water, etc.), along with any risk reduction measures that need to take place for safe use
- Insurance and liability implications
- Agreements for use with the owner(s) of the incline(s)

Example test sites

- Wheelchair-accessible vehicle boarding ramp
- A long and wide, inclined corridor within the building
- A ramp into an internal courtyard

Protocol

Test protocol should largely align to those used in "**Error! Reference source not found.**s", with appropriate modifications as noted above to account for the nature of the testing environment.

Suggested decision making tool

Test Method	Advantages	Limitations
Adjustable angle ramp	• Can be used with chairs of all wheel configurations. • Provides a specific angle of tip in all four directions. • Physical demonstration of limitations to the user and / or carers. • Reduced manual handling compared to a fixed angle ramp. • Potentially a portable system. • Low equipment cost. • Users are able to experience the points at which the chair becomes unstable. •	• Manual handling risks remain when the slope is inclined. • May be unsettling for occupant.
Fixed angle ramp	• Can be used with chairs of all wheel configurations. • Physical demonstration of limitations to the user and / or carers. • Potentially a portable system. • Low equipment cost. • Users are able to experience the points at which the chair becomes unstable.	• The test output is only pass or fail, which gives no indication of the extent of pass or fail, e.g., a failure on a 12° ramp means the chair is stable anywhere between at 11.9° and 0°. • Manual handling risks. • May be unsettling for occupant.
Electronic Force Plates	• Improved user experience and safety since the wheelchair does not need to tip towards its limit. • Quickly determining tipping angles for various scenarios and iterations of prescription. • Can take up less space for storage.	• Most only work with wheelchairs that have four wheels. • Reliant on hardware and software working correctly. • Requires calibration to discover confidence in the output. • Reliant on mathematical assumptions and some understanding of the underlying principles by the

		operator to ensure that these assumptions are not voided during testing and that the outputs are reasonable. • User does not get an impression of what the maximum tipping angle feels like. • Can be expensive and difficult to obtain and maintain.
Manual Tip Test	• No or very limited equipment required. • Generally quick to perform. • Can give an indication as to whether more formal stability testing is indicated. • Users are able to experience the points at which the chair becomes unstable. • Active user participation in testing and decision making for user-initiated tests.	• Manual handling risks. • Limited or unreliable numerical output. • Variation between assessors. • Risk of user injury. • Cannot safely assess lateral stability. • Typically can only be used for manual wheelchairs.
Environmental testing using inclines	• Can look at certain dynamic elements of stability as well as other important factors (such as pushing efficiency). • Can be used with chairs of all wheel configurations. • Physical demonstration of limitations to the user and / or carers. • Users are able to experience the points at which the chair becomes unstable.	• Risks associated with getting to and using public or well trafficked areas and liability issues if using public land or land owned by a third party. • Privacy and confidentiality issues. • Limited based on availability in the surrounding area and may not be conveniently located. • May not be suitable for use in all weathers or seasons. • A wider range of potential issues with the testing area (e.g., ground conditions).

What to do with data produced

Having undertaken a formal test, you will have in your possession a set of data.

This might comprise four tipping angles, fewer if lateral stability was not tested, or more if testing has been undertaken with the wheelchair in different angles of tilt and recline, or with the seat raised and lowered, or with the leg rests elevated, or with additional equipment attached.

Now comes the most difficult part, i.e., determining what the data has told you, and what actions are required as a result (if any). To be clear, there is no fixed set of rules to instruct you – each scenario is different, not only in terms of the user and their equipment but regarding external factors, primarily the environment in which the user will use the equipment, their own abilities and skills, together with those of any carers and family members.

Scenario 1: small, competent care team in place; user lives at home

To optimise mobility a reduction in rearward stability can be considered. The user and / or their carers can be educated in the balance between mobility and stability. Higher levels of risk may be taken (remembering that using a wheelchair at all carries inherent risk) to facilitate higher levels of benefit; this is because the abilities of the user and their carers offer risk mitigation. In other words. the likelihood of the person coming to harm is reduced. Training can be supported with documentation, possibly being tailored to the user in their particular context / environment.

Scenario 2: user lives in residential care supported by a large care team

Stability in all directions might best be optimised conservatively, i.e., erring on the side of caution; it must be accepted that doing so has a negative impact on pushing characteristics, but the user is at less risk of tipping over as a result. The risk of injury is reduced because the likelihood of a tipping incident has been reduced – this needs to be controlled because there is a far greater number of carers who are likely to be less familiar with the equipment and the user. Also worth considering for this sort of user environment is 'reasonably foreseeable misuse', e.g., anti-tip levers would be better permanently attached than removable; it might be advisable to limit the amount of combined tilt and recline (for example this might involve blocking use of a control lever, or even removing the control lever and cable from the chair entirely).

Scenario 3: user rocks violently back and forth, and leans out to the side of the chair so they can reach the floor

Clearly, to reduce the chances of injury the wheelchair will need to be made more stable. This will have an impact on mobility, so consideration may need to be given to the provision of other equipment which might include: (a) a powered add-on device; (b) a powered wheelchair with attendant control; (c) a static chair to reduce dependence on the wheelchair

Evaluating and communicating the numerical output of a test

The numerical output can be used as a tool alongside other factors of prescription. Its evaluation should be relative to the user and the factors surrounding them, taking a holistic view. This could mean adapting the pass / fail criteria to the user based on their skills, environment and goals.

The numerical output can also be used in parallel with other methods of testing stability, e.g., paired with an environmental test such as the incline of the slope to the front door.

Understanding and communicating what the number means in practical / visual terms may aid the user in relation to the real life environment, thereby developing skills in them for assessing and managing risks associated with wheelchair use.

It is important to note the numerical outcome is the result of a test in a controlled environment (dry, static, no adverse camber), so will not translate to all real world scenarios the user is likely to experience.

Application to the real world

Reference angles for stability

Due to the sheer number of variables involved, there is no singular definition for 'safe' or indeed functional / efficient tipping angles, only guidance. The person testing must evaluate the outcomes in relation to the user, their equipment, and the context in which they live.

The angle of 12° is a useful starting point for many applications. There is no scientific evidence or reference for this: it is a view based purely on the experiences of stability testing in clinical practice over many years and scenarios, with a wide variety of manual wheelchairs, powered wheelchairs, special needs buggies, and multiple forms of seating.

12° is, in reality, quite a steep slope. Looking at equivalence to roads it is slightly steeper than a hill gradient defined as 1:5 (20% or 11.3°). Buildings regulations demand a slope no greater than 1:12 (8.3% or 4.8°) for accessing dwellings (The Building Regulations Part M, Volume 1).

Depending on the context it might be possible to:

- derive greater benefit to the user by reducing rearward stability, and/or
- reduce risk of tip by increasing stability (rearward/ forward/ sideways).

In the case of the second scenario, the angle of 16° becomes a useful reference – beyond this level a wheelchair starts to become significantly more difficult to tip over (and to propel, in the case of a manual chair).

The application of tilt, recline, seat rise, elevating leg rests, and the fitting of additional equipment throws in another challenge. In theory a tilt test should be performed in the least stable configuration, but is that the maximum limits dictated by the chair, or the most likely pattern of use by / for the user? If the latter, the mechanical limits of the chair may need to be restricted, particularly in multi-carer environments.

It should be noted that in regard to active manual wheelchair users needing to perform a back-wheel balance, rearward stability will need reducing significantly, probably to around 2-4° – without this, attaining a back wheel balance will be more hazardous because lifting the castors off the ground requires more effort, which makes the balance point harder to catch before a rearward tip is induced.

Stability outside of testing - real life use of equipment

Out and about

Using a wheelchair in daily life comes with many challenges, especially when moving around outside, getting in and out of vehicles, and accessing buildings.

Common obstacles include:

- uneven pavement and loose paving stones
- sloped or cambered pavements
- high kerbs and blocked dropped kerbs
- rough surfaces like cobbles or tactile/blistered paving
- steep hills and inclines
- obstacles / drain covers / gutters / pot holes

These obstacles can make it difficult to stay balanced and may increase the risk of tipping. Users often have to carefully plan their routes to avoid problem areas. For a person pushing a wheelchair, these challenges can also cause physical strain, potentially leading to injuries.

Active users may use instability to negotiate these challenges but it is still a risk for them. Special wheelchairs may be available to hire to access specific terrains, for example wheelchairs with wide round tyres for the beach.

The front castors may become caught, causing a forward tipping risk. Cambered pavements designed to make wheeled access for cars easier increase a sideways tipping or sliding risk for a wheelchair traversing them. User manuals may provide guidelines on how to negotiate kerbs but the real physical world is often not ideal. Research has been done on the challenges to wheelchair users, interviewing them to understand the challenges and frustrations (Rosen et al, 2012).

Accessing buildings

Older buildings often have poor accessibility, with ramps that are too steep or placed at awkward angles. Some wheelchair users need to tip their chair slightly to get over obstacles, which increases the risk of tipping over. Even in designated disabled parking areas, sloped surfaces can make it difficult to transfer in and out of a vehicle safely.

Functional use and ‘how things should be’ vs reality

Using tilt for hoisting

When a wheelchair has an inbuilt adjustable tilt feature, the risk of instability is less, particularly if anti-tippers are fitted. It is very common, though, that users are hoisted into standard non-TIS wheelchairs, and in order to achieve optimal pelvic position chairs are often tipped manually on the rear wheels by a carer / family member, which presents certain risks.

In-vehicle transportation

Commonly carers / attendants will leave the wheelchair in a tilted position when tied down due to the user’s clinical needs, e.g., head control / swallow. Tilt is often used to aid head control for those who cannot achieve it independently, and when sitting upright their head moves / falls into forward flexion which affects swallowing and breathing. When in transit with limited supervision from carers / attendants this presents significant risk to the wheelchair user, so wheelchairs are often left in tilt as risk can be too great for some individuals. It is also important to note that many wheelchairs are not crash-tested to be used in tilt while occupied in a vehicle.

Fitting accessories, other fitted third-party items, and Electronic Assistive Technology

Many wheelchair users need or choose to carry personal and medical items with them, such as shopping, medical equipment, or communication devices. These items are often attached to the wheelchair, usually on the back, sides, or a tray underneath. However, this can affect the wheelchair's balance and increase the risk of tipping, especially when the wheelchair is tilted for comfort or medical reasons.

Note, however, that equipment stored underneath between the front and rear axles may actually increase stability by lowering and centring the CoG; if this is to be used to counter instability, it must of course be established that the same equipment will be stored in a similar way each time the wheelchair is used.

Personal items & medical equipment

Items commonly attached include:

- everyday necessities – food, drinks, personal care items
- medical equipment – ventilators, oxygen cylinders, suction machines, etc.
- communication devices and environmental control systems

These attachments shift the wheelchair's centre of gravity, affecting its stability. Heavy items at the back might make the wheelchair tip backwards, while items at the front could cause it to tip forwards.

Electronic Assistive Technology

Mounted communication devices

The heavier of these devices might weigh up to 4 kg. Typically, the device is attached to the seat rail via tubing. While the required location of the communication device may vary from person to person and may also vary depending on how the user is engaging with the device at that time (i.e., if actively using the communication device rather than using it in a stowed position to facilitate driving the wheelchair), it is not untypical for many devices such as eye-gaze communication devices to be located around 30 cm forward of the knees at about head height. Such a setup adds reduces (static) stability in the forward direction in terms of tipping / sliding.

Some users might require a device to be placed to the left or right. Such a placement will move the centre of gravity toward the side where the device is located, which is likely to reduce sideward stability and increase risk of tipping, sliding, and turning in the direction of the device. This is particularly applicable to narrow manual wheelchairs, e.g., those used by children and smaller adults.

Many communication devices will be stowed on the wheelchair when not in use, either via a folding mounting arm, a secondary mounting socket, or by hanging the device via a convenient strap or hook on the wheelchair. This can introduce significant variation in the weight distribution of the wheelchair and so impact on stability. Users may also hang personal items on the mounts, adding further unpredictable weight shifts.

The impact of EAT equipment mounting location on stability

Most common mounting setup

The most common item to be mounted to wheelchairs is a cushion; while these in and of themselves will typically have minimal impact on stability (exceptions may exist for certain types of modular and bespoke seating systems which can be significantly heavier than the original components), they can cause or require other configuration changes which may further impact stability. A particularly tall cushion can significantly increase the height of the user in the wheelchair and so raise the overall CoG which can impact stability.

Similarly, backrests and headrests are routinely added to wheelchairs; these will generally be mounted to the push handles at the rear of the chair and again may not have significant impacts on stability themselves but may cause other configuration changes which will require consideration when assessing stability.

For example, many rigid shell backrests will be mounted some distance in front of the push handles, which may require the user to sit further forward on the wheelchair than would normally be the case, significantly impacting the CoG.

To counter this, some wheelchairs can be adjusted to increase the seat depth and bring the user back into the optimal seating position; however, this can mean that the forces exerted by the user on the backrest act in such a way as to reduce stability, particularly if the rear wheel position is not changed as part of the adjustment.

Less common mounting setups

Some users might require a device to be placed to the left or right, such that the device is not only forward of the wheelchair's front contact point with the ground but also to the left (or right) of the wheelchair's leftmost (or rightmost) contact point with the ground. Such a placement will move the centre of gravity toward the side where the device is located, which is likely to reduce sideward stability and increase risk of tipping, sliding, and turning in the direction of the device.

Sometimes mount tubing is attached to static parts of the frame. From a stability point of view, such a setup is less influenced by the seat rail position (tilt, recline, rise) but might introduce other risks to the user not related to stability.

Sometimes mount tubing is attached to the seat back. From a stability point of view, the stability effects of the chair's recline position will be exaggerated as compared to the more typical seat rail attachment point.

Real-world mounting considerations

Hanging anything but the intended device on a mount tubing is problematic for stability and other reasons, but the effects are much greater on a folding or swing away mount. The additional weight on mount tubing might reduce stability enough to cause tipping / sliding / turning leading to harm to the user or to others.

Mount tubing overhang

Mount tubing overhanging from the bottom of a frame clamp introduces opportunity for hooking on or colliding with objects in the environment as the wheelchair user moves past, which could result in a sudden force at that point which could tip or spin the chair unexpectedly, particularly if the user is moving at a significant speed. The installer should therefore take care to reduce mount tubing overhang from the bottom of the frame clamp as much as possible.

Swing away or folding mounts

Mount tubing in a swung-away or folded position introduces opportunity for hooking or colliding with objects in the environment as the wheelchair user moves past. Due to the relatively long moment arm, the release fail-safes built into the frame clamp should engage, but there could still be enough force prior to the release to tip or spin the chair, particularly if the user is moving at a significant speed.

Stability and the effect on sliding and traction

By adjusting the setup of a wheelchair to change how stable it is, you can impact on how resistant to sliding a wheelchair is as well as how much traction it has. This is commonly done by moving the centre of gravity forwards and backwards relative to the wheelbase.

By placing the centre of gravity closer to the drive wheel, but still within the wheelbase, traction will be increased as the drive wheel is pressed into the ground. Conversely, placing the centre of gravity too far away from any of the wheelchair's drive wheel points of contact with the ground will reduce the traction at that point, which could lead to sliding due to reduced weight being applied to the drive / braked wheel (affected by slope and weather conditions).

Placing the centre of gravity too close to the castors can make turning extremely difficult, as well as reducing drive wheel traction; it is also likely to cause premature castor wear.

It is important to note that there are many other factors which relate to how much traction or resistance to sliding a wheelchair has, and while configuration changes to tune the stability of a wheelchair to meet the user's needs can have an impact, the appropriate stability of the wheelchair and user should generally be the primary consideration. Any changes to traction from adjusting stability can generally be accommodated with other changes (e.g., changing the tyre profile or type, tuning motor power to account for asymmetrical weight distribution, etc).

Unless there is an overriding need to prioritise traction or sliding that cannot be addressed by other means (by changing the tyre profile or type, adjusting the motor profiles, etc), it is generally recommended to consider the functional stability of the wheelchair to be the main objective of changing the centre of gravity of the chair.

Stability can adversely affect wheelchair performance, particularly in powered wheelchairs, where the centre of gravity position may cause slides or loss of traction (Moody et al., 2012). Wheelchair users are exposed to various terrains such as uneven surfaces throughout daily life, and intermittent loss of traction can cause users to slide or slip when traversing terrains, often making the wheelchair unstable (Sivakanthan et al., 2020). A wheelchair user fearing tips and slides is common, but this can further lead to anxiety and reduced independence through risk aversion (Moody et al., 2012).

Environmental sliding (e.g., in a bus)

Sliding is often seen while a wheelchair is in transport. In most WAVs (wheelchair accessible vehicles) this will be addressed with an appropriate wheelchair tiedown and occupant restraint system (WTORS). However while using public transport such as buses and trains, many wheelchairs will be unrestrained or have only limited support from the vehicle (such as having a padded wall / backrest which it is intended for the wheelchair to back against before engaging the brakes).

Factors which may have been tuned to improve stability or address other concerns of the user (such as seat tilt, weight distribution between the wheels, seat to ground height, etc.) can impact the ability of the wheelchair to resist sliding when external forces are applied (such as the bus braking and turning).

The most common issues to see are:

- rotation around the drive wheels (typically seen where the chair "spins" and most of the displacement of the chair is seen at the castor end(s))
- drive wheels sliding (typically the entire chair will slide; however, the slide will tend not to involve the chair rotating)

Adjusting the centre of gravity to sit more heavily over the drive wheels will tend to allow the castor end of the chair to slide, while having a balanced weight distribution will tend to allow the chair to slide as a unit.

Where the centre of gravity is set over the castors the drive wheels may occasionally be seen sliding, but in this case the chair will also tend to rotate around the castors.

Environmental traction (e.g., delivering power through the wheels)

Increasing the proportion of weight through the drive wheel will tend to improve the ability of the drive wheel to translate the power delivered into motion of the wheelchair. It is important to remember that, with the exception of rare types of wheelchair (such as two-wheeled wheelchairs), it is important to maintain enough weight over the castor wheels that they can perform their various functions (stability of the wheelchair including proper functioning of any suspension system, steering, etc).

Changing the size of the drive wheels can also impact on traction and stability, firstly by changing the amount of torque a wheel is able to generate, secondly by changing the contact area with the ground (larger diameter wheels tend to have a slightly increased contact area), and thirdly by impacting on the height of the wheelchair and thus the position of the centre of gravity (generally increasing the size of the drive wheel will increase the height of the wheelchair, although there may be exceptions).

The most appropriate weight distribution for different types of wheelchair can be debated and reference should certainly be made of the guidance provided by the manufacturer and other literature; however, how this is functionally achieved to allow best functioning in the environments in which the chair is to be used can be difficult to determine, and may rely on compromise, particularly where a chair is expected to perform in several different environments.

Point of sliding when performing stability testing across a slope

With the chair positioned across a slope (ideally perpendicular to the direction of the slope), the way in which a chair slides and the angle at which it does so can give an indication of both the ability of the chair to withstand laterally applied external forces, and how the centre of gravity is positioned within the wheelbase.

In such testing, the sliding seen will align to the cases already discussed in the section above, “Environmental sliding (e.g., in a bus)”.

Method for influencing stability and mobility

Stability is dependent on where the centre of gravity acts over the wheelchair's areas of contact with the floor. Once the centre of mass is acting outside these areas of contact, the chair becomes unstable and is at risk of tipping. Thus, the main components which are most likely to affect stability include the distribution of contact points relative to the centre of gravity.

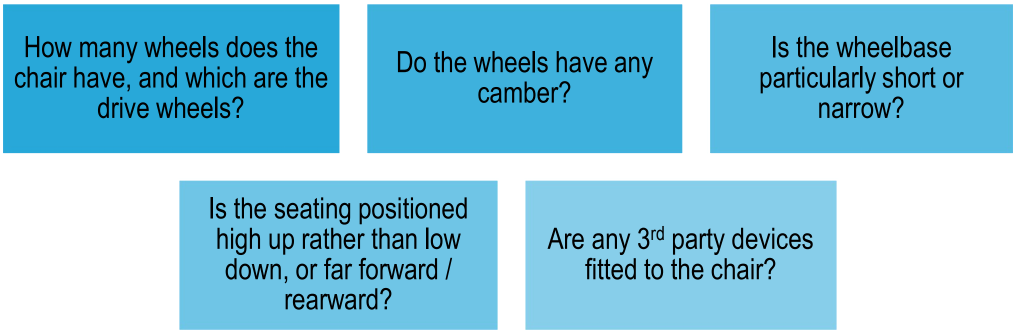


Figure 1 - Factors which may influence stability and mobility

Any changes to the configuration of the chair which will alter the centre of gravity or the distribution of contact points, such as typical changes from the use of fixed tilt or tilt-in-space, backrest recline, leg rest elevation, and seat riser, the use of external components such as trike wheels, powerpacks, etc., particularly those which apply a driving force to the chair.

Methods for increasing wheelchair stability

Increasing wheelchair stability can be useful for passive users, those with involuntary movements, or where frequently navigating inclines / uneven terrain, although it is important to note that some amount of instability can be desired for traversing uneven terrain.

- Lower centre of gravity
    - Minimise seat to ground height
    - Choose a heavier base, even considering provision of an attendant powered chair in extreme circumstances
    - Position carried medical equipment (e.g. oxygen cylinder) to avoid or offset instability
- Widen points of contact by increasing distance between front and rear wheels, and between wheels side to side; it may also be achieved laterally by increasing the negative camber of the drive wheels
- Anti-tippers (forwards and rearwards)
- Castor outriggers
- In regard to tilt-in-space wheelchairs / buggies, choosing one using 'floating' pivots rather than fixed pivots

Methods for decreasing wheelchair stability

Decreasing wheelchair stability can be useful for active users (particularly in the rearward direction), or where attendants are having difficulty pushing, steering or clearing obstacles.

- Reduce rearward stability by moving castors and rear wheels closer together (forwards to back)
- Moving the combined CoG of the person and any seating backwards relative to the rear axle
- Reduce overall weight of chair, bearing in mind that a lightweight chair set up poorly can feel heavier to push than a heavier chair set up well

Fluidity of stability, and the problem of optimal stability

By increasing the stability of a chair, mobility may be sacrificed.

When prescribing a wheelchair, we are providing individuals with mobility devices. Therefore, mobility (and getting from A to B) is the main focus. The wheelchair was designed to move, and some risks may come with that.

Posture vs function – the user may benefit from active user lightweight equipment which has then been supplemented with heavy accessories, e.g., postural backrest. This then has to be considered with regard to how it affects the stability of the wheelchair, possibly setting the wheelchair into a more passive position which affects propelling and diminishes the benefits of having lightweight wheelchair in the first place.

Lot of experienced active wheelchair users will use instability for, e.g., accessing pavements, and this is a very subjective and individual matter. This can be a clinical challenge as the safety aspects around tipping conflict with the safety aspects around taking away a highly skilled user's ability to manoeuvre.

Equally, stability is not just about here and now, it may need to change over time. An example may be a new active user; the longer that individual is using their chair, the more their skills and confidence will develop, meaning their stability may be able to increase over time, to allow their mobility to increase over time. On the other hand, individuals with a deteriorating condition, such as Motor Neurone Disease, may see a deterioration in function over time, as well as in their confidence, leading to an increase in stability for reassurance.

Users may have the capacity to perceive stability and may adjust their position to reduce the risk of tipping. Therefore, training and awareness can help a user better manage risk actively and allow increased mobility.

Tolerance of stability can inform prescription over time; revisiting the setup of chairs as users become more experienced or develop a greater understanding of their needs should be expected and encouraged.

Dynamic Stability

Testing equipment and methodology for dynamic stability

While dynamic stability is usually outside the scope of most testing undertaken by wheelchair services, mainly due to time constraints in clinic and availability of suitable terrain, test protocols exist which look at the dynamic stability of wheelchairs. As may be imagined, they can be somewhat abstract or very narrow in their scope compared to the actual use of wheelchairs. They are included here for the sake of completeness only.

The following testing protocols should be carried out with a full understanding of ISO 7176-2 and its limitations in a clinical setting. A static stability test should always be completed (ideally using an electronic force plates) and CoG optimised prior to carrying out dynamic stability testing with the end user. Safety of the end user is paramount and their driving ability must be taking into consideration before carrying out dynamic testing.

The following tests are taken directly from ISO 7176-2. They give an indication as to what tests can be carried out. The turning tests in particular are likely to be the least feasible to carry out with the end user as they may be dangerous to perform outside a testing environment. It is at the clinician's discretion as to what tests they feel are suitable for their patient / client.

Tests for rearward dynamic stability

The following are tests which were initially designed for use in a test environment and not with the end user in a clinic setting. These can be used as a guide to influence the testing you carry out with your patients; e.g.. ramps of all angles are unlikely to be available ,and allowing the chair to tip is unrealistic with a patient in the chair

Starting forwards

This test determines stability when a wheelchair starts on a horizontal surface and on an uphill slope.

a) Position the wheelchair on the horizontal test plane.

b) From a stationary position, ask the user to operate the input control device to give maximum acceleration in the forward direction.

c) Observe the dynamic response of the wheelchair and score it according to Table 2.

d) Repeat b) to c) on the 3°, 6° and 10° ramps starting with the wheelchair on each ramp facing uphill.

Stopping after travelling forwards

This test determines stability when a wheelchair stops on a horizontal surface and rocks backwards as a counter movement. This test also determines stability when stopping on an uphill slope if the wheelchair rolls or rocks backwards before coming to a complete stop.

a) Run the wheelchair at maximum forward speed on the horizontal test plane.

b) Ask the user to completely release the input control device.

c) Observe the dynamic response of the wheelchair and score it according to Table 2.

d) g) Repeat a) to c) travelling forwards uphill on the 3°, 6° and 10° ramps.

Braking when travelling backwards

This test determines stability when a wheelchair stops suddenly from maximum reverse speed travelling on the horizontal and downhill.

a) Run the wheelchair at maximum reverse speed on the horizontal test plane.

b) Ask the user to apply deceleration by releasing the input control device.

c) Observe the dynamic response of the wheelchair and score it according to Table 2.

d) Repeat a) to c) travelling backwards downhill on the 3°, 6° and 10° ramps.

Tests for forward dynamic stability

Braking when travelling forwards

a) Run the wheelchair at maximum speed forwards on the horizontal test plane.

b) Ask the user to apply deceleration by releasing the input control device.

c) Observe the dynamic response of the wheelchair and score it according to Table 2.

d) Repeat a) to c) on the 3°, 6° and 10° ramps travelling forwards downhill.

Travelling forwards down a slope onto a horizontal surface

a) Run the wheelchair forwards down the 3° test ramp to reach the horizontal test plane at maximum speed.

b) Observe the dynamic response of the wheelchair at the transition and score it according to Table 2.

c) Repeat a) and b) using the 6° and 10° ramps.

Travelling forwards up a step transition at maximum speed

The intent of this test is to use the impact with the step to induce a tip. The wheelchair may or may not climb the step. It is also important to note that this may be unsafe to carry out with a user in the wheelchair.

Any kerb-climbing devices should be set in their normal position for driving the wheelchair up a kerb.

a) Position the wheelchair on the horizontal test plane far enough from the step transition to allow the wheelchair to achieve maximum speed.

b) Run the wheelchair forwards at maximum speed along the horizontal test plane to hit the 12 mm step at 90° ± 5°.

c) Observe the dynamic response of the wheelchair at the transition and score it according to Table 2.

d) Repeat a) and b) with the step heights of 25 mm and 50 mm.

e) If the manufacturer claims that the wheelchair is capable of handling higher step transitions, repeat a) to c) at intervals that are multiples of 25 mm, increasing step heights until the wheelchair can no longer travel up the step transition with a score of 2 or greater. At each height, score the response of the wheelchair according to Table 2.

Travelling forwards down a step transition from a standing start

This test determines stability when a wheelchair very slowly drops down a step.

a) Position the wheelchair on the horizontal test plane above the step, so that the front wheels are at the edge of the step.

b) Run the wheelchair at the lowest practical speed, forwards down the 12 mm step and in a direction 90° ± 5° to the front of the step.

c) Observe the dynamic response of the wheelchair at the transition and score it according to table A1.

d) Repeat a) and b) with the step height of 25 mm and 50 mm.

e) If the manufacturer claims that the wheelchair is capable of handling higher step transitions, repeat a) to c) at intervals that are multiples of 25 mm, increasing step heights until the wheelchair can no longer travel down the step transition with a score of 2 or greater. At each height, score the response of the wheelchair according to Table 2.

Tests for dynamic stability in lateral directions

This test is unlikely to be suitable for end user testing as can pose a high risk of lateral tipping.

Turning on a slope

a) Position the wheelchair on the horizontal test plane.

b) From a stationary start, apply maximum speed command turning to the left in a minimum turning radius until the wheelchair is facing in the reverse direction. If the wheelchair has direct steering, turn the steering control for a minimum radius turn and then apply maximum forward power.

c) Observe the dynamic response of the wheelchair and score it according to Table 2.

d) Repeat a) to c) turning to the right and record the lower score together with the side toward which this occurs.

e) Repeat b) to d) on the 3°, 6° and 10° test ramps, starting with the wheelchair facing downhill and finishing with the wheelchair facing uphill.

Turning in a circle at maximum speed

Run the wheelchair at maximum speed in the forward direction on the horizontal test plane. It is important to note that this test is generally not feasible to carry out.

a) Turn the wheelchair in circles of decreasing radius while continuing to command maximum possible speed. For each circle, note the score as in table A1.

b) Determine the minimum diameter circle to the nearest 100 mm in which the wheelchair will run at maximum possible speed with a score of 2 or greater.

c) Measure the diameter of the circle traced by the centreline of the wheelchair.

d) Repeat a) to d) turning in the opposite direction.

e) Record the larger diameter together with the corresponding direction in which the wheelchair is turning.

A wand with chalk attached and projecting from the wheelchair may assist in following a circle.

Turning suddenly at maximum speed

Most wheelchairs with direct steering will not remain stable during this test. Caution should be exercised during the testing process.

a) Run the wheelchair at maximum speed in the forward direction in a straight path on the horizontal test plane.

b) Operate the input control device to produce a 90° turn with a minimum turning radius.

c) Observe the dynamic response of the wheelchair and score it according to table A1.

d) Repeat a) to c) turning in the opposite direction.

e) Record the lower score together with the corresponding direction in which the wheelchair is turning.

Scoring system for dynamic stability

Table 2 – A scoring system for quantifying response of wheelchair test manoeuvres for dynamic stability - reproduced from ISO7176-2

Observed dynamic response		Score
No tip	At least one lifting wheel remains on the test plane.	3
Transient tip	All lifting wheels lose contact, then drop back onto the test plane, whether or not any anti-tip devices contact the test plane.	2
Stuck on anti-tip device [a]	All lifting wheels lift off, the wheelchair anti-tip device(s) contacts the test plane, and the wheelchair remains stuck on the anti-tip device(s).	1
Full tip	The wheelchair tips completely over (90° or more from its original orientation) unless caught by a restraining device or test personnel for test purposes.	0
[a] When determining whether the wheelchair is "stuck" on the anti-tip device(s), this implies that the wheelchair occupant could not easily restore the wheelchair to the upright position without assistance while remaining seated in the wheelchair. If the wheelchair is not equipped with an anti-tip device a score of 1 cannot be awarded.		

Guidance relating to the measurement of dynamic stability in power chairs

The West of Scotland Mobility and Rehabilitation Centre (WestMARC) have used the testing methodology outlined in ISO 7176-2 along with their own clinical expertise to develop guidance on the measurement of dynamic stability in power chairs. This guidance has been reproduced in *Appendix 2: WestMARC guidance on the measuring of dynamic stability in power chairs*, with their kind permission.

Conclusions

Balancing benefits with risks – a management methodology to consider the holistic system

It is right for us to consider the risks associated with wheelchair provision, but we must remember that the fundamental purpose of a wheelchair is to facilitate mobility: making a wheelchair too stable will thwart mobility, yet having the chair too 'tippy' will be unsafe.

Thus, we must balance stability with mobility, meaning risks must be taken, at some level, to provide benefit.

Furthermore, we must remember that stability tests, whether formal or informal, are conducted in a controlled environment, meaning we must factor in the person's context and circumstances, both in the present and in the immediate / longer-term future. The stability assessment checklist at the end of this document provides a useful reference in this respect.

Also needing to be considered is how benefits, risks, and control measures are communicated. This becomes more challenging if the person has learning disabilities, and / or where there are many care staff involved – in these cases it may be necessary to make the wheelchair more stable, thus trading an element of mobility for greater safety.

Most health organisational risk management policies utilise risk matrices, typically 5x5, as described by the international standard ISO14971, Application of Risk Management to Medical Devices. Whilst use of such a methodology is no doubt helpful to managing risk, there are two significant considerations to be made for this field of work:

1) Risks are difficult to quantify, particularly when it comes to determining likelihood / probability; thus, the outcome of a matrix calculation must be treated with a degree of caution, and certainly not in isolation, because:

2) Use of wheelchairs in the home and community is complicated by several variables, e.g., different terrains, different carers, fluctuating or deteriorating conditions, highly skilled users

All of this means we are required to make a judgement, and this must be based upon an evaluation of:

- our clinical assessment outcomes
- the person's aims and desires
- stability test outcomes
- risk calculations
- benefit derivations

Recommendations for future work

Testing ramps

There have been several independent designs of stability testing ramps, of both fixed and angle adjustable types; however, there is not currently a commercially available design available. At the time of writing, the prevailing method of obtaining testing ramps is to commission one with an appropriate local fabrication service with a locally developed design.

Future work would include the development and validation of an open-source testing ramp design.

Electronic force plate systems

Sourcing electronic force plate systems is extremely difficult, despite a number of projects aimed at developing newer versions of these devices. While the various equations used in some devices can still be found in published work and there are a number of mathematical models available to interpret readings, there are no real open-source or commercial systems available for services to purchase.

On-board data recording

As has been stressed throughout this document, static testing is only useful up to a point, and the use of wheelchairs is as varied as the people using them. Therefore, data logging of various information such as forces, angles, pushing / motor power, etc., for real life wheelchair use would provide significant information for tuning the setup of wheelchairs for their users.

Universal standardised testing protocols and decision making guidance

While this document has hopefully collated a range of useful information relating to when testing might be considered, carrying out testing, and clinically interpreting the results obtained, and ISO 7176 does provide some potentially clinically applicable testing methods, there remains a need to standardise this across wheelchair services and ensure best practice.

References

The Building Regulations Part M Vol 1, ISBN 978 1 85946 747 3

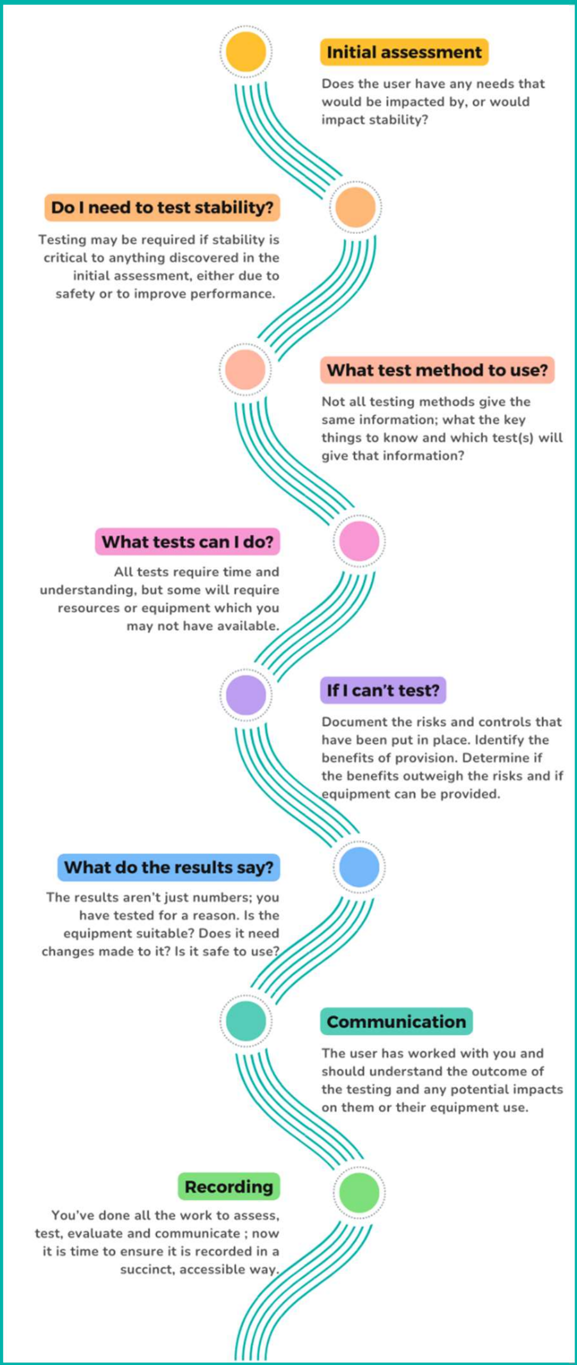
Appendix 1: Stability Assessment Checklist

Please note that these are suggestions of considerations relating to stability and not an exhaustive list, nor should they substitute for clinical reasoning. Space is left to add considerations in each section should you wish to use this as a template.

Service user details

Assessor:	

Name:	
NHS no:	
Date:	



Initial assessment

The following factors are examples of what to consider where stability may play a part; there are likely to be additional factors specific to an individual you may want to record.

Activities of daily living	☐
Environments of use	☐
Method / efficiency of propulsion	☐
Position of seating or other wheelchair components	☐
Posture	☐
Transfers	☐
User's additional equipment needs	☐
User's goals	☐
User's level of function	☐
User's uncontrolled movement	☐

Additional factors assessed:

Service user details

Assessor:	

Name:	
NHS no:	
Date:	

Do I need to test stability?

Using the information from your assessment, you can note down which factors may require stability testing. Scores can be given to indicate how critical stability testing will be to determining whether the user will be safe and / or effective in their provision.

There is no score which would indicate stability testing **has** to be done, but many low score factors, or a small number (or even one) which has a high score, may suggest it is better to test.

More critical	5	4	3	2	1	Less critical

Factor	**Criticality**	**Comments and clinical reasoning**
Total / highest score	/	

Testing <u>not</u> required due to:	☐ Low criticality ☐ Low score ☐ Other (comment)	**Testing required due to:**	☐ High criticality ☐ High score ☐ Other (comment)

It is important to reflect on what answers you hope to gain from stability testing as this can impact on your choice of test method(s). Determining this now can help you get the most from what is available. E.g., “I need to know how best to set up the chair for propelling efficiency" means you are more likely to need to know about weight distribution than rearward stability.

Key things to know from testing are:

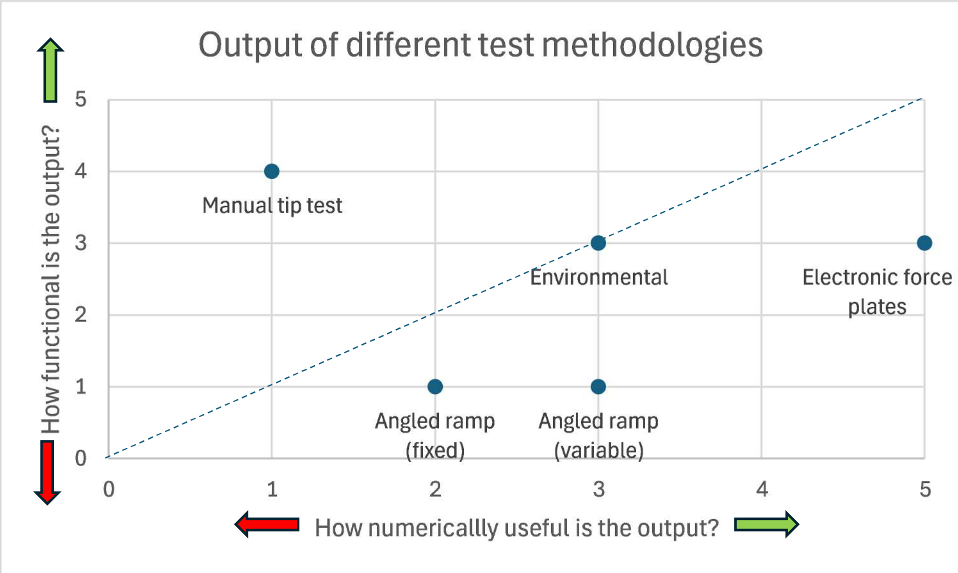
Service user details

Assessor:	

Name:	
NHS no:	
Date:	

What test method to use? What tests can I do?

Using the **key things to know from testing**, it is possible to look at the test methods and identify which may give you that key information. The tests you can do will depend on the equipment, skills, and time you have available. If you are routinely lacking any of these things, you should keep a record to identify the service need.



Key thing(s) to know	Best test for this	Can I do this test?	
		☐ Yes	☐ No
		☐ Yes	☐ No
		☐ Yes	☐ No
		☐ Yes	☐ No
		☐ Yes	☐ No
		☐ Yes	☐ No

Where you cannot do the best test to find out what you want to know, there may be alternatives which could get you part of the way there, or allow you to infer the information that you require. For example, using a variable ramp can allow you to work out the centre of gravity of a chair and occupant, although it is more time-consuming than using electronic force plates.

Some test methods may have other advantages; e.g., environmental testing may present you with a long incline which can be used to assess pushing efficiency by measuring the number of pushes and the time taken to cover the distance of the incline.

Service user details

Name:	
NHS no:	
Date:	

Assessor:	

If I can't test?

Document the risks, risk reduction measures, and the residual risk in the same way that you would had you been able to test; **it is recommended to use your local risk assessment documentation to ensure consistency**. If the risks are sufficiently controlled, or the benefits outweigh any residual risk, then provision should be considered. An example is given briefly below.

Hazard	Risk	Risk reduction measure	Residual risk score
Suspected lack of rearward stability.	User will fall backwards from the chair and suffer an injury.	Anti-tippers fitted to chair and set to balance function (e.g., tipping back for getting over kerbs) vs safety as per SOP. Set rear wheel to medium-active position. Unable to stability test due to lack of equipment.	6/25 – well controlled

What do the results say? Communication

Now you have carried out stability testing, you should have data that you can reference back to your **key things to know** – what does this data tell you? Your test selection should allow you to answer the questions you have posed. It is answering these questions, rather than specifically what angle a chair tips at, that is important, and it is this that you need to **communicate** to the user (and / or family, etc.).

Key thing to know	Test used	Results	Communication and functional implication
What equipment can be carried on the back of the chair?	Angled ramp (variable)	Chair unstable at X degrees with Y kg of equipment in place	"You can safely carry A and B, but not C; that will need to go in a basket under the seat."

Service user details

Assessor:	

Name:	
NHS no:	
Date:	

Recording

Ensure that any data is properly saved with the date of the test, an ID linked to the service user, etc. Ideally, the data should be saved directly to their electronic record, although this cannot always be done (in some cases a PDF export or similar can be done, which may be sufficient). It is also important to summarise the investigations done and the specific recommendations made – an example table is presented below to aid with this. If not already done, a risk assessment should be completed / updated with the risk reduction measures identified as part of testing.

Key thing to know	**Test used**	**Results**	**Communication and functional implication**

Appendix 2: WestMARC guidance on the measuring of dynamic stability in power chairs

This guidance was developed by West of Scotland Mobility and Rehabilitation Centre (WestMARC), Glasgow and is reproduced with their permission.

Introduction

Rear wheel braked Static stability is relatively simple to measure using a Force plate stability rig and associated software. This should always be carried out 1st and CoG position optimised before carrying out dynamic testing. Ideally achieving 60-70% weight over rear wheels but ensuring a rearward braked tipping angle of 20° or higher. This ensures good traction and helps prevent rearwards tipping on acceleration up a slope. If using a mid wheel drive, 50% of the weight should be over the centre drive wheel if possible, however not mandatory as the suspension in these chairs will accommodate some leeway.

The end user should be in their final prescribed sitting position before carrying out dynamic testing (seat to ground height; seat depth/width; seat tilt angle; etc)

Dynamic stability is much harder to measure and at present (May 2025), must be measured in an objective assessment of the chairs performance while being driven by the end user. With that in mind, these following assessment techniques are to be used as a guide and only utilised by suitably trained clinicians whom have an understanding of power chair performance and CoG adjustment.

The tests used have been developed using ISO 7176-2 as a guide. The test methods have had to be modified due to the constraints involved in the clinical setting, either within a clinical centre or at the patient's home/outdoor environment and also the time involved in carrying out the tests.

Before testing the chairs dynamic stability, the patients CoG position should have been optimised following static stability test methods

Unfortunately, if these tests result in poor performance (loss in traction and/or loss in wheel contact with the ground beyond a reasonable level (with MWD chairs)) a change in prescription may be required which can be unfeasible due to time and costs required.

However there are changes that can be made quickly and cheaply to improve dynamic stability. Such as: reducing the accelerations and decelerations in the drive profiles; tweaking the CoG position of the user to try and make dynamic stability more favourable (including height); tweaking suspension (firmer preventing wheel lift and compression resulting in lurching); discussing with the user the limitations of the chair in certain situations (depending on cognition); getting the user to tilt the chair up or down depending on the direction of slope)

Dynamic stability focus for rear wheel drive chairs

From a standing start, accelerate up a slope of max 7°. Start in a slow speed and repeat the test to max speed. If the front castors lift up, there is a potential issue and changes should be made. The patient may realise what they need to do with their body to counteract this; They could tilt the chair forwards; accelerations could be reduced; CoG could be brought forwards without reducing the weight over rear wheels too much.

From a rolling start, go down a slope of max 7°, and ask the patient to remove their hand from the control. The chair should decelerate and stop in a controlled manner. If the rear wheels lose traction or lift, all control is lost. This can be more dangerous than a potential tip. Changes must be made to prevent this such as reducing the deceleration or max speed; Moving CoG rearwards without making tipping backwards a risk; seeing if the user can lean or tip the chair backwards when going down a slope.

Lateral stability – This is more difficult to assess. A drop kerb/camber and pavement can be used, with the user traversing the pavement, down the drop/camber, and then back up the other side, following the dip in the kerb. How does the chair perform? Does the chair lurch to the side? How many wheels leave the ground and does it look manageable for that patient to cope with?

Driving rearwards down a ramp (WAV?). Do the front wheels lift?

Dynamic stability focus for Mid-wheel drive chairs

The same as above applies, however suspension systems are more substantial resulting in the chairs being more forgiving. The suspension will compress down at the back when going uphill preventing the front wheels leaving ground, until it bottoms out. This can happen in aggressive acceleration or poor CoG set up. Or the user being heavy. When going down hill, the rear wheels may leave the ground on deceleration and the front of the seat may tip forwards which will be unnerving for the user. Deceleration parameters can be reduced, or the seat can be tilted when going down hill. Potentially a different mid wheel drive chair could be used which prevents this lurching.

Lateral stability – As above, but again the suspension can absorb undulations a lot better in drop kerbs and cambers, which can make mid-wheel drive chair much safer for outdoor users.

Driving rearwards down a ramp (WAV?). Do the front wheels lift? This is more forgiving in a mid-wheel drive and some front wheel lift can be expected.

Appendix 3 – Images and examples of stability testing ramps

Figure 2 - Portable, folding, angle adjustable ramp - deployed

Figure 3 - Portable, folding, angle adjustable ramp - stored

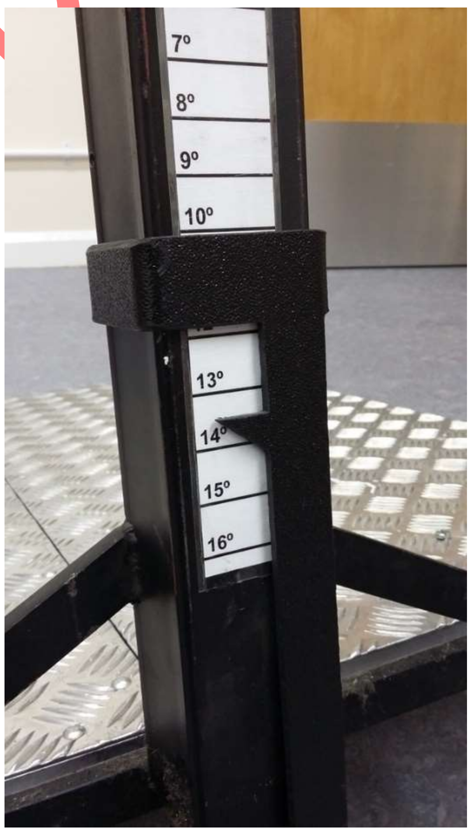


Figure 4 - Portable, folding, angle adjustable ramp - angle indicator

Figure 5 - Portable, folding, angle adjustable ramp - lifting jack fixation point

Figure 6 - Portable, folding, angle adjustable ramp - folding ramp

Figure 7 - Portable, folding, angle adjustable ramp - lifting jack with stored ramp

Figure 8 - Portable, folding, angle adjustable ramp - lifting jack


Figure 9 - Fixed angle ramp stored against a wall


Figure 10 - Fixed angle ramp deployed

Appendix 4 – PMG 2024 responses to testing methods used

The Stability working group ran a breakout session at the PMG conference in July 2024 to facilitate discussions around stability in wheelchairs. At the beginning of each session, the team took a quick census of what methods the population of the room used in daily practice. The data from the two sessions is compiled in the table below:

What methods do you use?

Method	Session 1	Session 2	**Total**
Environmental Assessment	11	12	23
Electric Ramp	4	4	8
Variable Ramp	10	2	12
Fixed Ramp	4	6	10
Manual Tip	20	30	50
Total	49	54	103

Table 2 – Census of testing methods used by professionals in PMG breakout rom

Caveat: This census was a rough count of hands raised. The data may not be precise; however, rough trends can be observed. Note: people were able to raise their hand for more that one method.

Appendix 5 – Swansea research into testing methods used

Testing Method		Number of Services/Trusts
Static ramp		5
Load cells		4
Multiple/Additional methods		3
	Static ramp and clinician observation	1
	Load cells and real environment	1
	Static ramp and Load cells	1
Total		12
Testing Method		Manufacturers
Static ramp		2
Tilting ramp (adjustable)		1
Multiple/Additional Methods		
Static ramp, load cells and dynamic testing		1
Total		4

Table 3 - List of services and the testing systems they employ for stability testing