OPTIMIZING A WHEELCHAIR

Taking Advantage of the Technology to Get Best Outcomes, Now and In the Future

PRESENTED BY

Tom Whelan
V. P. Product Development

Ki Mobility
Better by Design

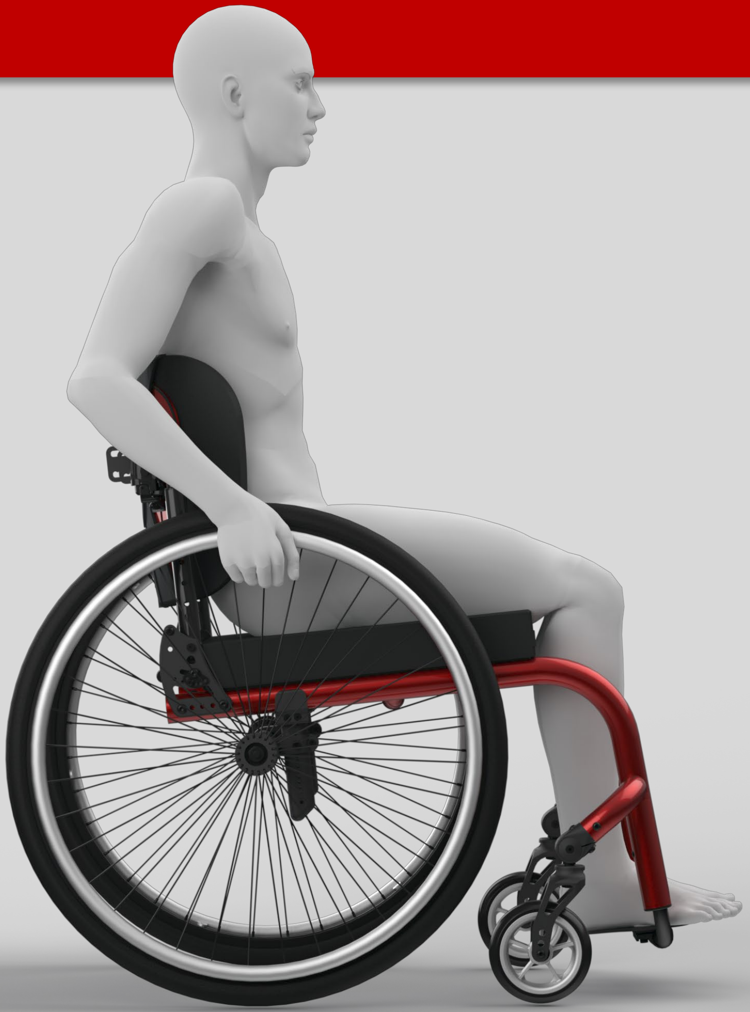
This Presentation is Part of a Series

1. How Do People Actually Use Their Manual Wheelchairs, and What Really Matters?
2. The Impact of Wheels and Tires on Wheelchair Propulsion Efficiency
3. Optimizing a Wheelchair: Using the Technology to Ensure Ongoing Success

Why are we tackling this subject matter?

A Wheelchair is a Machine

It provides a mechanical advantage to make mobility easier



WHEELCHAIR MACHINE

The wheelchair as a machine has an inherent mechanical efficiency

- There is nothing that the user, *in the act of propelling it*, can do to improve it

What can be done to affect the inherent efficiency of this machine?

- Wheelbase Adjustment
- Wheel and Tire selection
- Seating Adjustment

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The Two Components of Propelling a Wheelchair

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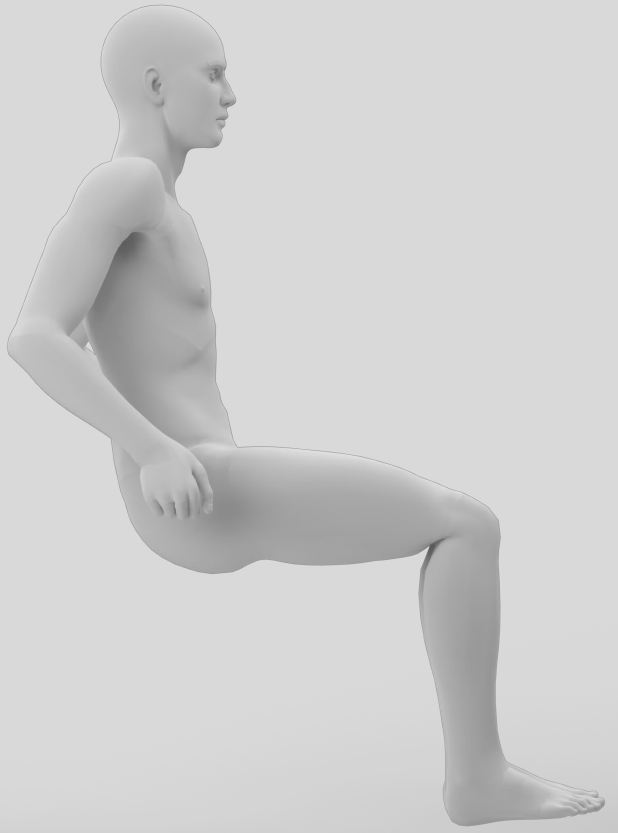
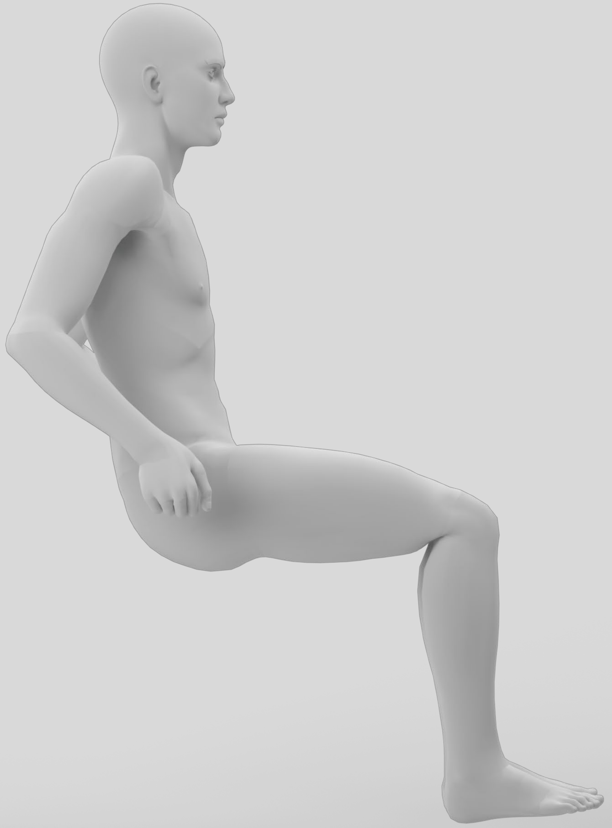


The Two Components of Propelling a Wheelchair



Dissatisfaction and Abandonment of Wheelchairs

Dissatisfaction with, abandonment of, mobility equipment is high

Why?

- Lack of user opinion in selection (Phillips & Zhao, 2010)
- Improper fit to the user and to tasks the user wishes to undertake (Scherer & Galvin, 1996)
- Myth that "a user's assistive technology requirements need to be assessed just once" (Scherer & Galvin, 1996)

What can we do to address it?

ROLE OF WHEELCHAIR FOR USER

Wheelchair [ˈ(h)wēlˌCHer]

NOUN

a chair fitted with wheels for use as a means of transport by a person who is unable to walk as a result of illness, injury, or disability.

A type of mobility device for personal transport

(Taber, 2005)

ROLE OF WHEELCHAIR FOR USER

ROLE OF WHEELCHAIR FOR USER

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Rehabilitation Research and Practice
Volume 2012, Article ID 753165, 7 pages
doi:10.1155/2012/753165

Research Article

Manual Wheelchair Use: Bouts of Mobility in Everyday Life

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Background. This study aimed to describe how people move about in manual wheelchairs (MWCs) during everyday life by evaluating bouts of mobility or continuous periods of movement. *Methods.* A convenience sample of 28 MWC users was recruited. Participants' everyday mobility was measured using a wheel-mounted accelerometer and seat occupancy switch for 1-2 weeks. Bouts of mobility were recorded and characterized. *Results.* Across 29,200 bouts, the median bout lasted 21 seconds and traveled 8.6 m at 0.43 m/s. 85% of recorded bouts lasted less than 1 minute and traveled less than 30 meters. Participants' daily wheelchair activity included 90 bouts and 1.6 km over 54 minutes. Average daily occupancy time was 11 hours during which participants wheeled 10 bouts/hour and spent 10% of their time wheeling. Spearman-Brown Prophecy analysis suggested that 7 days were sufficient to achieve a reliability of 0.8 for all bout variables. *Conclusions.* Short, slow bouts dominate wheelchair usage in a natural environment. Therefore, clinical evaluations and biomechanical research should reflect this by concentrating on initiating movement, maneuvering wheelchairs, and stopping. Bouts of mobility provide greater depth to our understanding of wheelchair use and are a more stable metric (day-to-day) than distance or time wheeled.

1. Introduction

The study of activity has been of interest for many years as a means to relate activity and health outcomes. The study of activity specifically among persons with disabilities has garnered recent interest with respect to health and community participation [1, 2]. Decreased mobility can impact health status and has been associated with issues such as diabetes and obesity [3–6].

As a means to characterize activity, research has documented how far people walk daily [7–9], and guidelines have been developed to establish goals or metrics for walking activity [10, 11]. Bohannon synthesized published data and documented similar walking activity across gender, and differences across certain geographic regions [12]. Furthermore, he found that most studies reported that adults, especially older adults, in the United States walked fewer than the 10,000-step criterion.

Analogous data has also been collected on manual wheelchair mobility with authors reporting the distance traveled over a day and sometimes reporting the amounts of time spent moving and average speed [13–17]. Table 1 lists the results of five such studies. Despite diverse subject groupings, the daily distance results are fairly similar with the exception of a study using competing athletes.

Other research into mobility considered *how people move* as opposed to *how far people move*. Bouts of mobility, or continuous segments of movement, have been reported as a means to describe ambulation and wheelchair movement [6–8, 18, 19]. In ambulation studies, steps taken over short epochs of time are reported as a means to describe walking patterns [6, 7]. Results indicated that people overwhelmingly walk in short bursts. Levine reported that 97% of ambulation bouts lasted less than 200 seconds, and Orendurff et al. reported 90% lasted less than 100 steps.

Bouts of wheelchair mobility have been measured and reported for power wheelchair users [19]. When applying this construct to wheeled mobility, bouts of mobility reflect volitional transitions between functional activities and are defined by a combination of distance traveled and minimum velocity. Bouts of powered wheelchair movement mimic the reported ambulation data in that most bouts were short in

(Sonenblum, Sprigle, & Lopez, 2012)

Wheelchair users are in movement only about 10% of the time up in their chairs.

Involved in other functional activities for much of the other 90% of the time.

ROLE OF WHEELCHAIR FOR USER

Individuals who use wheelchairs do much more than propel from wheelchair

- For many, it is the position from which they perform all ADLs

How Do We Approach the Prescription Process?

1. Body Function & Structure
2. Activity & Participation
3. Environmental & Personal Factors

HOW DO WE APPROACH THE PRESCRIPTION PROCESS?

Body Function & Structure

COGNITIVE IMPAIRMENT
SKIN INTEGRITY
RANGE
PERCEPTION OF
OF DISEASE
POSTURAL ASYMMETRIES
PAIN
MOTION
STRENGTH
STATIC DYNAMIC
BALANCE
ENDURANCE

HOW DO WE APPROACH THE PRESCRIPTION PROCESS?

Activity & Participation

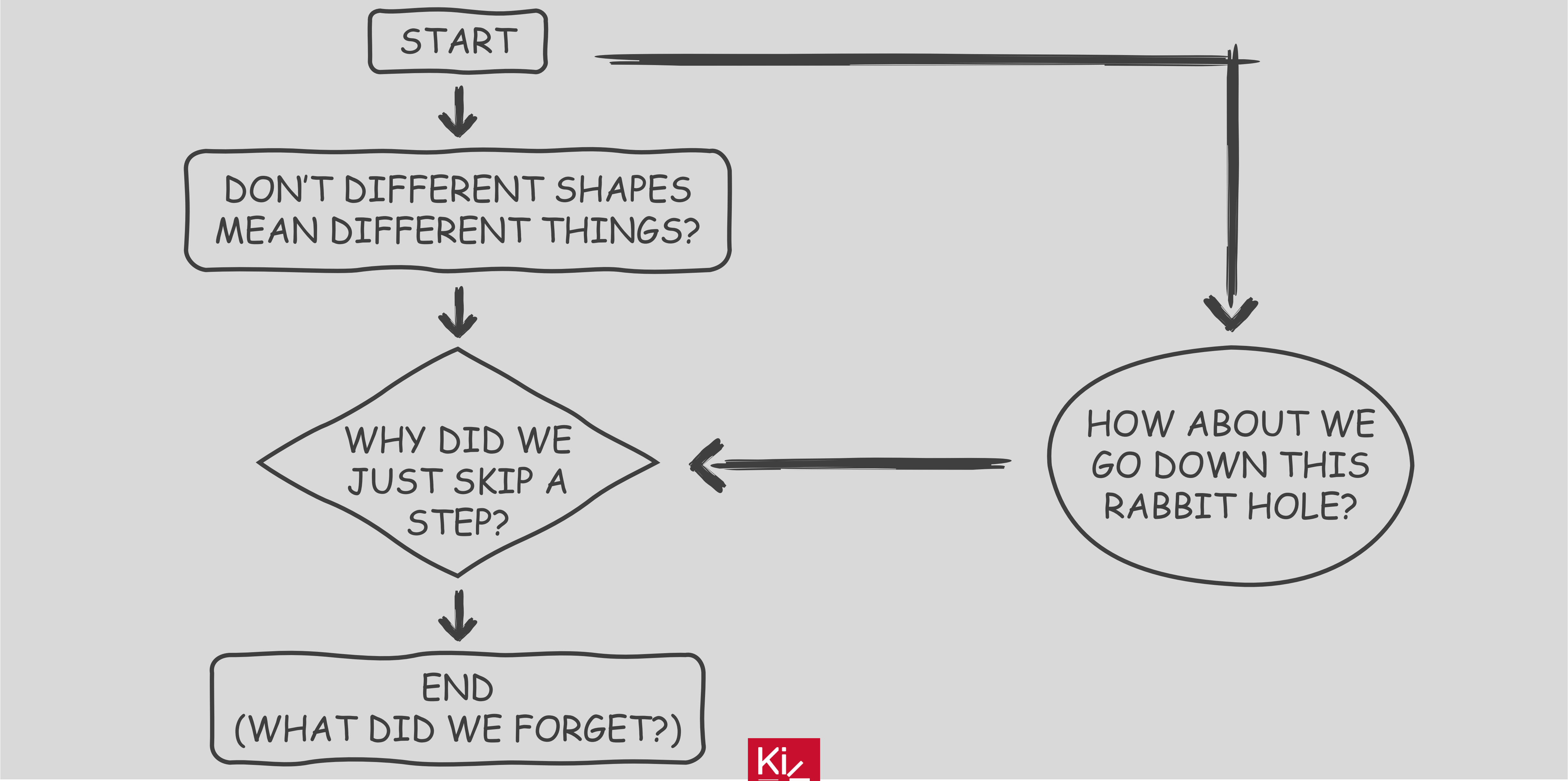
Assistance Level
Meal Preparation
Essential Duties
Oral Facial
Hygiene
Toileting
MRADLs
Transfer
Style
Employment
Bathing
Dressing

HOW DO WE APPROACH THE PRESCRIPTION PROCESS?

Environmental & Personal Factors

ROLES
LIFESTYLE
HABITS
FAMILY
TRANSPORTATION
SUPPORT AND RELATIONSHIPS
HOME
TECHNOLOGY ACCESS AND TOLERANCE
ACCESSIBILITY
COMMUNITY ACCESSIBILITY

HOW DO WE APPROACH THE PRESCRIPTION PROCESS?



HOW DO WE APPROACH THE PRESCRIPTION PROCESS?

Return to Evidence-based Practice

Establish a Foundation Posture

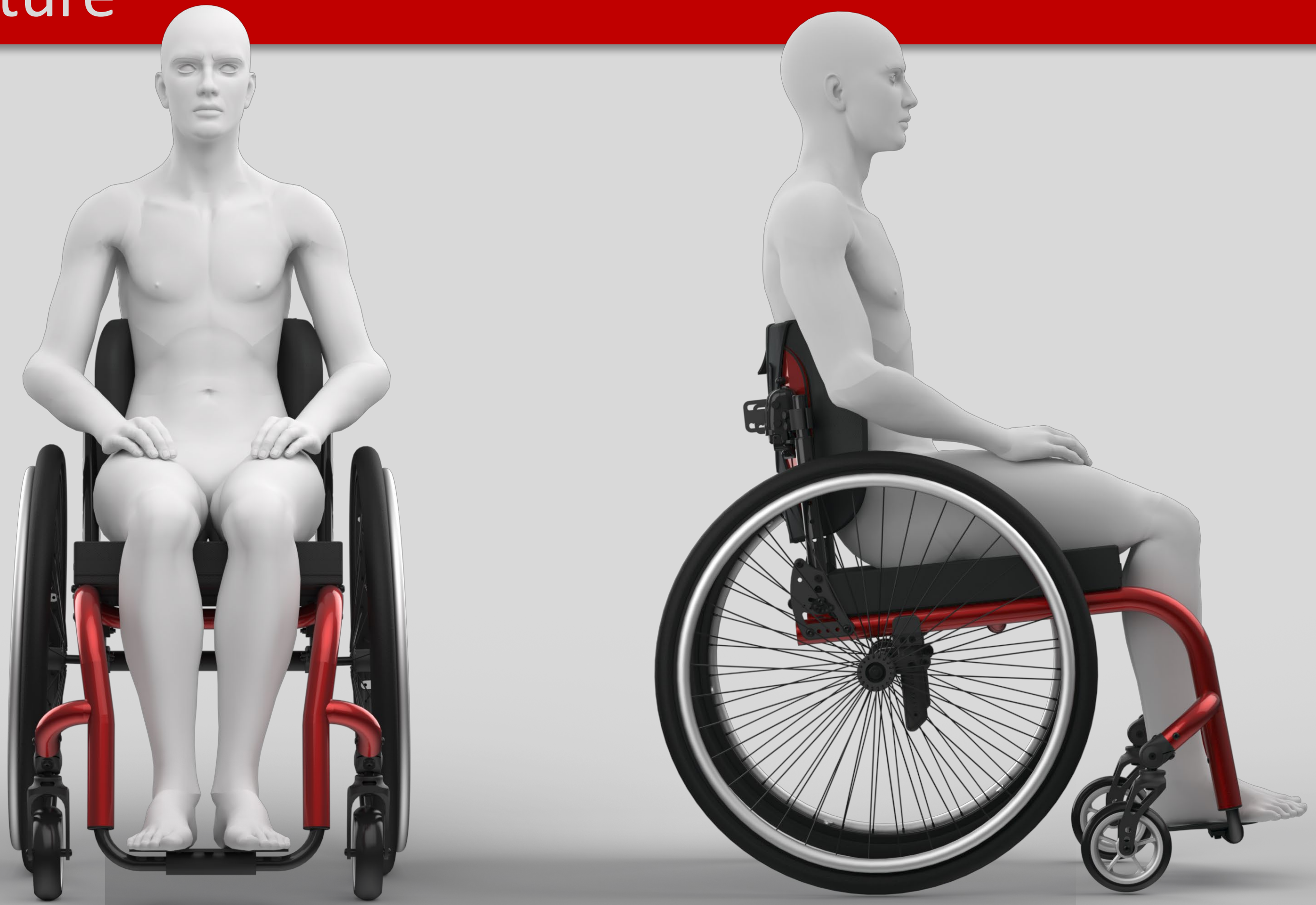
We cannot consider

- functional activities
- wheelchair propulsion

until postural stability has been addressed

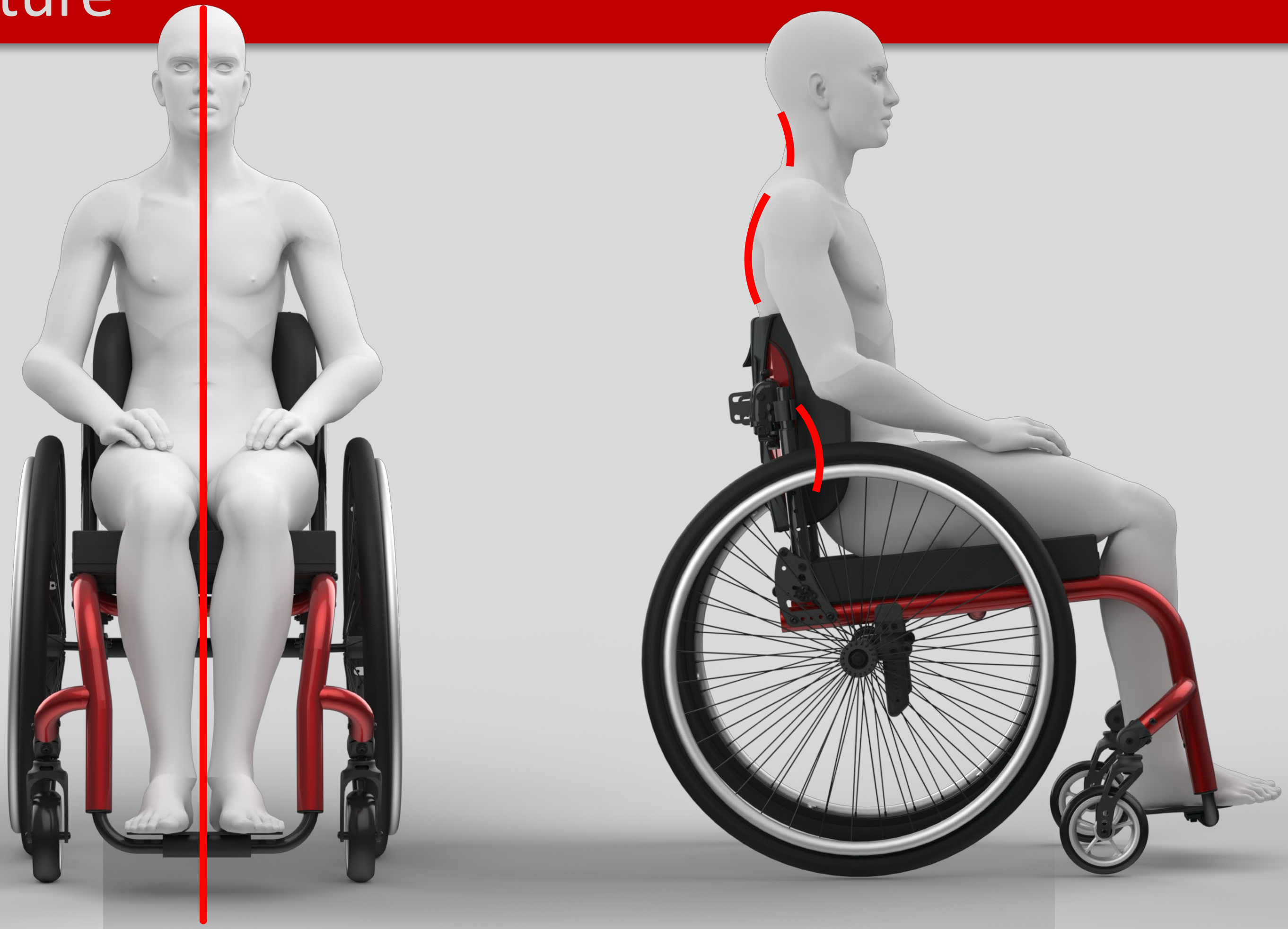
FOUNDATION POSTURE

Optimal Static Posture



FOUNDATION POSTURE

Optimal Static Posture



OPTIMAL STATIC POSTURE

An individual's neutral alignment is dependent on:

- Range of motion
- Strength
- Muscle imbalances
- Endurance
- Muscle tone and response
- Lifestyle/habits

STATIC POSTURAL CONTROL

In order to maintain static postural control, an individual needs to be able to maintain a position of balance

DYNAMIC POSTURE

Dynamic posture is person's alignment during activity

DYNAMIC POSTURAL CONTROL

Dynamic posture is person's alignment during activity

Requires ability to maintain **Center** of **Gravity** (**CG**) over a constantly changing **Base of Support** (**BoS**)

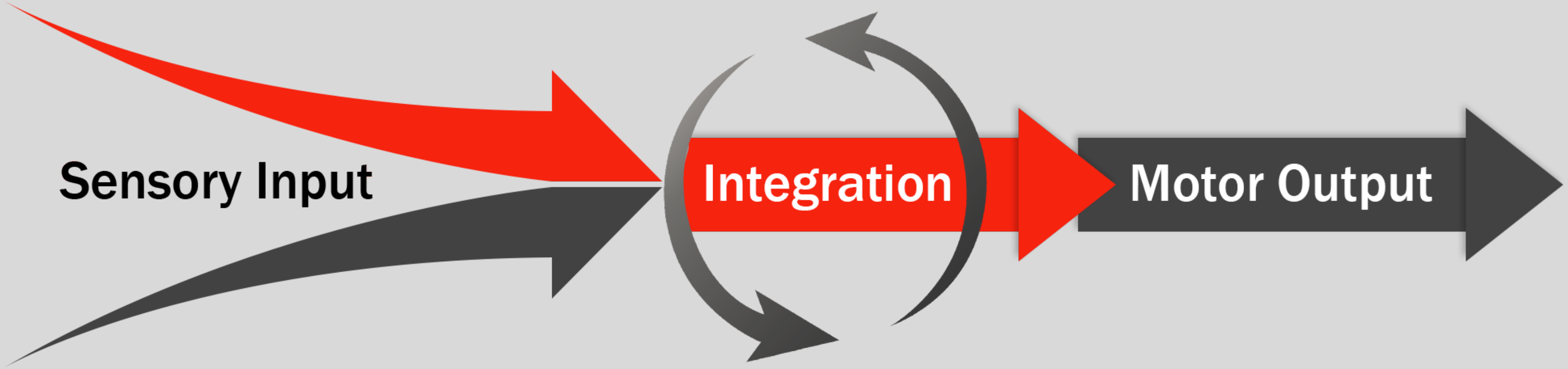
DYNAMIC POSTURAL CONTROL

Dynamic posture is person's alignment during activity

For an individual who uses a wheelchair, requires maintaining a changing **CG** over a fixed **BoS**

DYNAMIC POSTURAL CONTROL

Dynamic postural control requires integration of sensory input for motor output



DYNAMIC POSTURAL CONTROL

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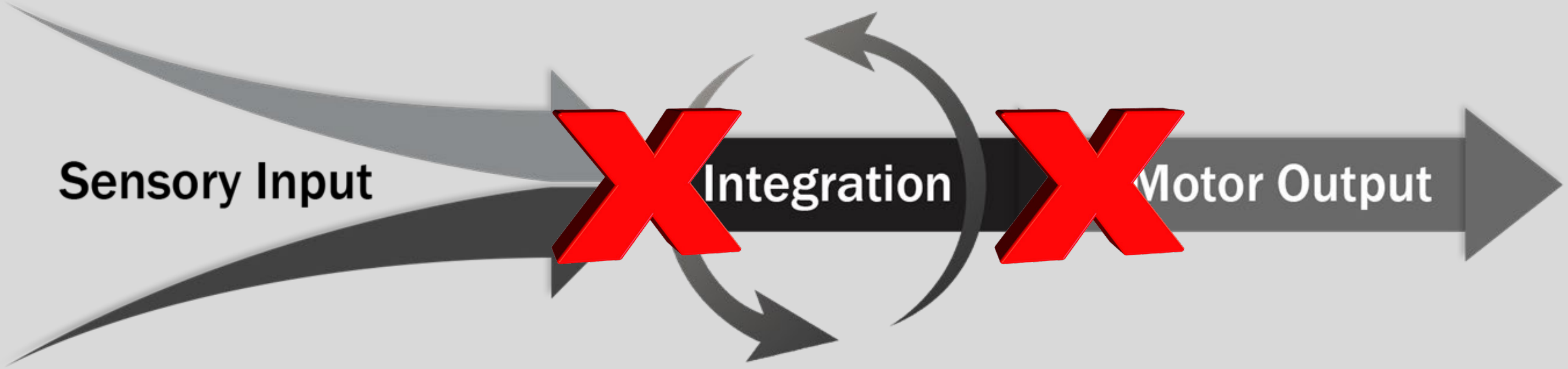

DYNAMIC POSTURAL CONTROL

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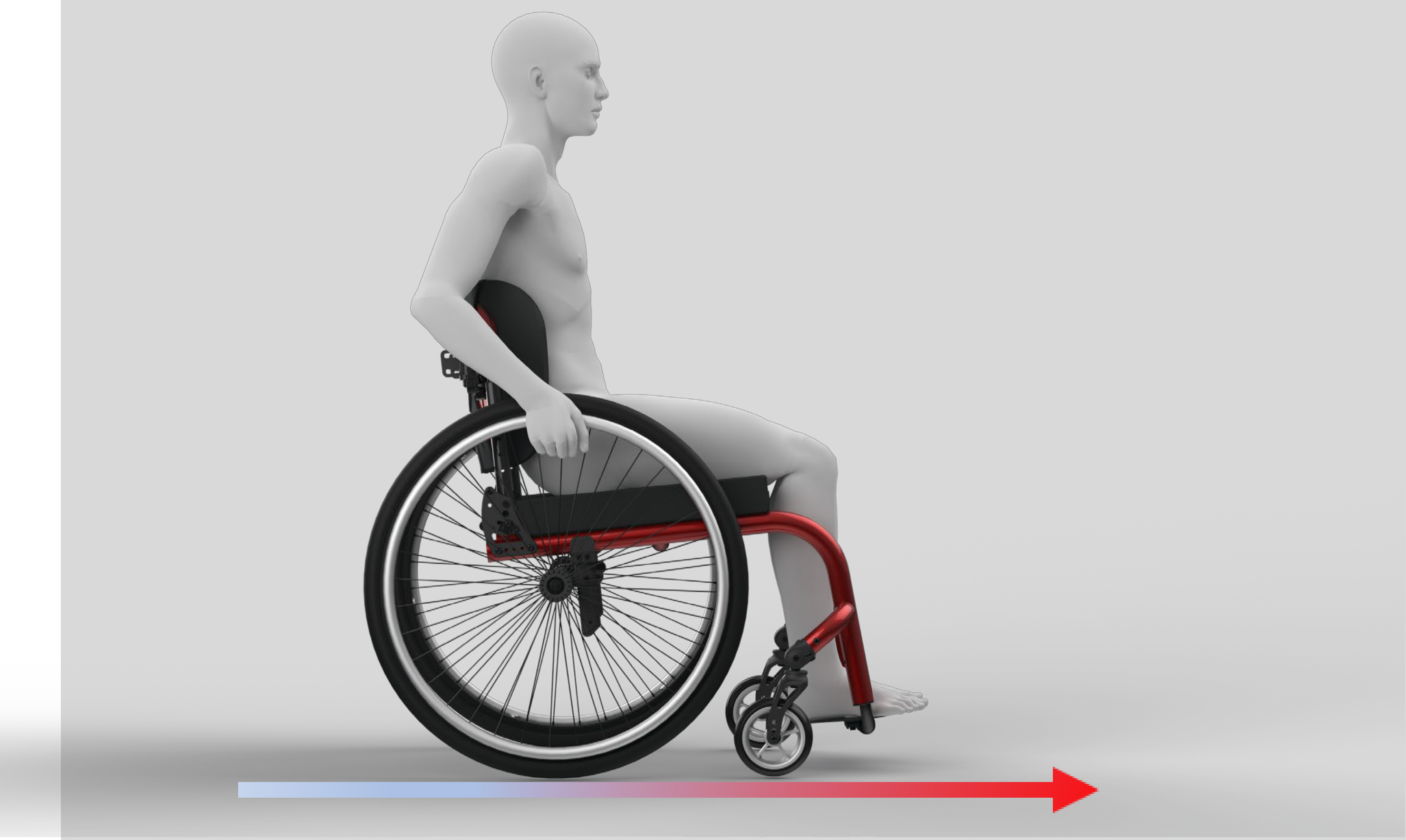
DYNAMIC POSTURAL CONTROL

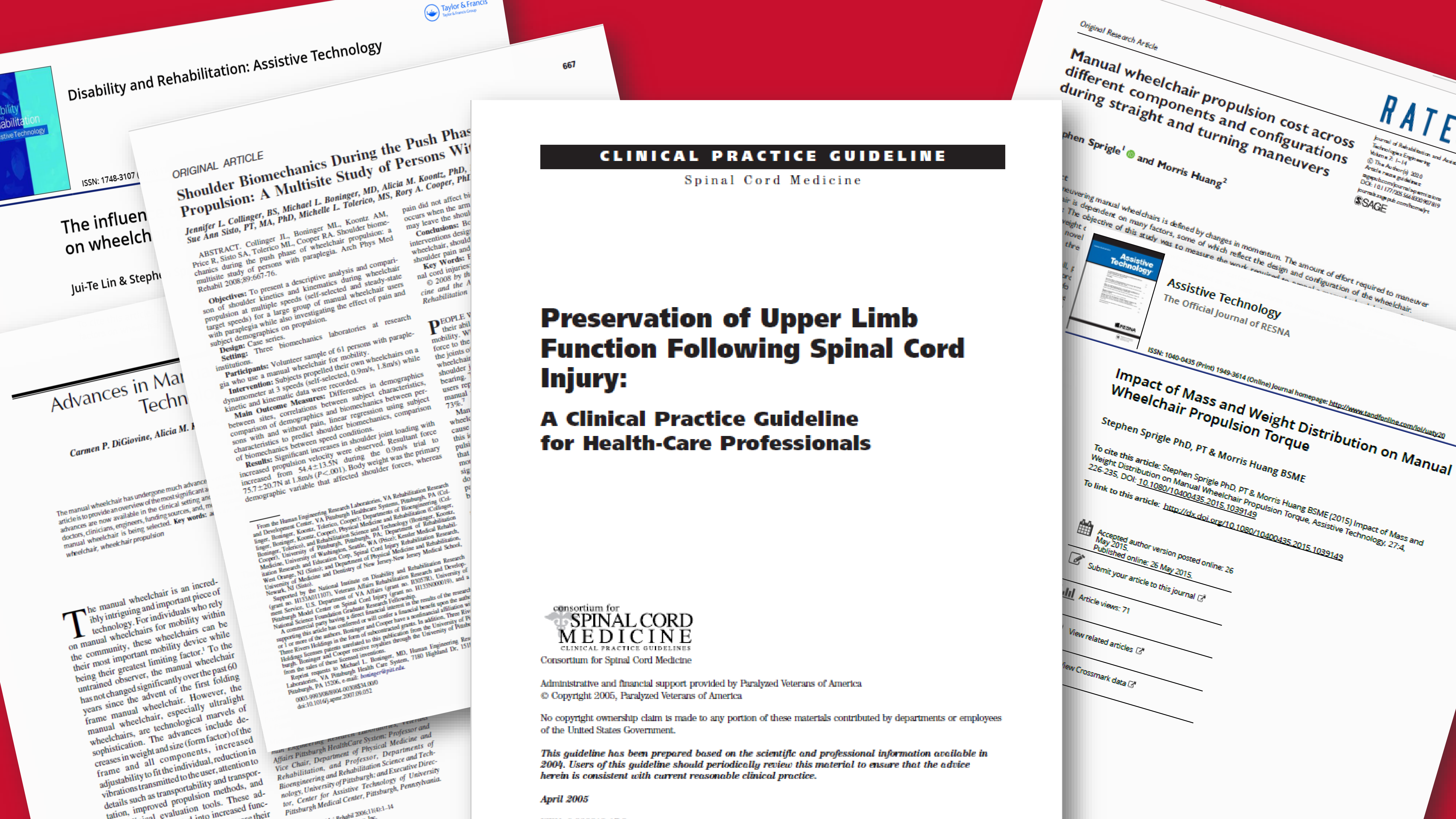
Put stability of posture to the test with dynamic functional activities

- Activities chosen by user

DYNAMIC POSTURAL CONTROL

Then we can put stability of posture to the test during propulsion




CLINICAL PRACTICE GUIDELINE
Spinal Cord Medicine
Preservation of Upper Limb Function Following Spinal Cord Injury:
A Clinical Practice Guideline for Health-Care Professionals
consortium for SPINAL CORD MEDICINE
CLINICAL PRACTICE GUIDELINES
Consortium for Spinal Cord Medicine
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This guideline has been prepared based on the scientific and professional information available in 2004. Users of this guideline should periodically review this material to ensure that the advice herein is consistent with current reasonable clinical practice.
April 2005
Disability and Rehabilitation: Assistive Technology
Taylor & Francis
ISSN: 1748-3107
ORIGINAL ARTICLE
Shoulder Biomechanics During the Push Phase of Wheelchair Propulsion: A Multisite Study of Persons With Paraplegia
Advances in Manual Wheelchair Technology
Carmen P. DiGiovine, Alicia M. Koontz
Original Research Article
Manual wheelchair propulsion cost across different components and configurations during straight and turning maneuvers
Stephen Sprigle and Morris Huang
RATE
SAGE
Assistive Technology
The Official Journal of RESNA
Impact of Mass and Weight Distribution on Manual Wheelchair Propulsion Torque
Stephen Sprigle PhD, PT & Morris Huang BSME

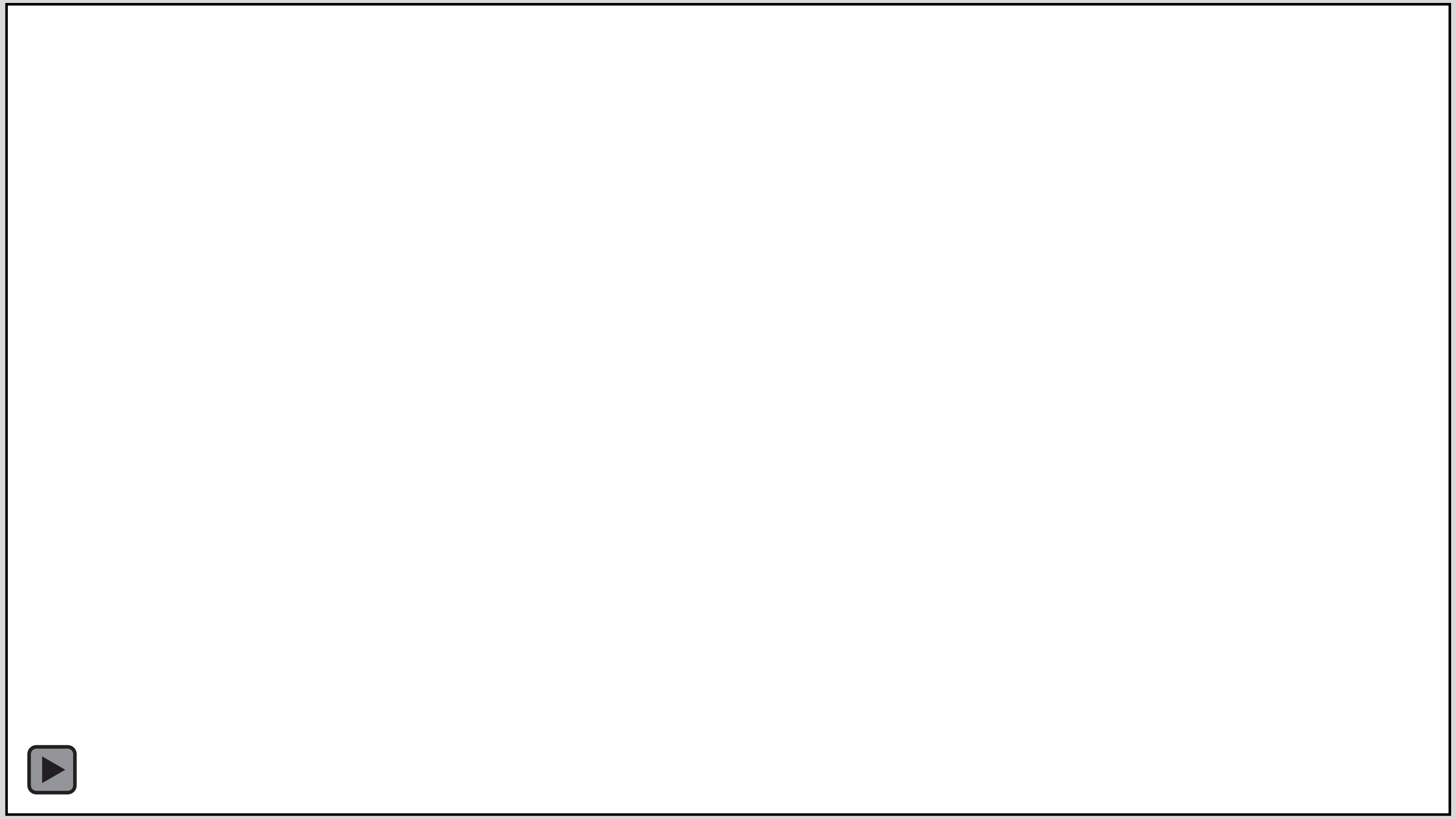
Setup Factors

SEAT HEIGHT
SEAT ANGLE
BACK ANGLE
FRONT FRAME ANGLE
BACK HEIGHT
VERTICAL AXLE POSITION
HORIZONTAL AXLE POSITION

AXLE POSITION IN HORIZONTAL PLANE

Influences two important aspects of wheelchair mobility

- Stability
- Propulsion efficiency

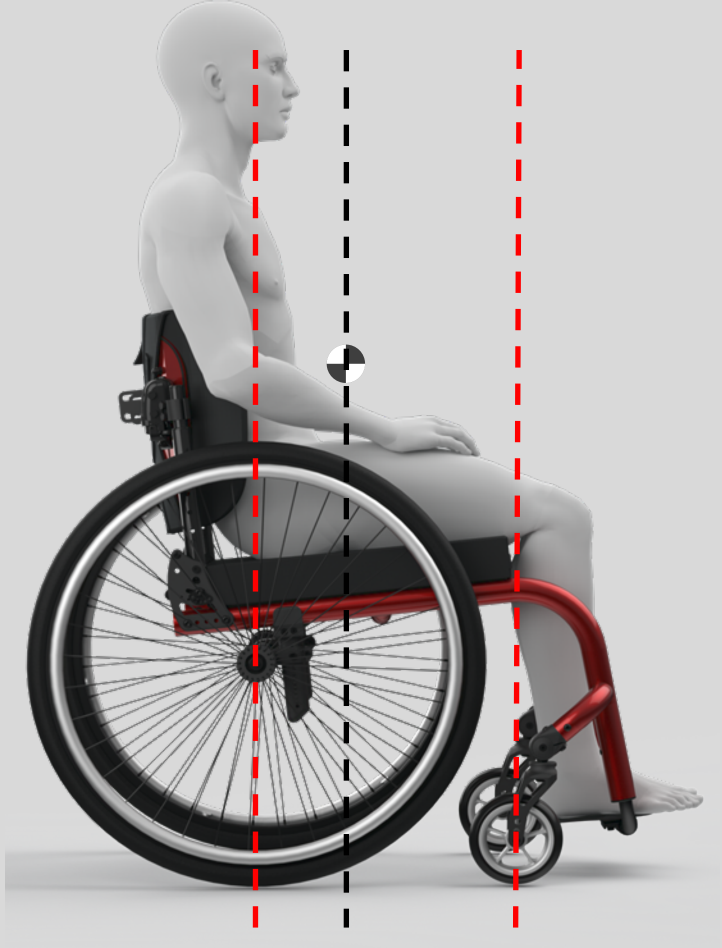


(Medola, 2014)

AXLE POSITION IN HORIZONTAL PLANE

Center of Gravity (CG) Location vs. Mass Distribution

CG Location in Wheelbase



AXLE POSITION IN HORIZONTAL PLANE

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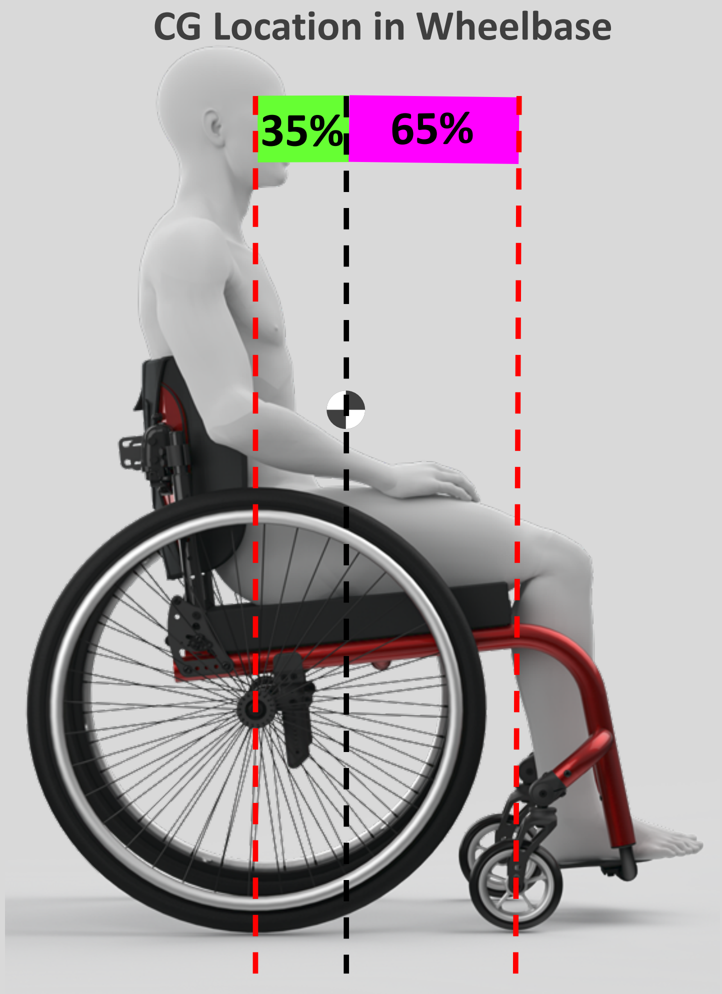

AXLE POSITION IN HORIZONTAL PLANE

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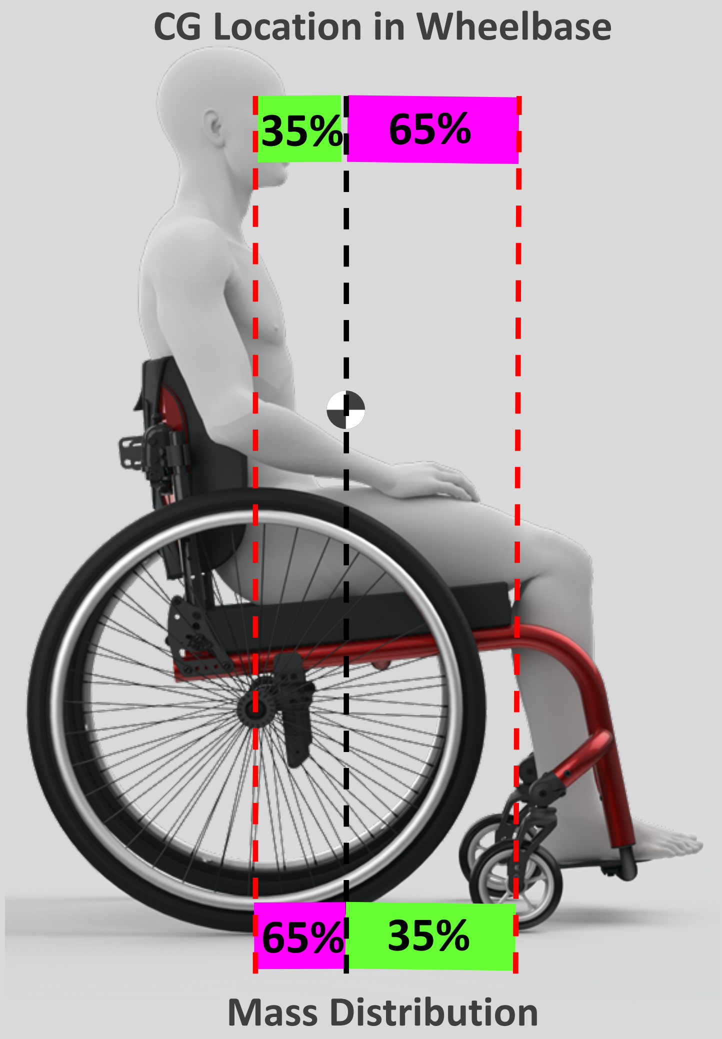
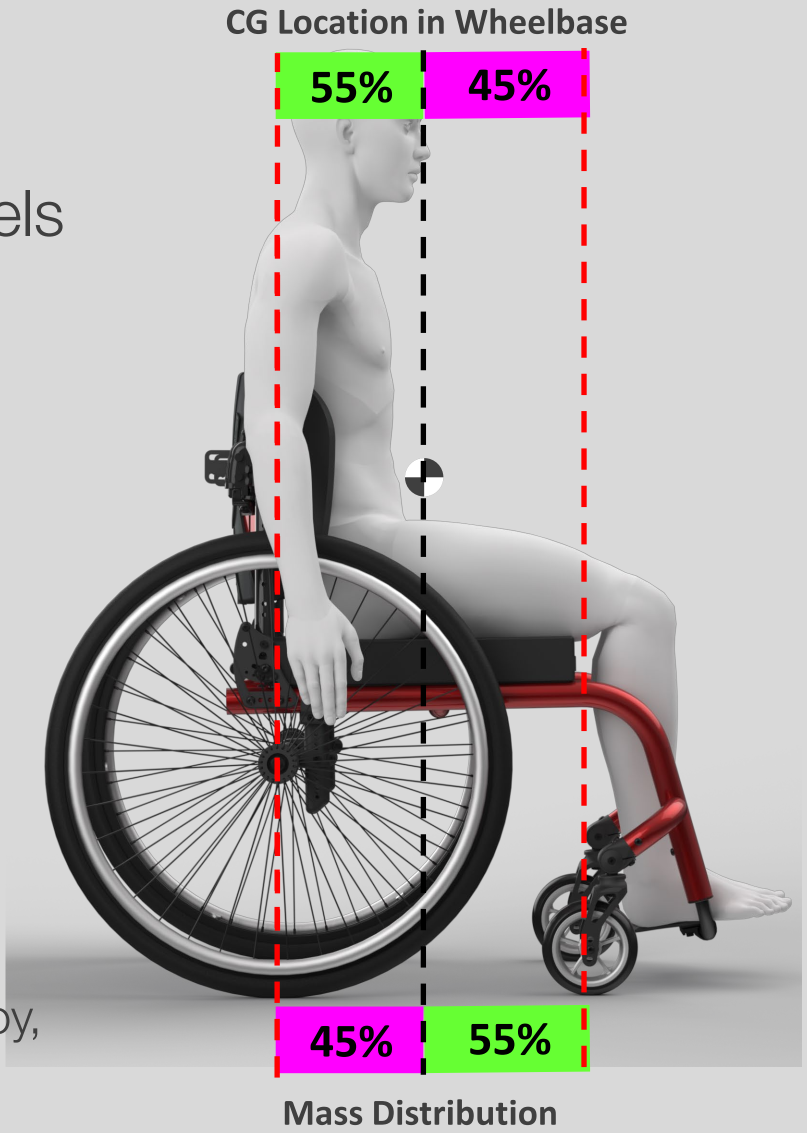


AXLE POSITION IN HORIZONTAL PLANE

More rearward drive wheel position

- Decreases system mass over drive wheels
- Improves rearward chair stability
- Increases rolling resistance
- Decreases user access to drive wheel

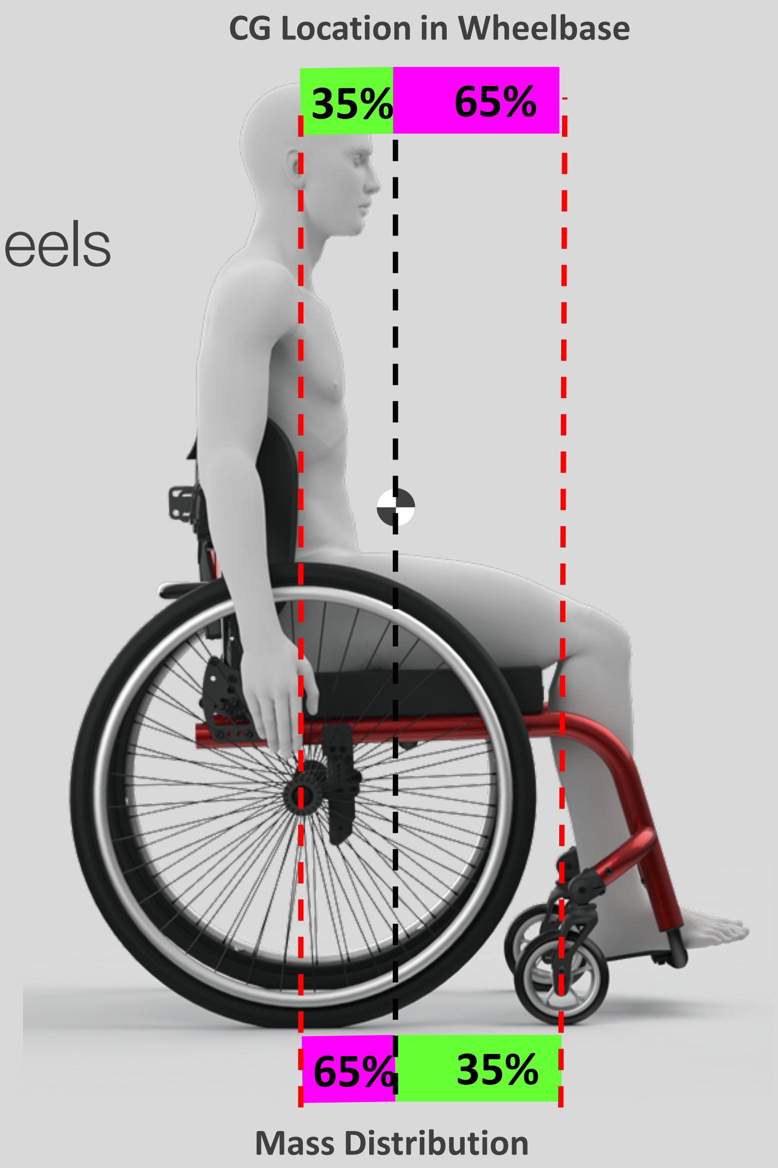


(Gorce, 2012, Boninger, 2005, Freixes, 2010, PVA, 2007, Mulroy, 2005, Brubaker, 1986, Slowik et al., 2013)

AXLE POSITION IN HORIZONTAL PLANE

More forward drive wheel position

- Increases system mass over the drive wheels
- Decreases rearward chair stability
- Decreasing rolling resistance
- Increases user access to drive wheel



AXLE POSITION IN HORIZONTAL PLANE

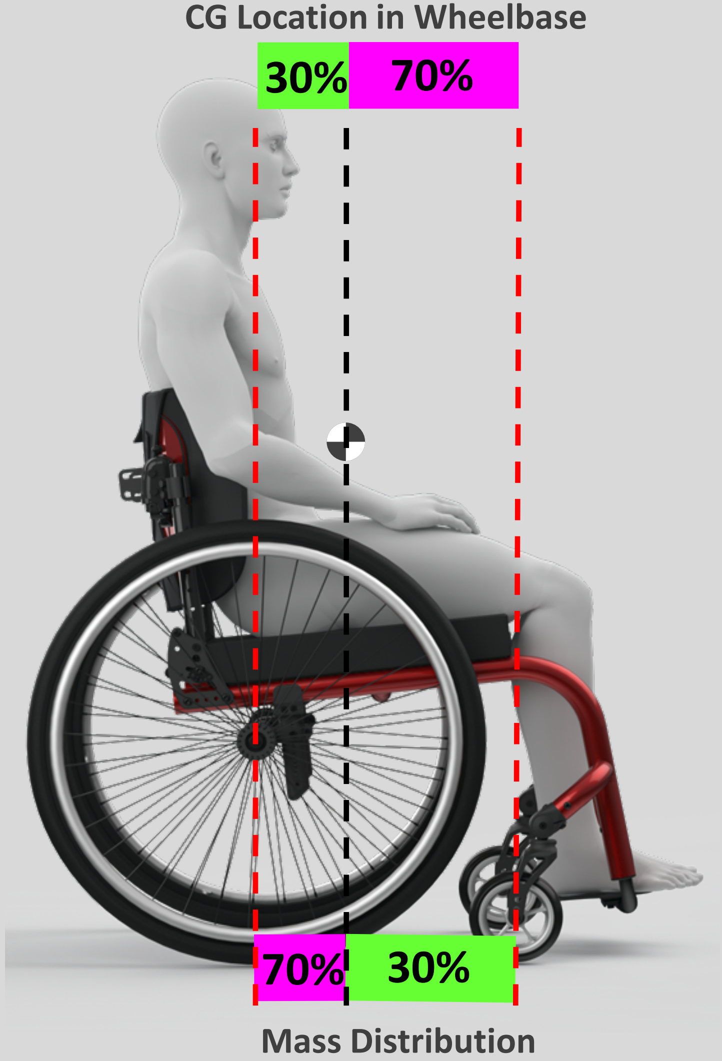
May need to prioritize stability for some users

AXLE POSITION IN HORIZONTAL PLANE

For others, you may need to prioritize agility concurrent with their skill level

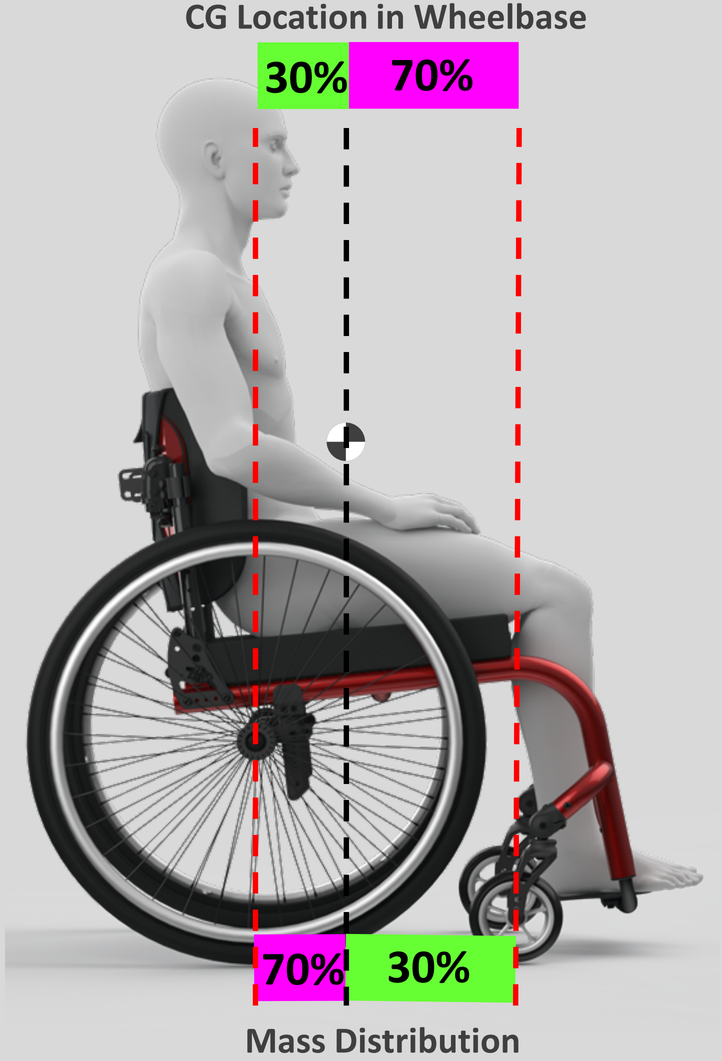
AXLE POSITION IN HORIZONTAL PLANE

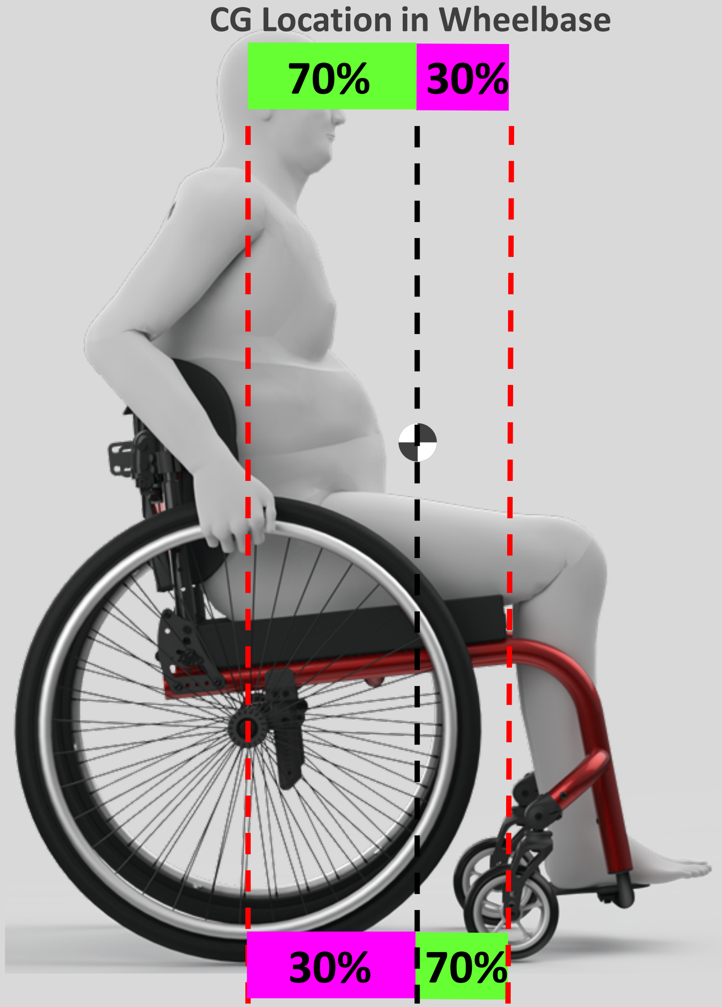
CG is impacted by physical characteristics



AXLE POSITION IN HORIZONTAL PLANE

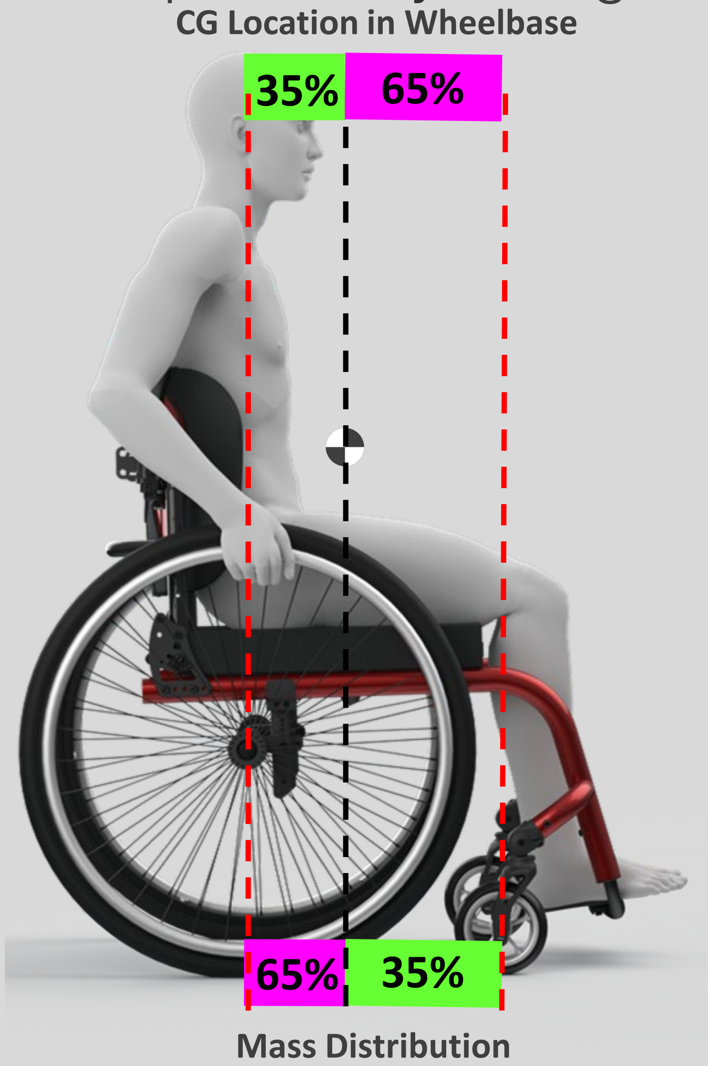
CG is impacted by physical characteristics





AXLE POSITION IN HORIZONTAL PLANE

CG can be impacted by changes in posture resulting from changes to the chair



AXLE POSITION IN HORIZONTAL PLANE

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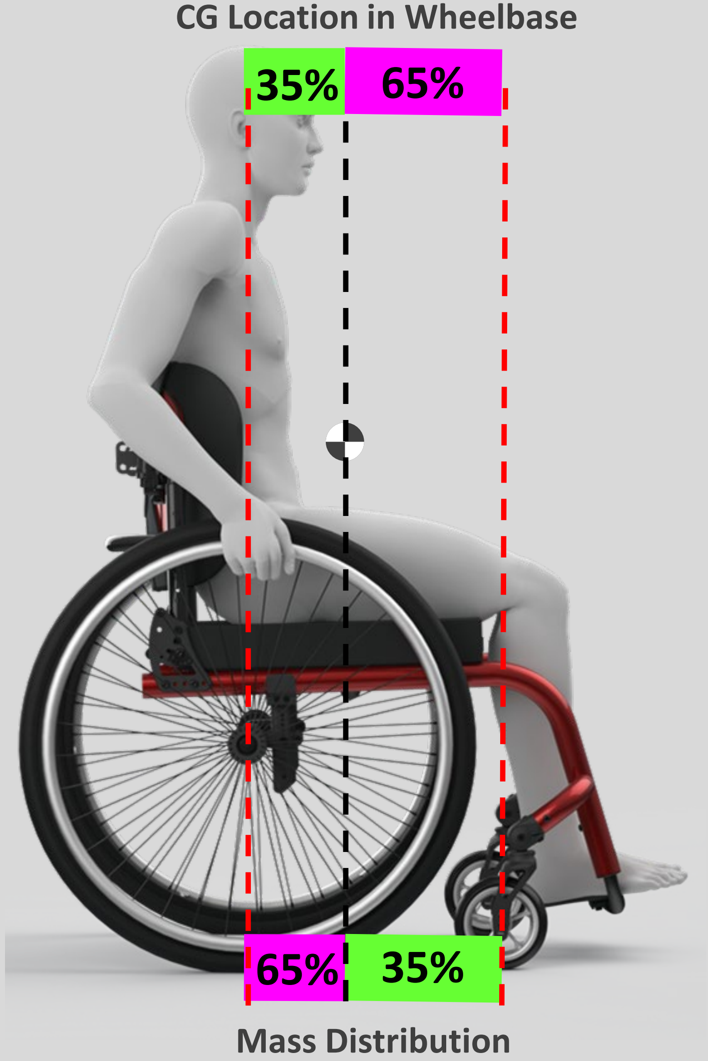
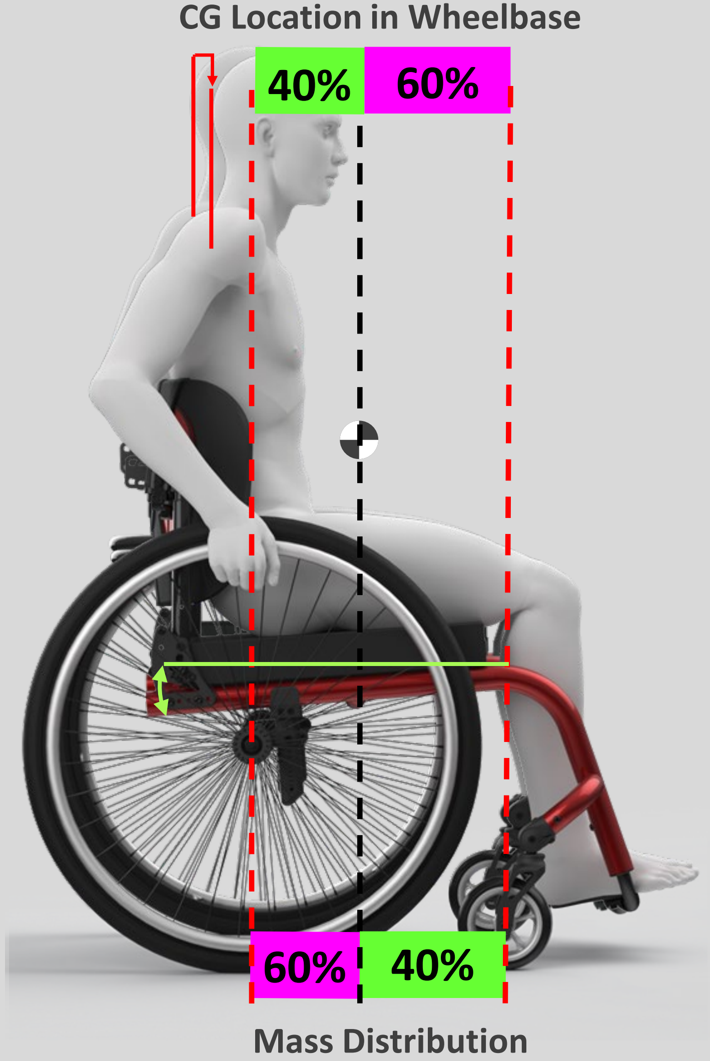
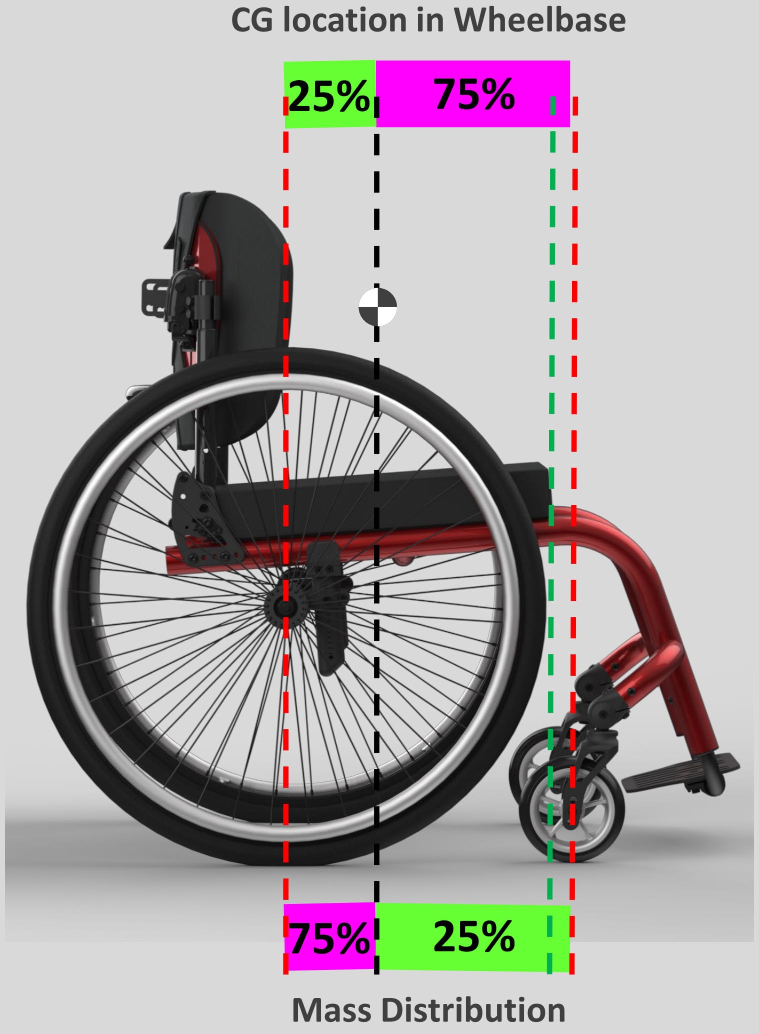




AXLE POSITION IN HORIZONTAL PLANE

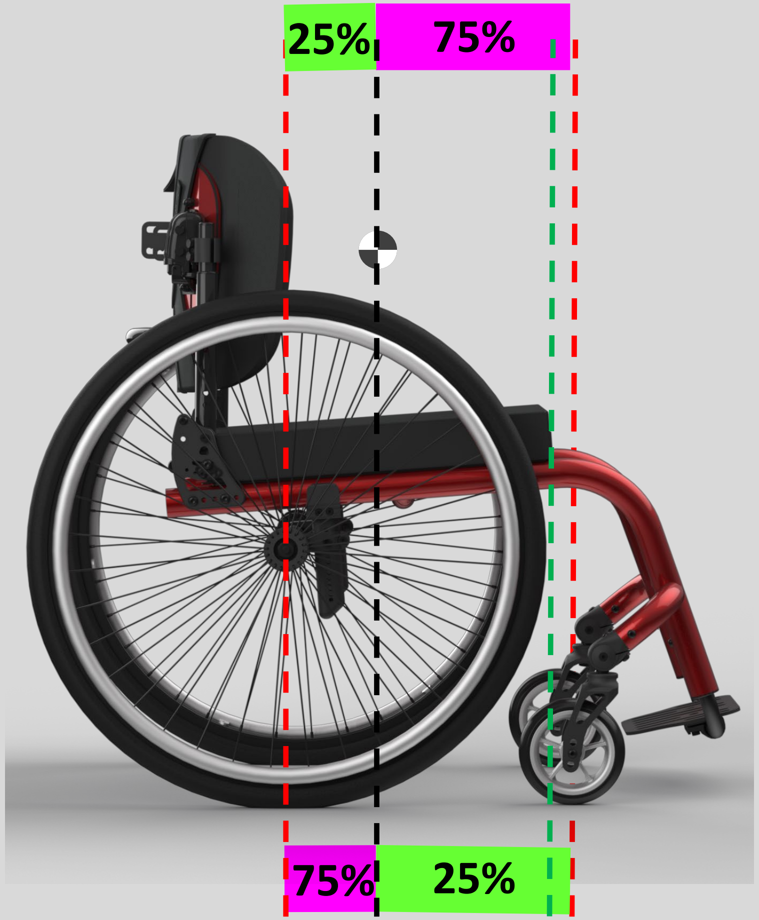
CG can be impacted by frame length



AXLE POSITION IN HORIZONTAL PLANE

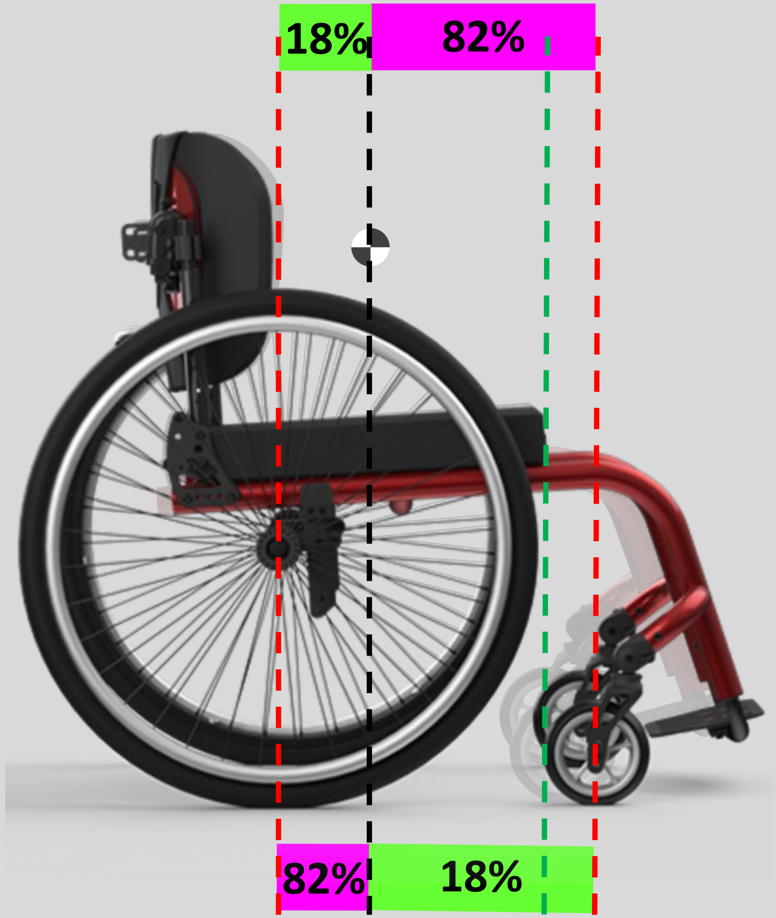
CG can be impacted by frame length

CG location in Wheelbase



Mass Distribution

CG location in Wheelbase



Mass Distribution

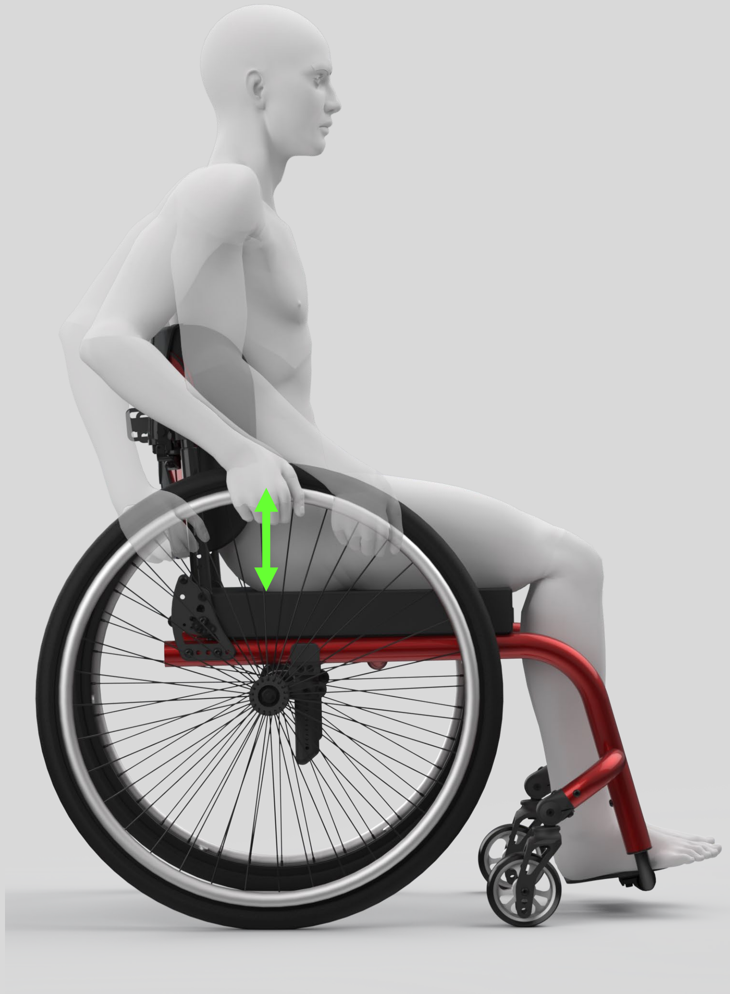
AXLE POSITION IN VERTICAL PLANE

Vertical axle position impacts

- Stability
- Propulsion efficiency

AXLE POSITION IN VERTICAL PLANE

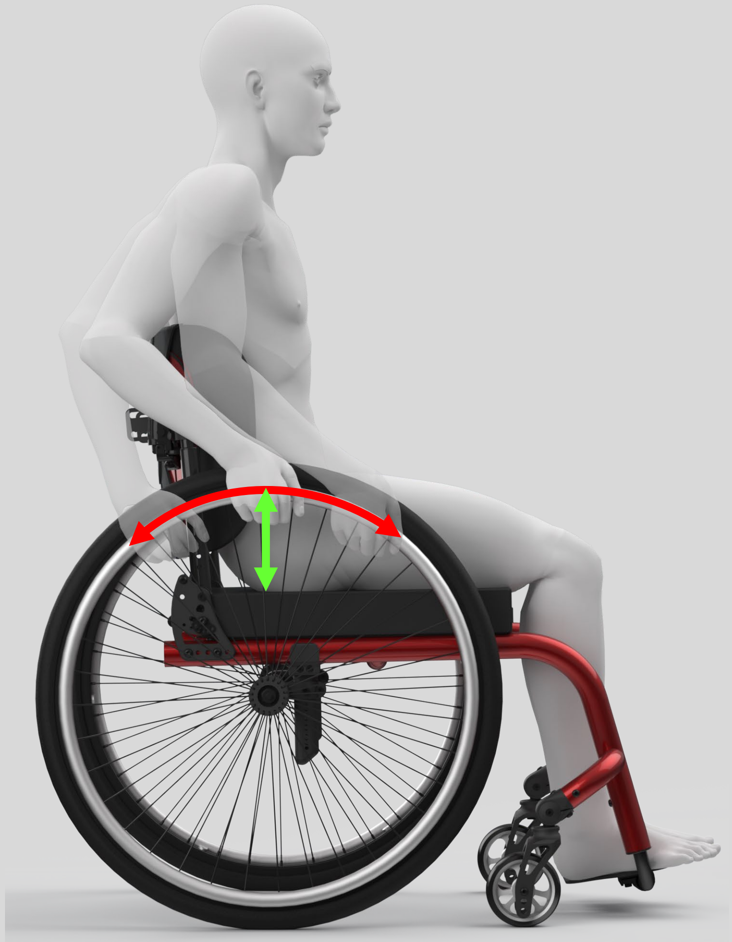
Rear seat height relative to the drive wheel



AXLE POSITION IN VERTICAL PLANE

Rear seat height relative to the drive wheel

- Determines available wheel arc for propulsion

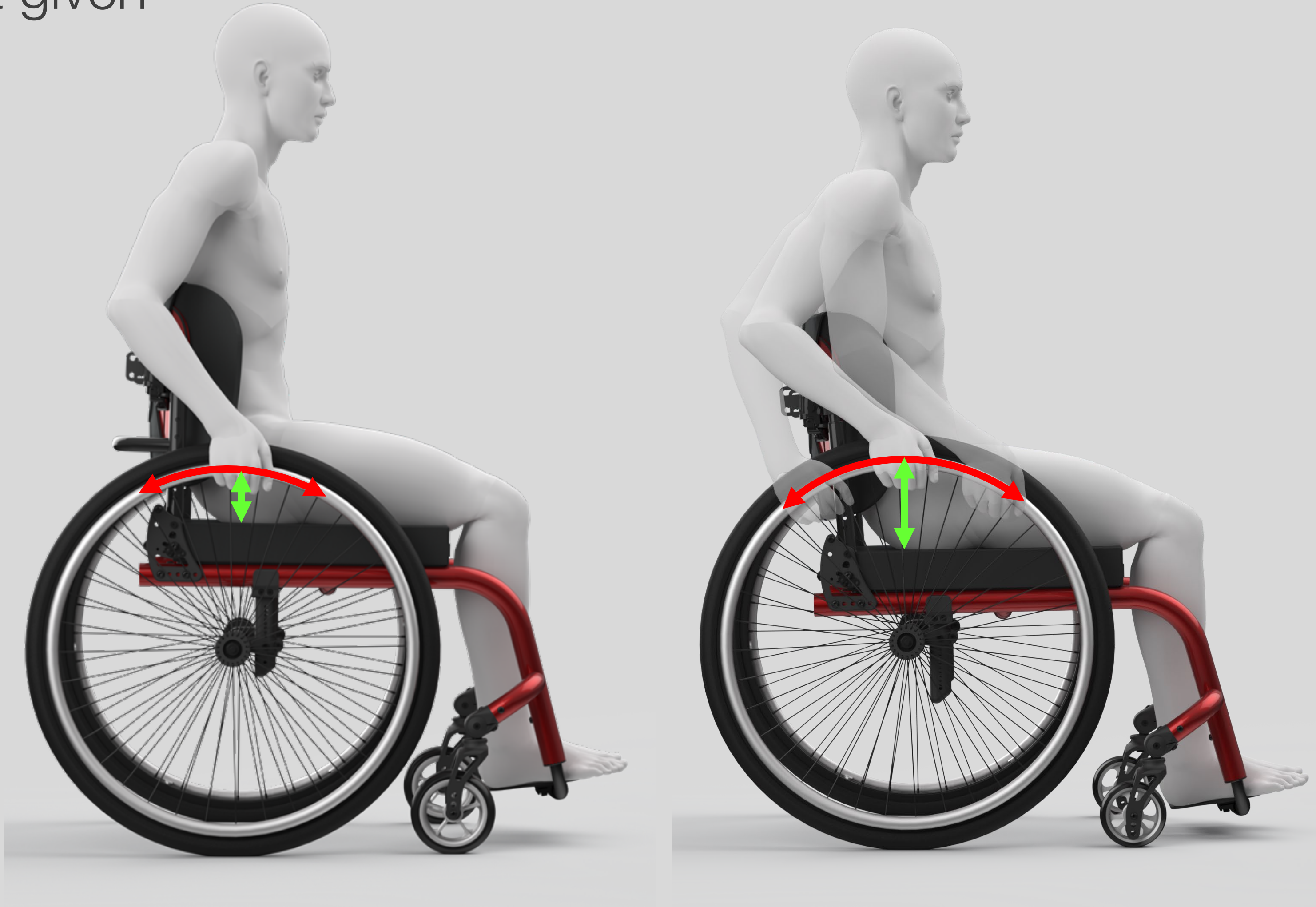


(Van der Woude, et al., 1989)

AXLE POSITION IN VERTICAL PLANE

Higher seat heights for a given wheel diameter

- Reduces available wheel arc



(Van der Woude, et al., 1989)

AXLE POSITION IN VERTICAL PLANE

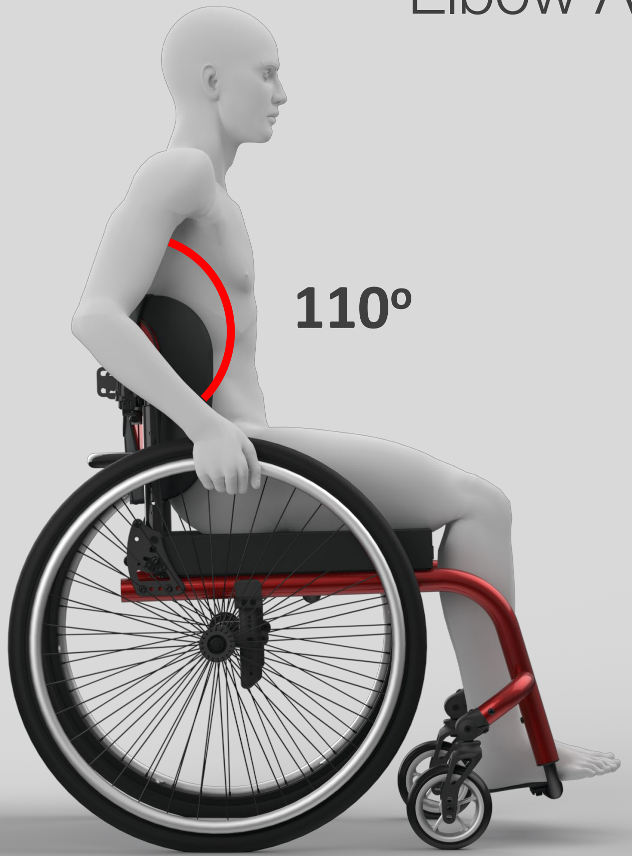
Higher seat heights for a given wheel diameter

- Shown to increase push frequency
- Increased potential for muscular fatigue

(Boninger, et al., 2000 & Boninger, et al., 2005)

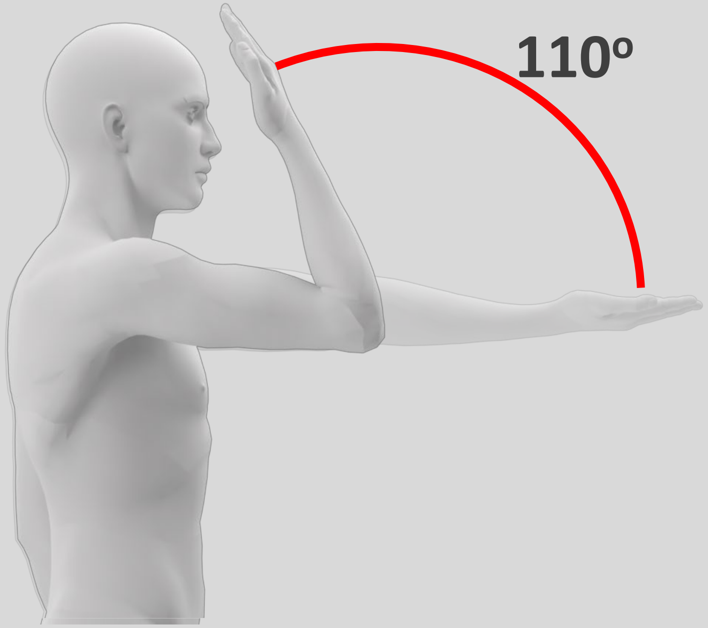
AXLE POSITION IN VERTICAL PLANE

Elbow Angle VS Elbow Flexion Angle



Elbow ANGLE

As opposed to



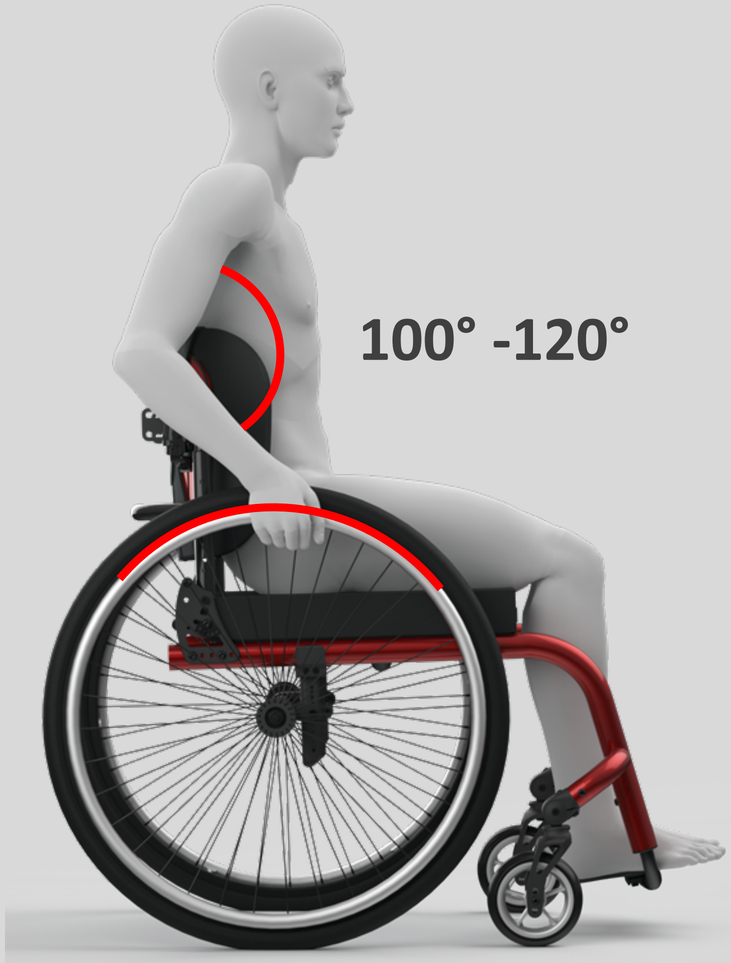
Elbow FLEXION

AXLE POSITION IN VERTICAL PLANE

100-120 degrees of elbow angle when hand is at top of handrim (12 o'clock)

- Maximizes user access to handrim throughout push stroke
- Places shoulder and elbow in most mechanically advantageous positions
- Protects the upper extremity by eliminating harmful ranges for shoulder and elbow

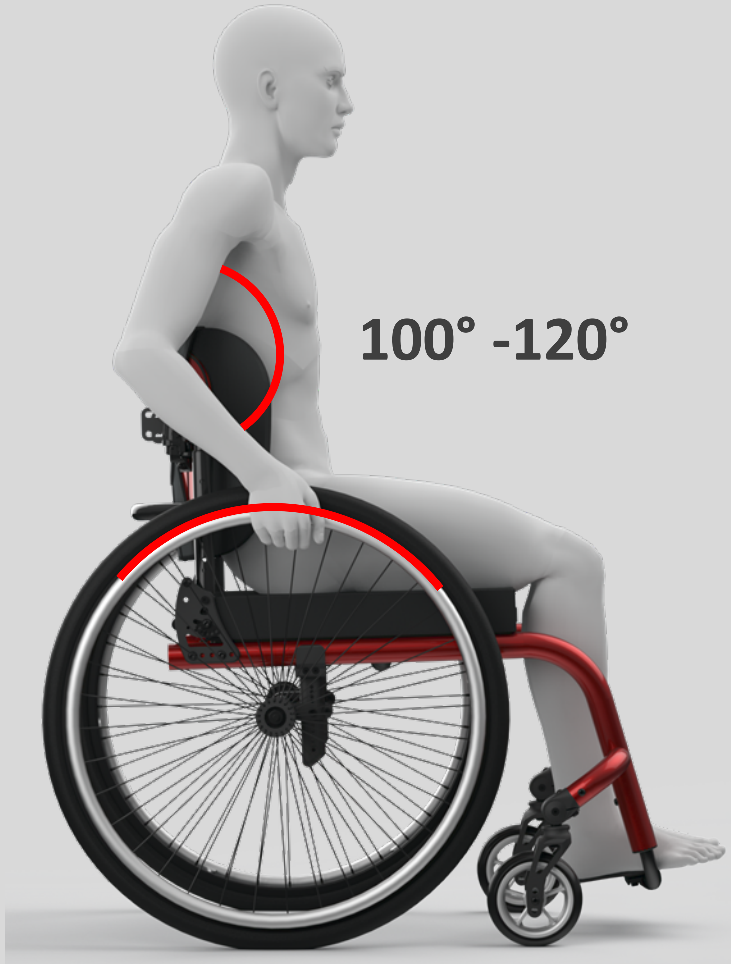
(Van der Woude, et al., 2009, Van Der Woude, et al., 1990, Mejis, et al., 1989)



AXLE POSITION IN VERTICAL PLANE

100-120 degrees of elbow angle when hand is at top of handrim (12 o'clock)

- Associated with improved propulsion efficiency
- Associated with decreased energy expenditure

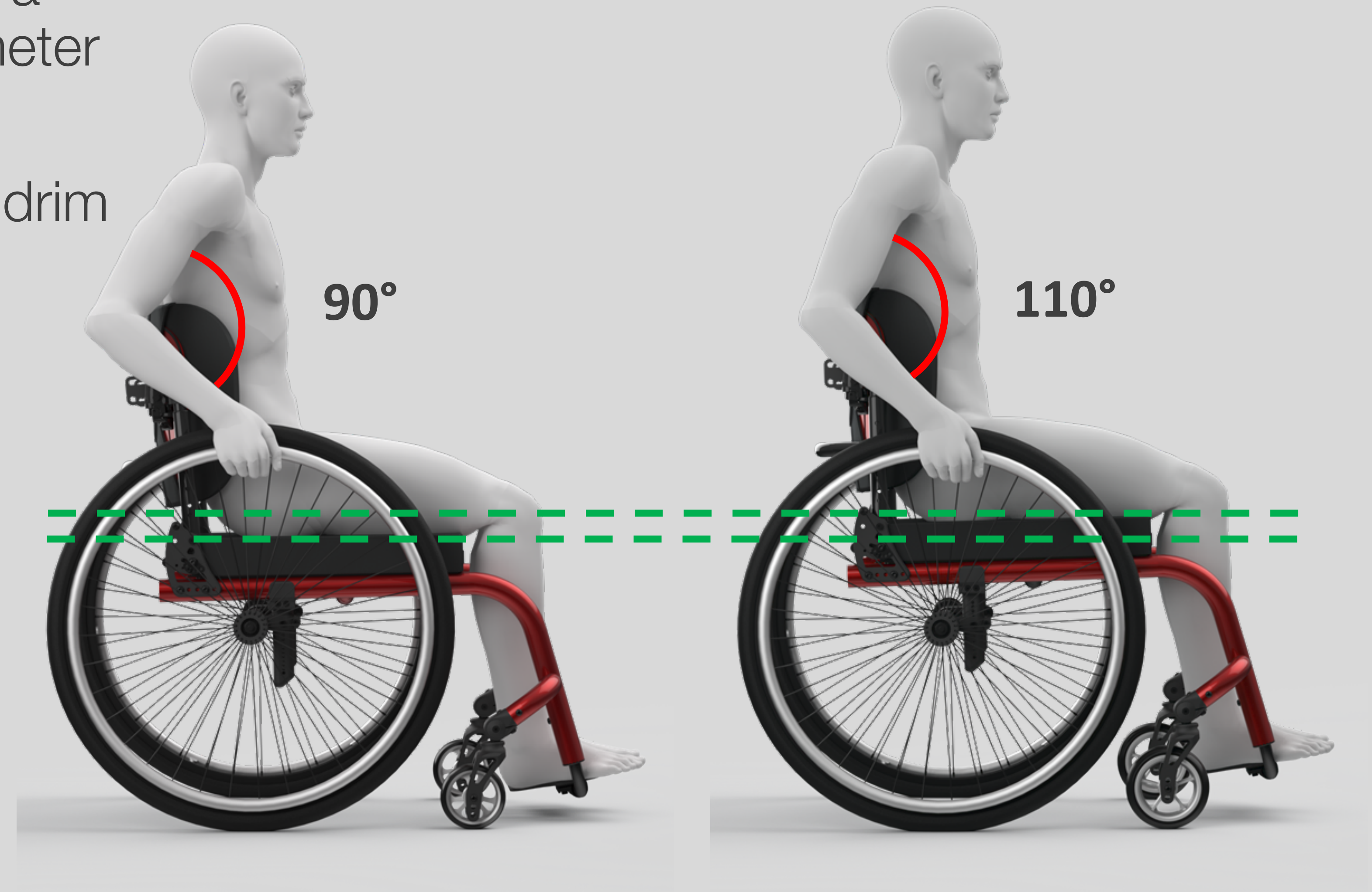


(Van der Woude, et al., 2009, Van Der Woude, et al., 1990, Mejis, et al., 1989)

AXLE POSITION IN VERTICAL PLANE

Lower seat heights for a given drive wheel diameter

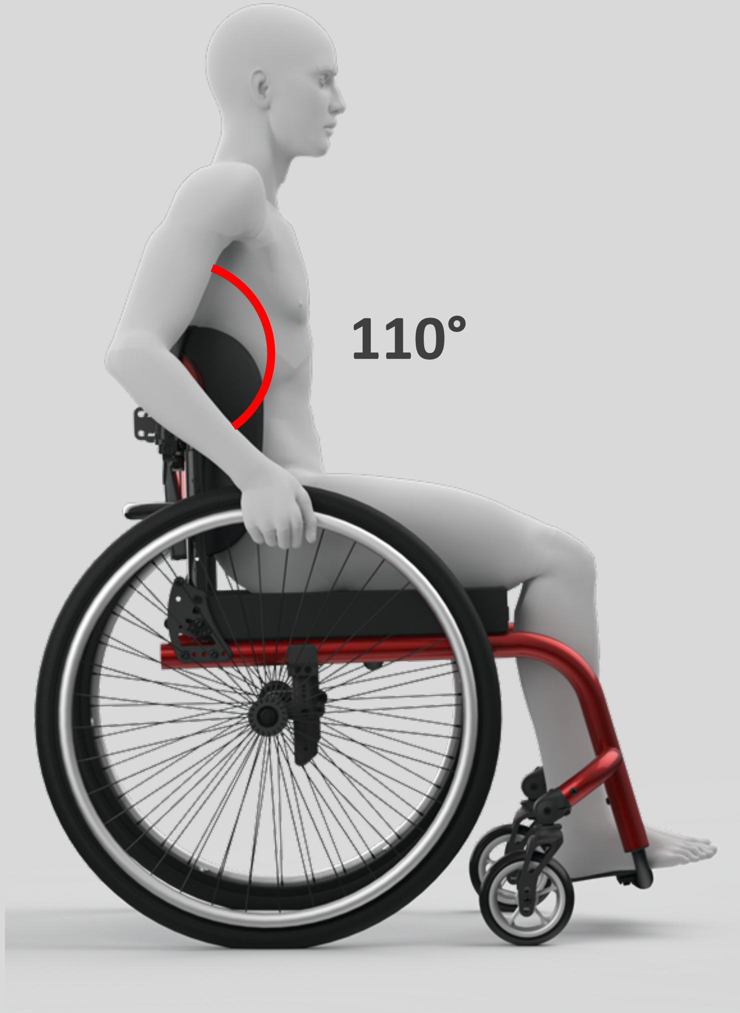
- Less efficient handrim forces
- Less efficient cardiorespiratory parameters



(Van der Woude, et al., 2009)

AXLE POSITION IN VERTICAL PLANE

Vertical axle placement can be impacted by seat cushion height



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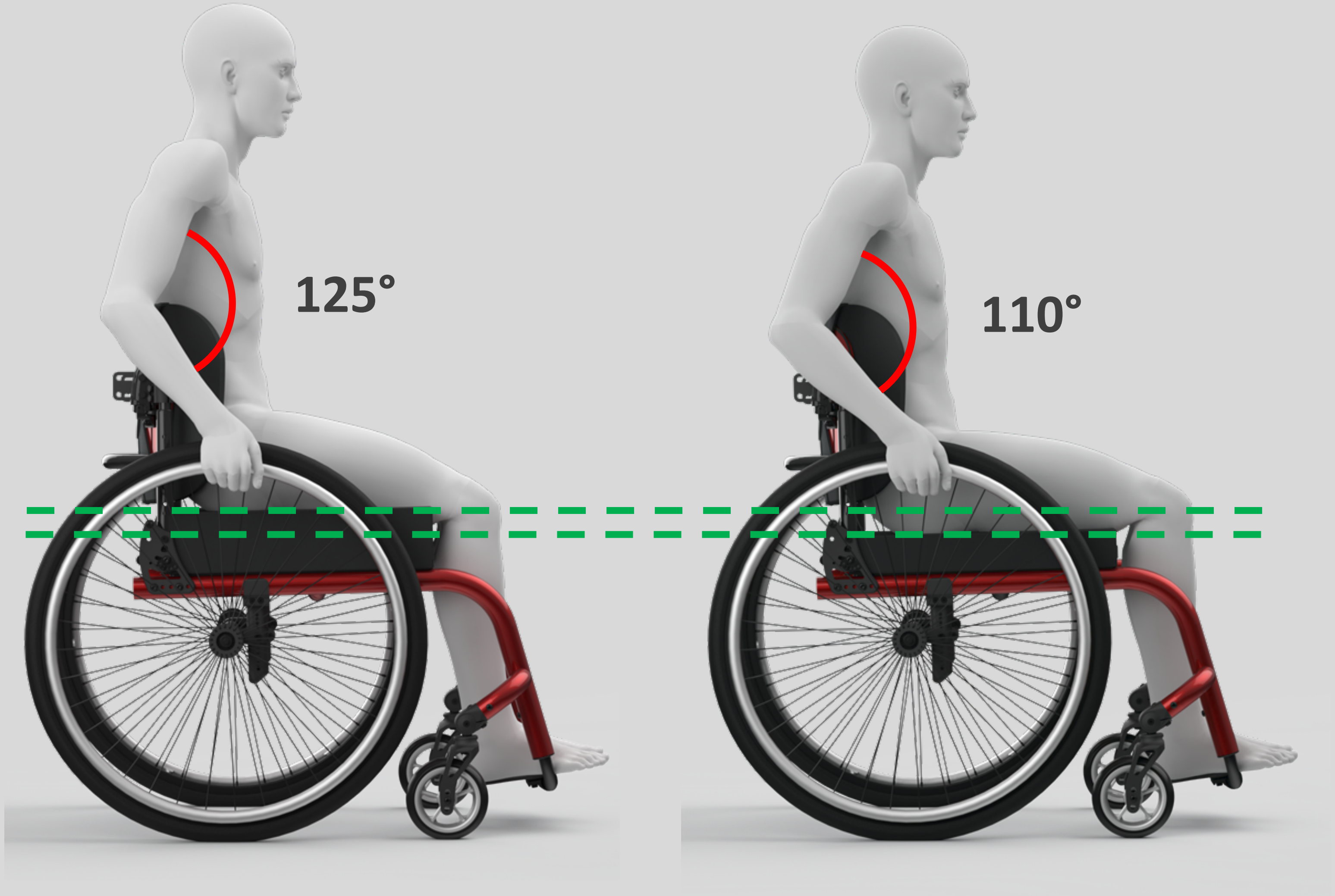
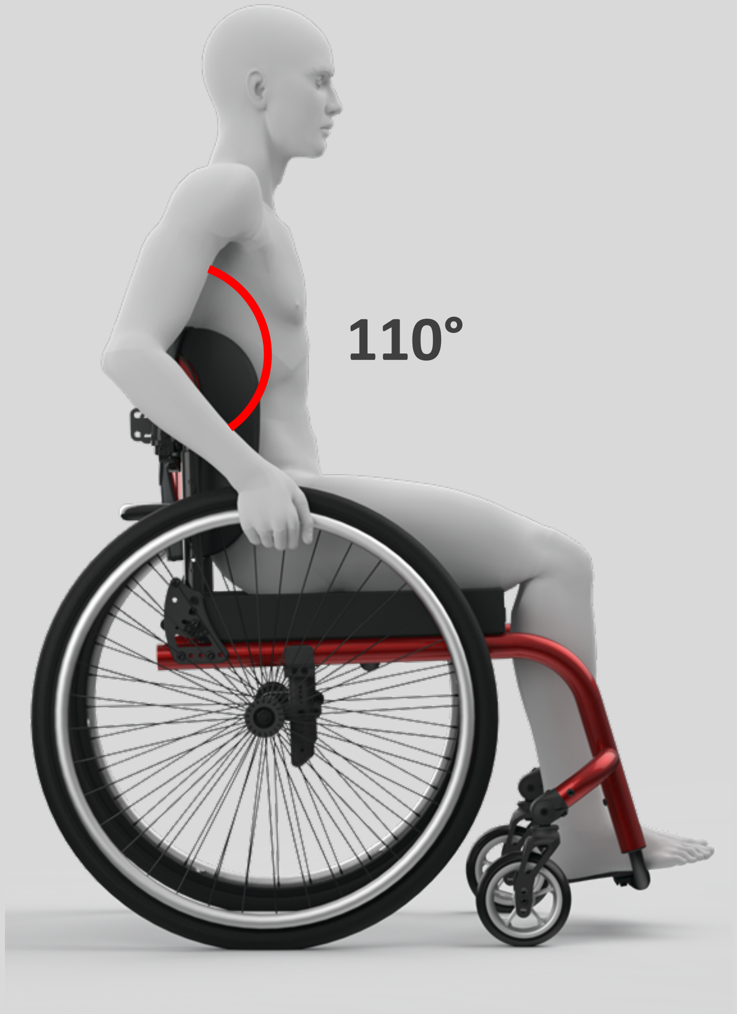


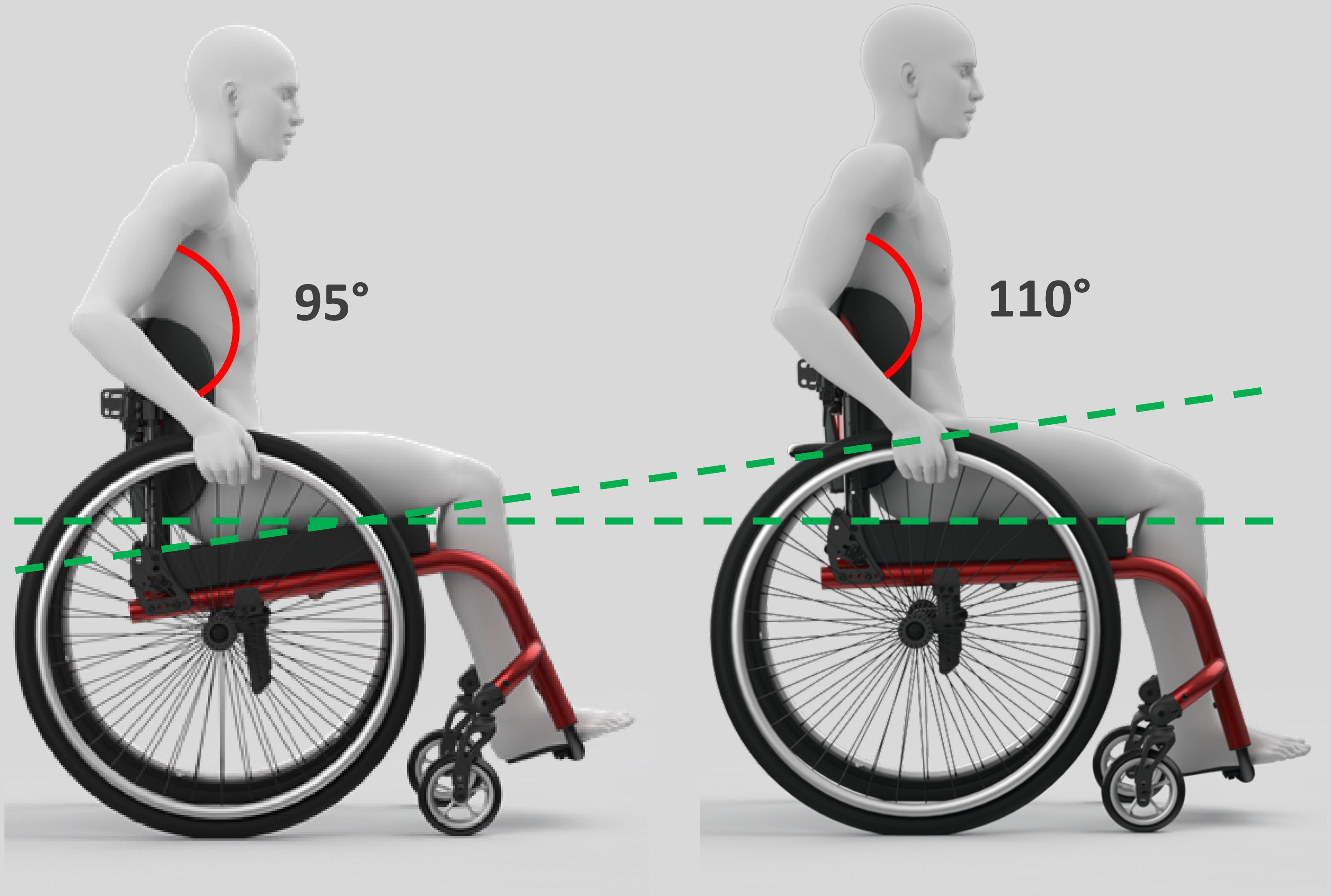
AXLE POSITION IN VERTICAL PLANE

Vertical axle placement can be impacted by the need for seat slope



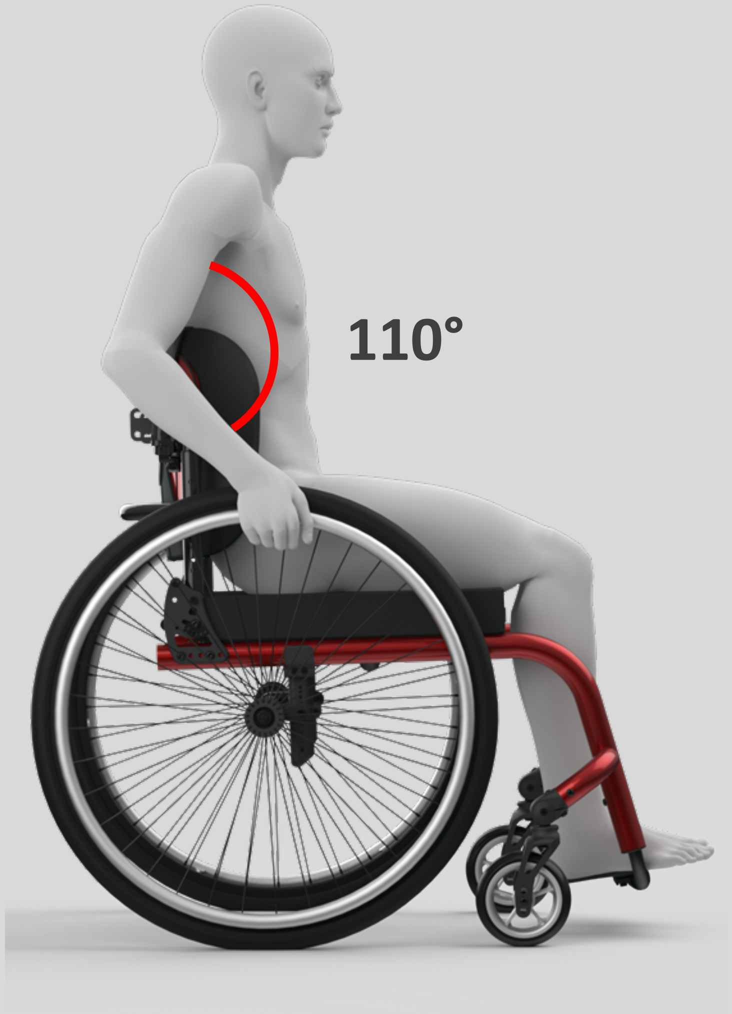
AXLE POSITION IN VERTICAL PLANE

Vertical axle placement can be impacted by the need for seat slope



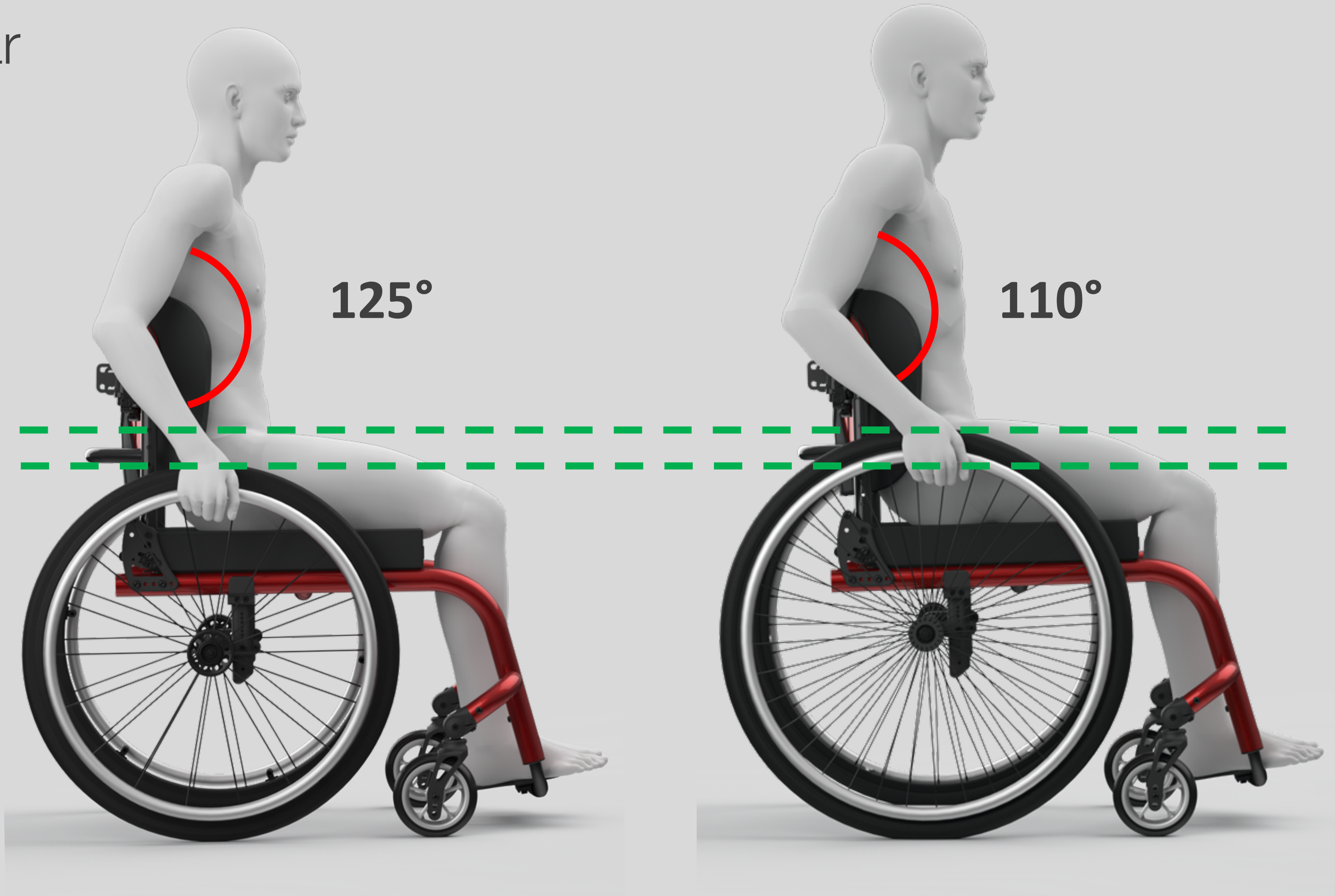
AXLE POSITION IN VERTICAL PLANE

Vertical axle placement can be impacted by rear wheel diameter



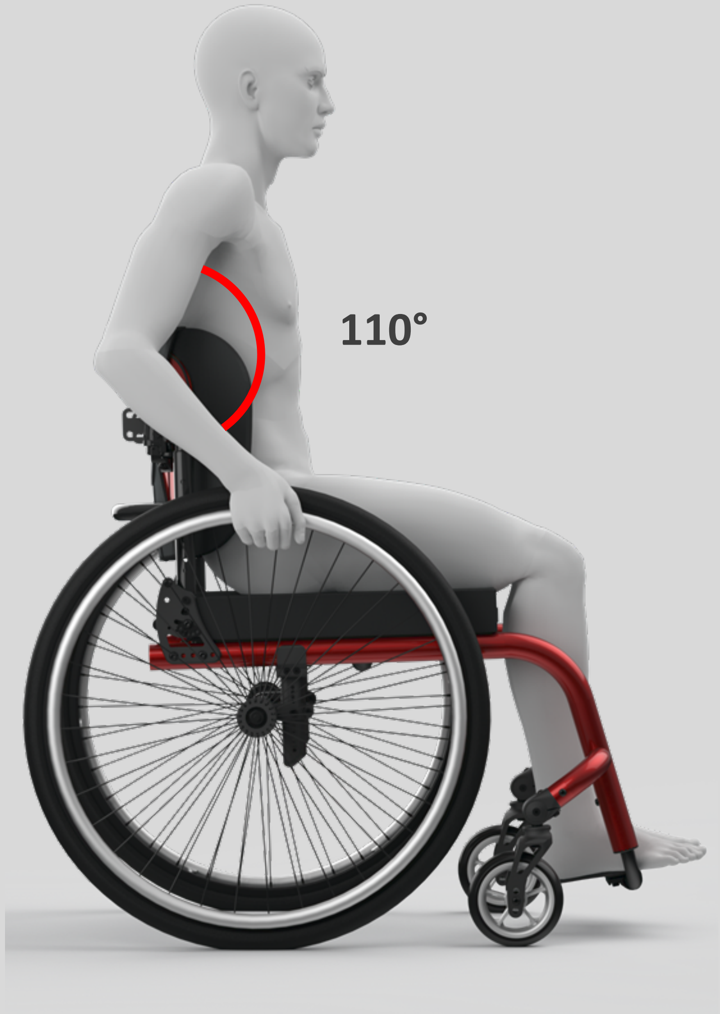
AXLE POSITION IN VERTICAL PLANE

Vertical axle placement can be impacted by rear wheel diameter



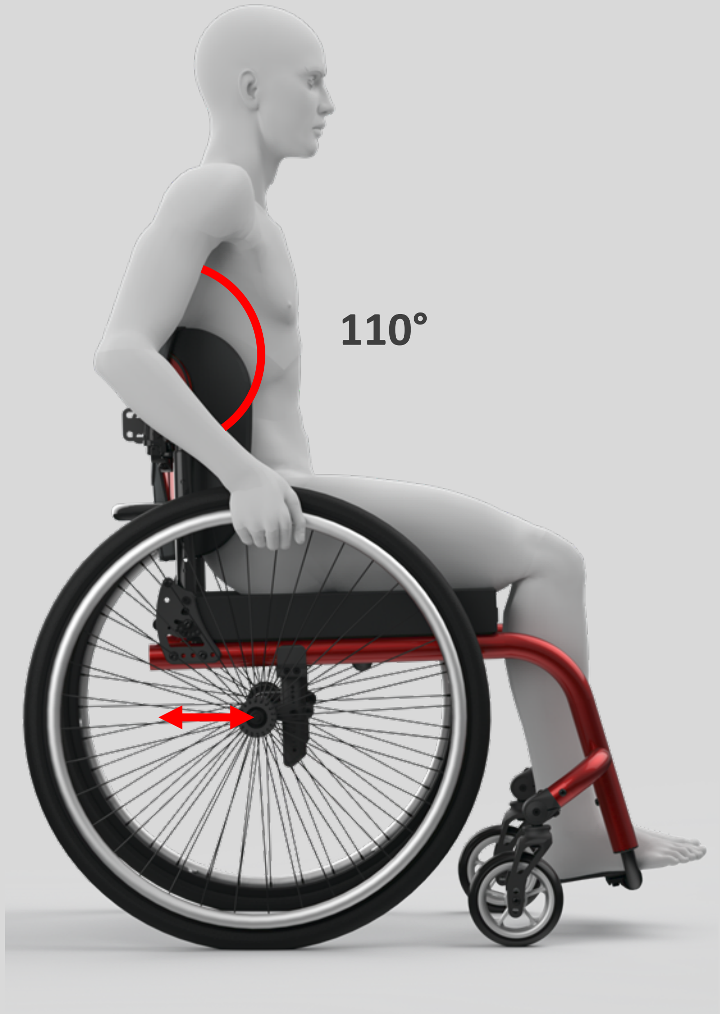
AXLE POSITION IN VERTICAL PLANE

Elbow angle can be affected by other set up choices



AXLE POSITION IN VERTICAL PLANE

Horizontal axle placement can impact elbow angle



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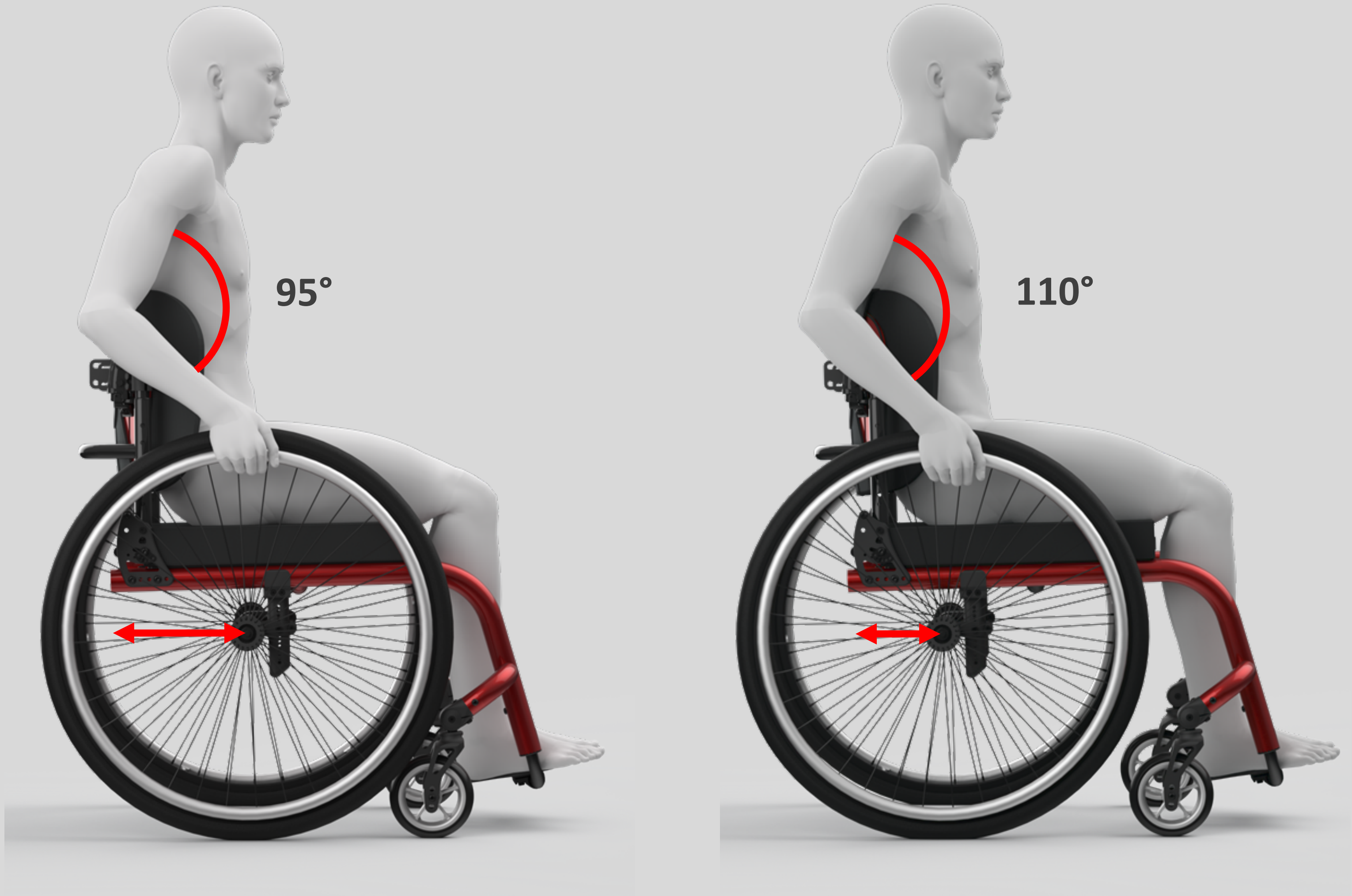
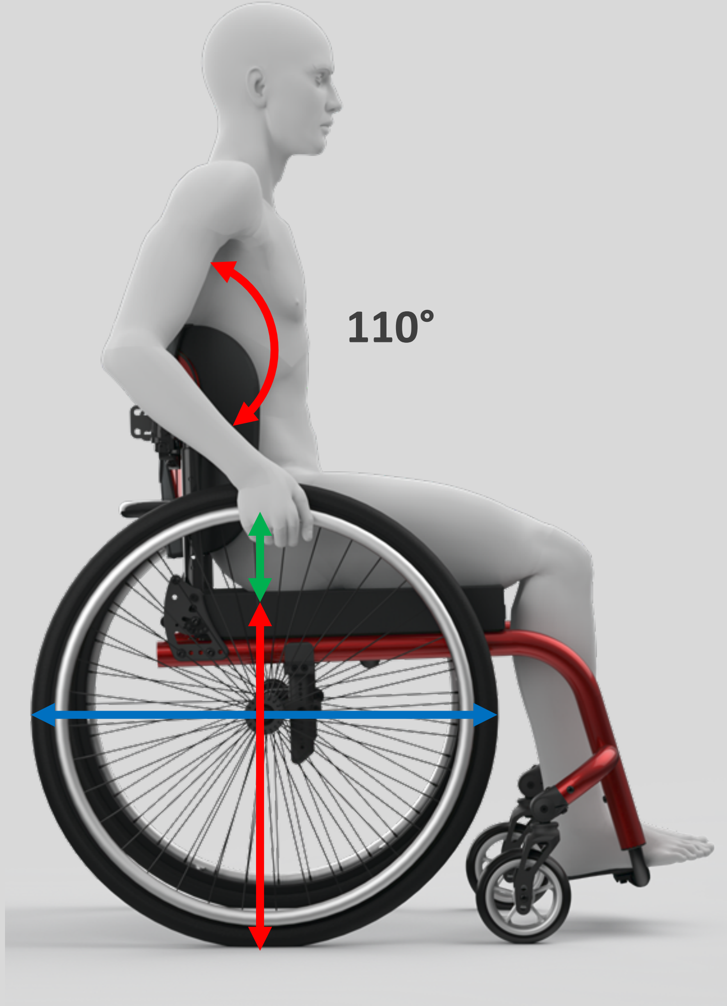


AXLE POSITION IN VERTICAL PLANE

Formula for Wheel Size

- Measurements needed:
  - Seat to Palm (SP)
    - measured in the desired seated posture
    - with an elbow angle of 110°
  - Rear Seat Height (RSH)
  - Wheel Diameter (WD)

SP + RSH = WD



SEAT ANGLE

Often thought of as the difference between Front Seat Height and Rear Seat Height or “Dump”

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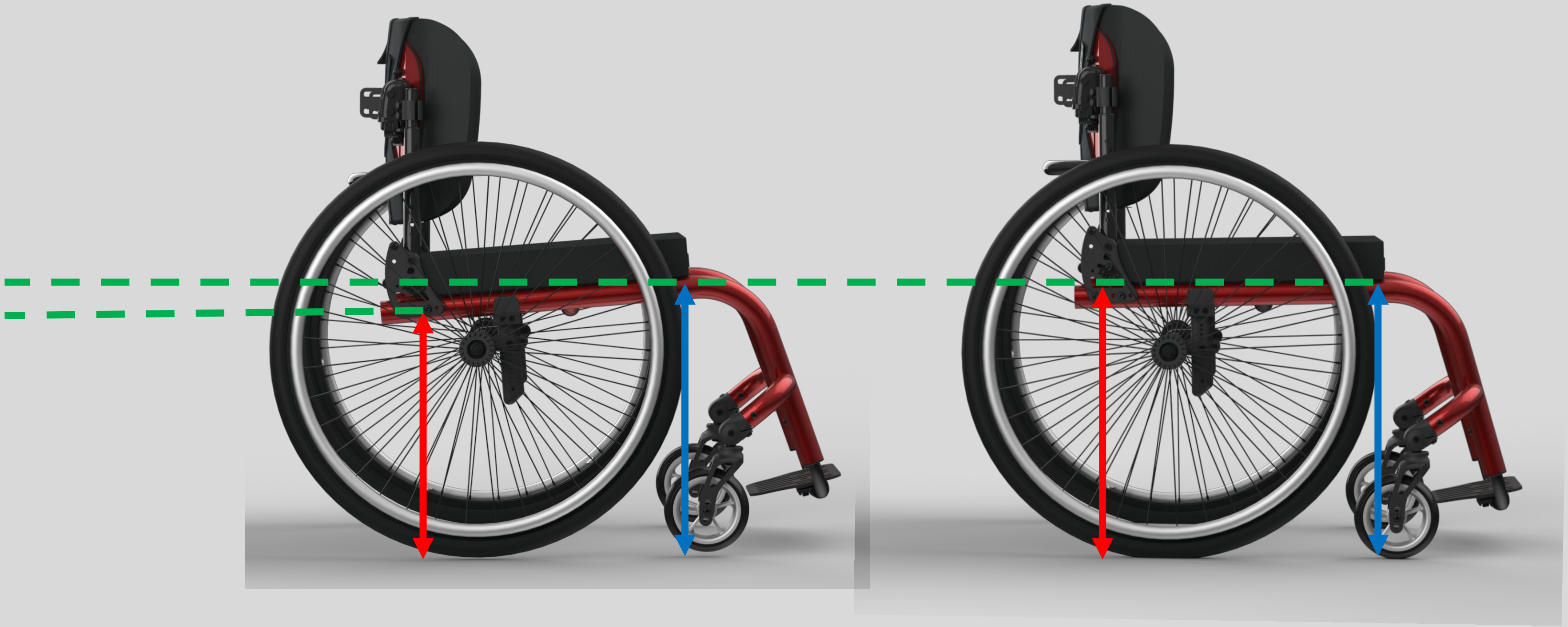
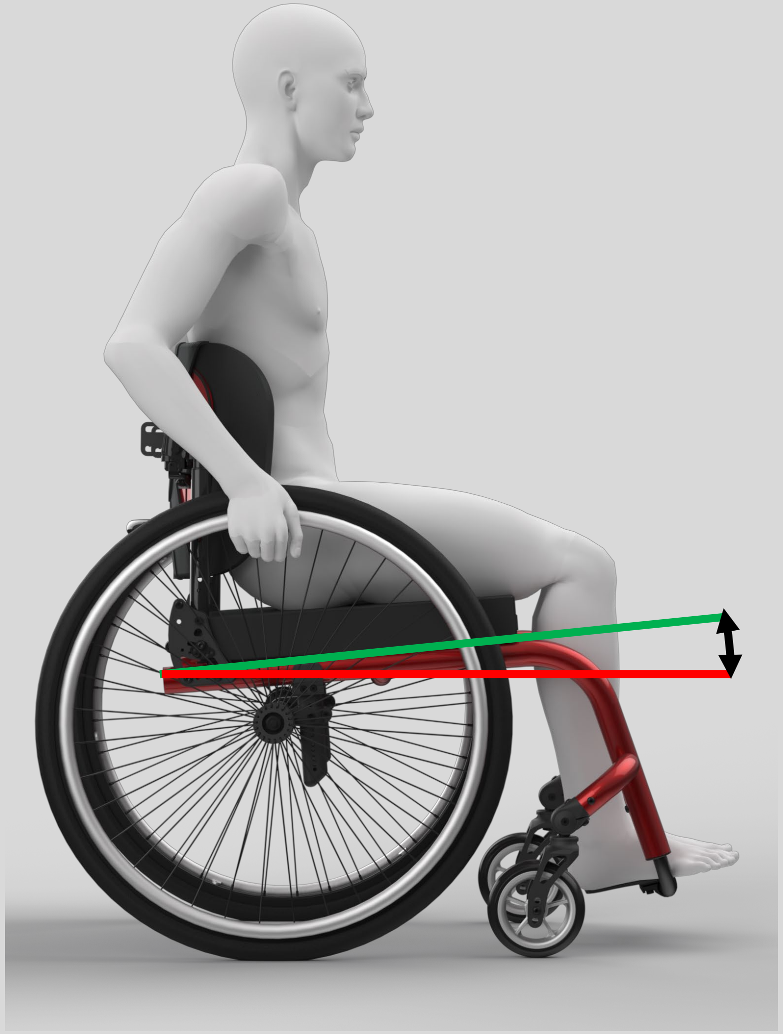


SEAT ANGLE

Angle is the figure formed by two rays, sharing a common endpoint

- Seat Inclination relative to the Horizontal Plane

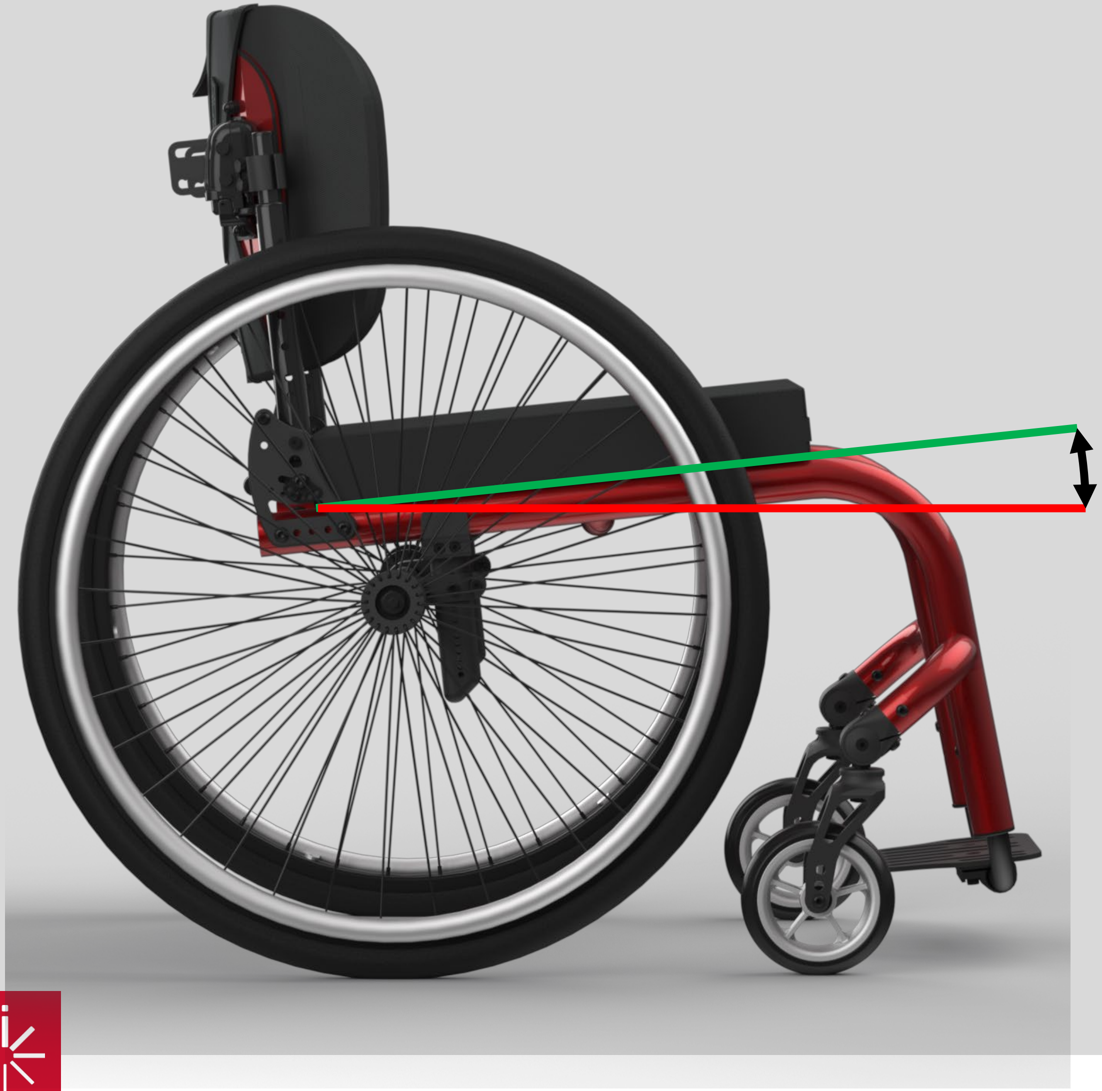


SEAT ANGLE

Formula for Seat Angle

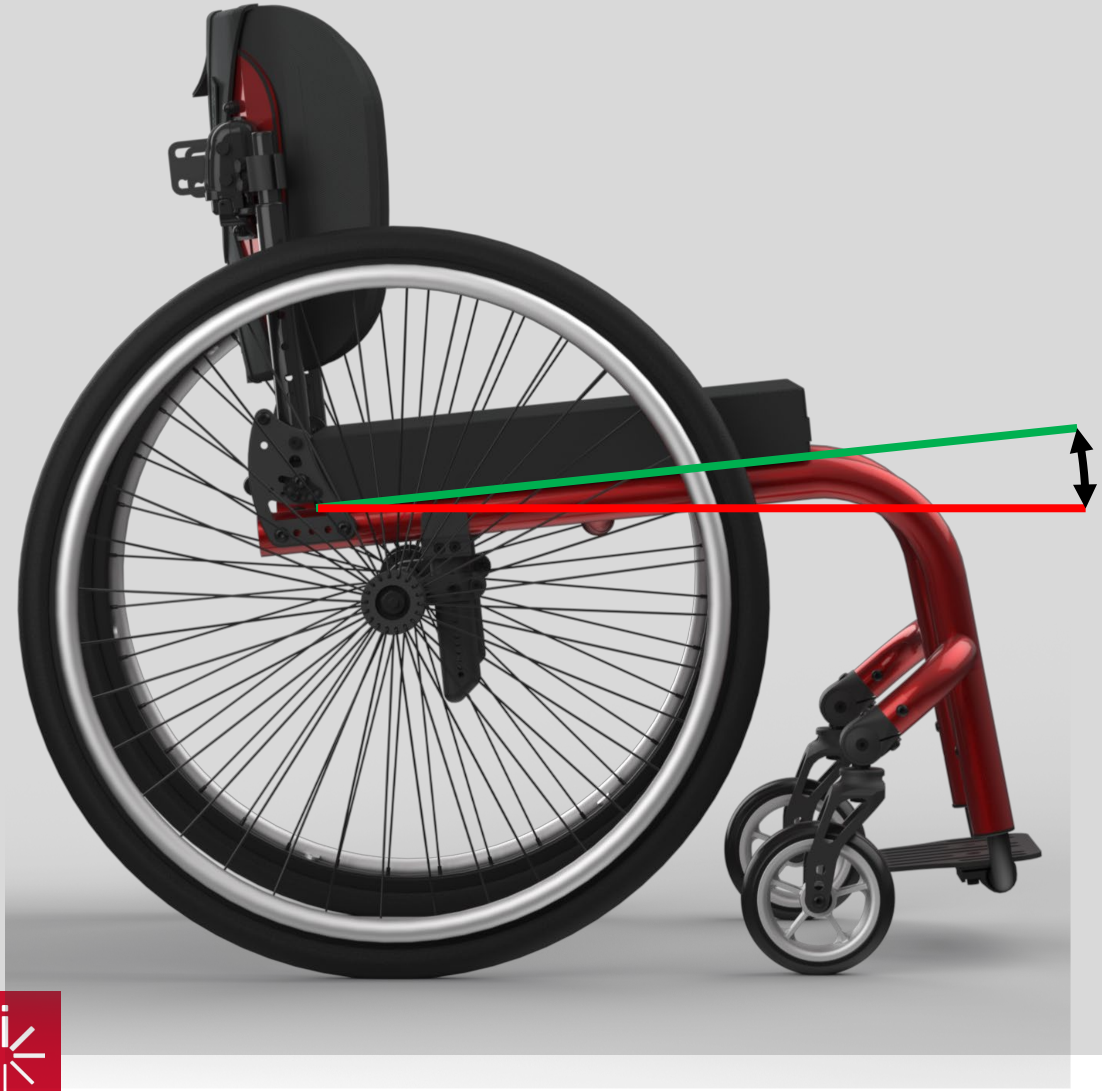
- Measurements needed:
  - Front Seat Height (FSH)
  - Rear Seat Height (RSH)
  - Seat Depth (SD)

- FSH-RSH="Dump"
- Dump/SD =sine
- Inverse of sine converted to degrees = Seat Angle



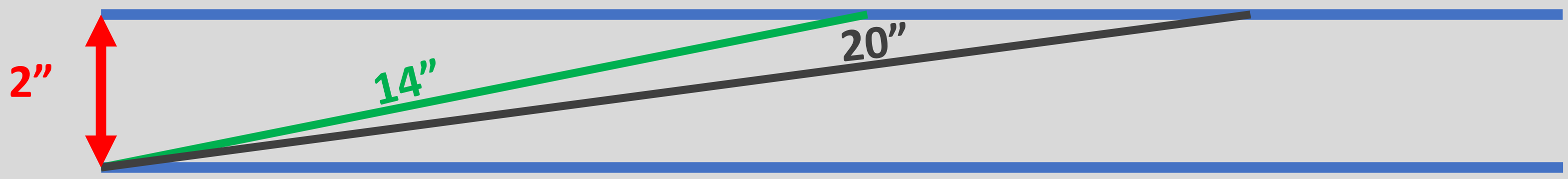
SEAT ANGLE

"Dump"	Seat Depth	Seat Angle
0	0	0°
2	14	8.2°
2	15	7.6°
2	16	7.1°
2	17	6.7°
2	18	6.4°
2	19	6°
2	20	5.7°
3	14	12.2°
3	15	11.4°
3	16	10.7°
3	17	10.1°
3	18	9.5°
3	19	9°
3	20	8.6°



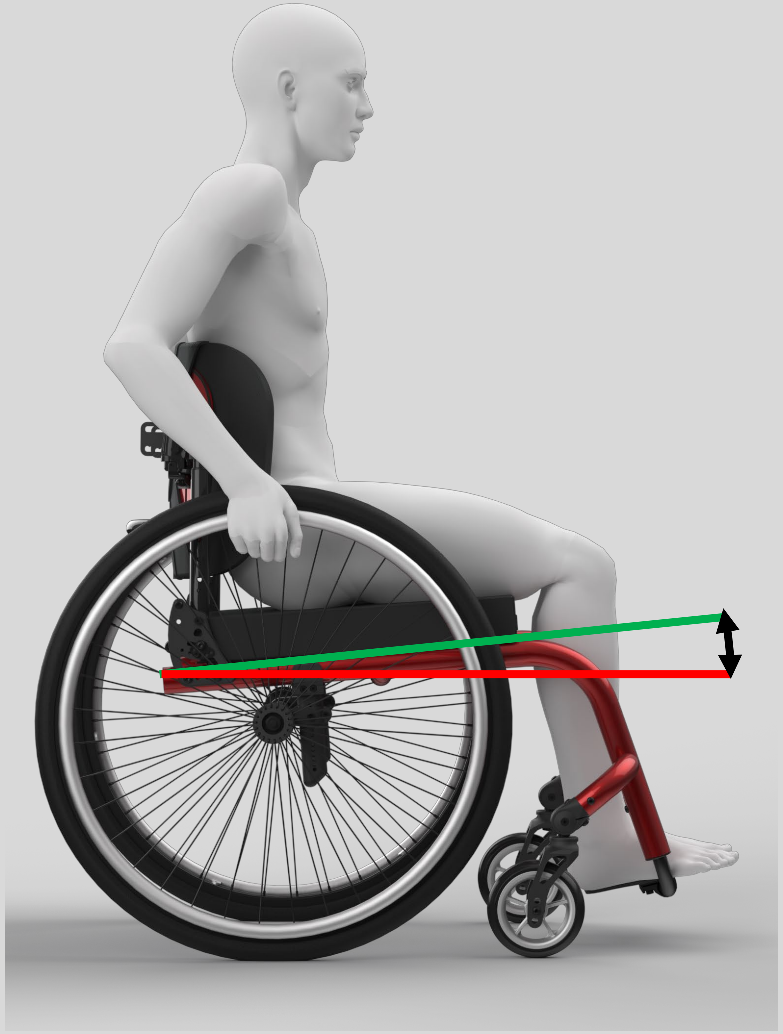
Rise over Run

Rise over Run



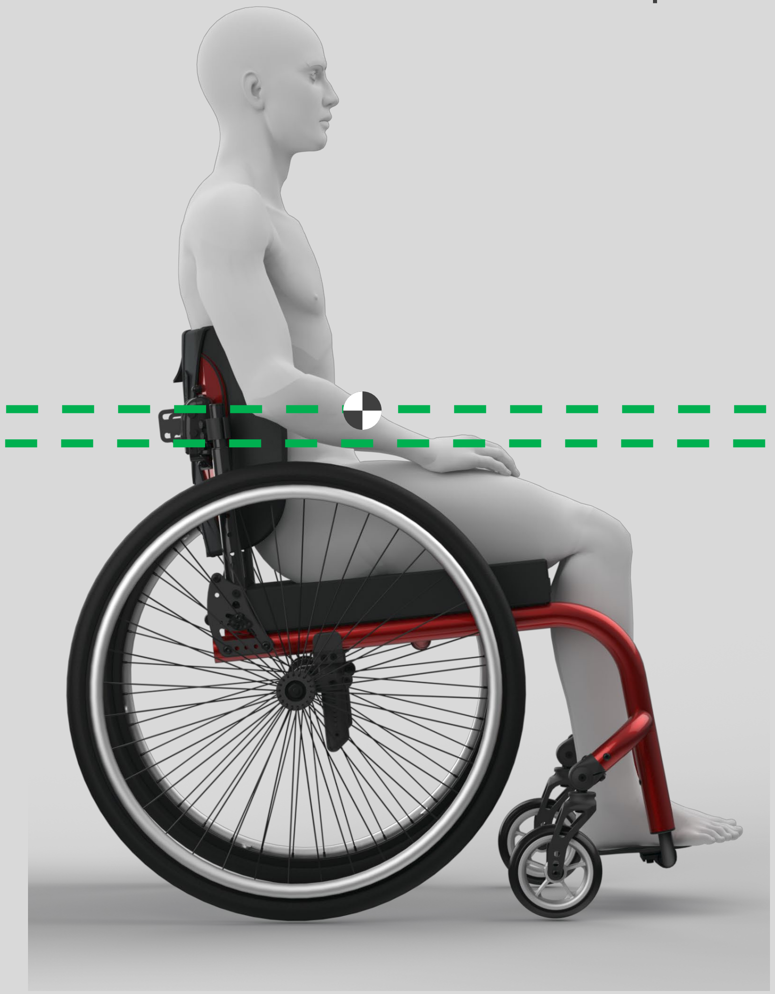
SEAT ANGLE

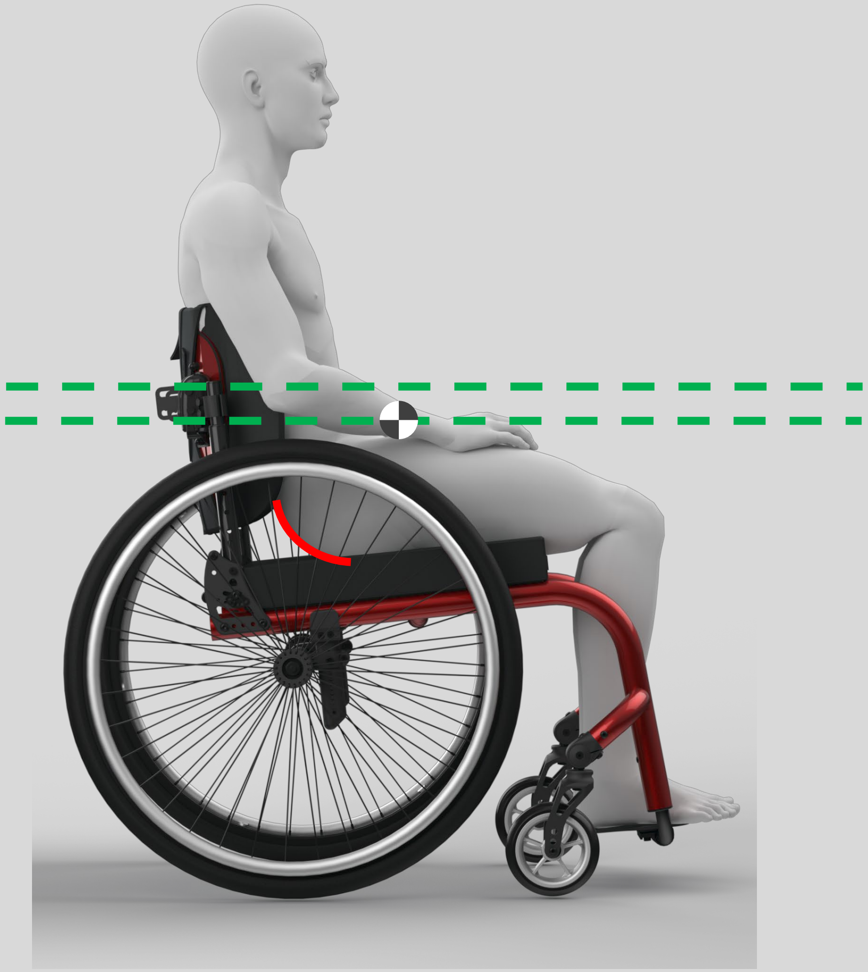
Can be important to functional stability



SEAT ANGLE

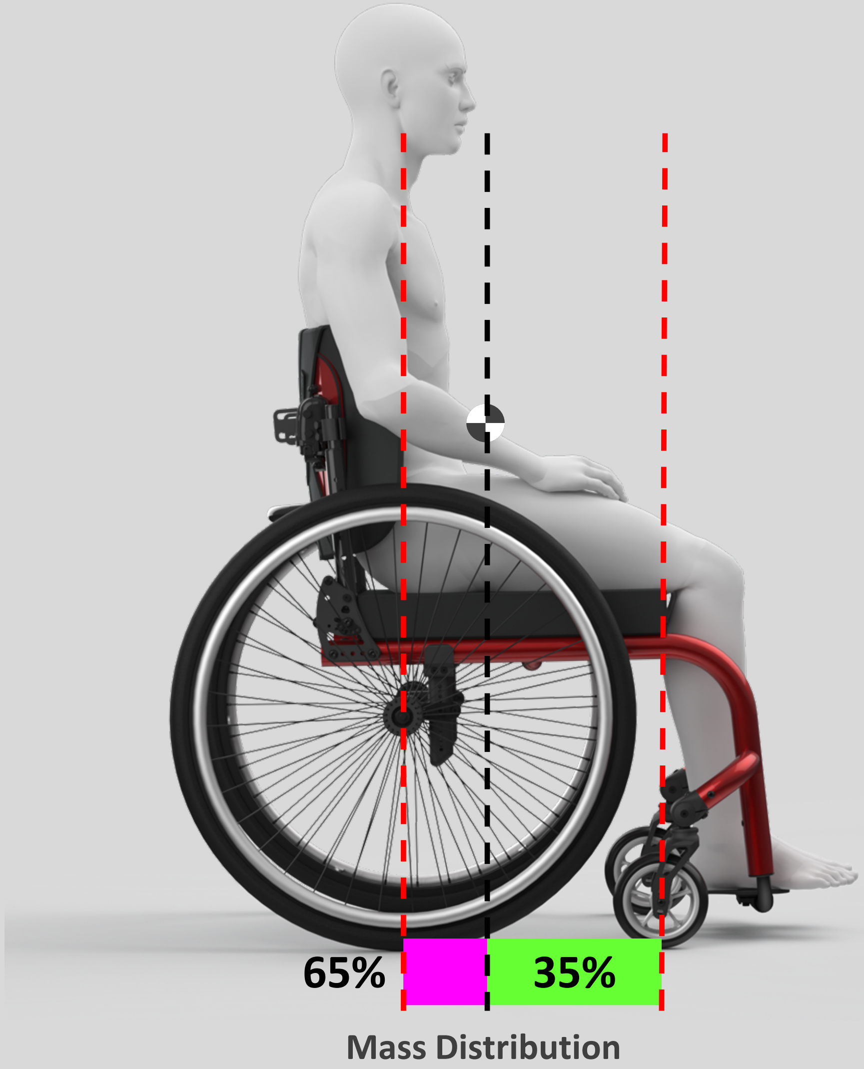
The higher one's **CG** the more postural stability is challenged





SEAT ANGLE

- Lowering **CG** improves seated stability
- Can impact weight distribution over rear wheels



SEAT ANGLE

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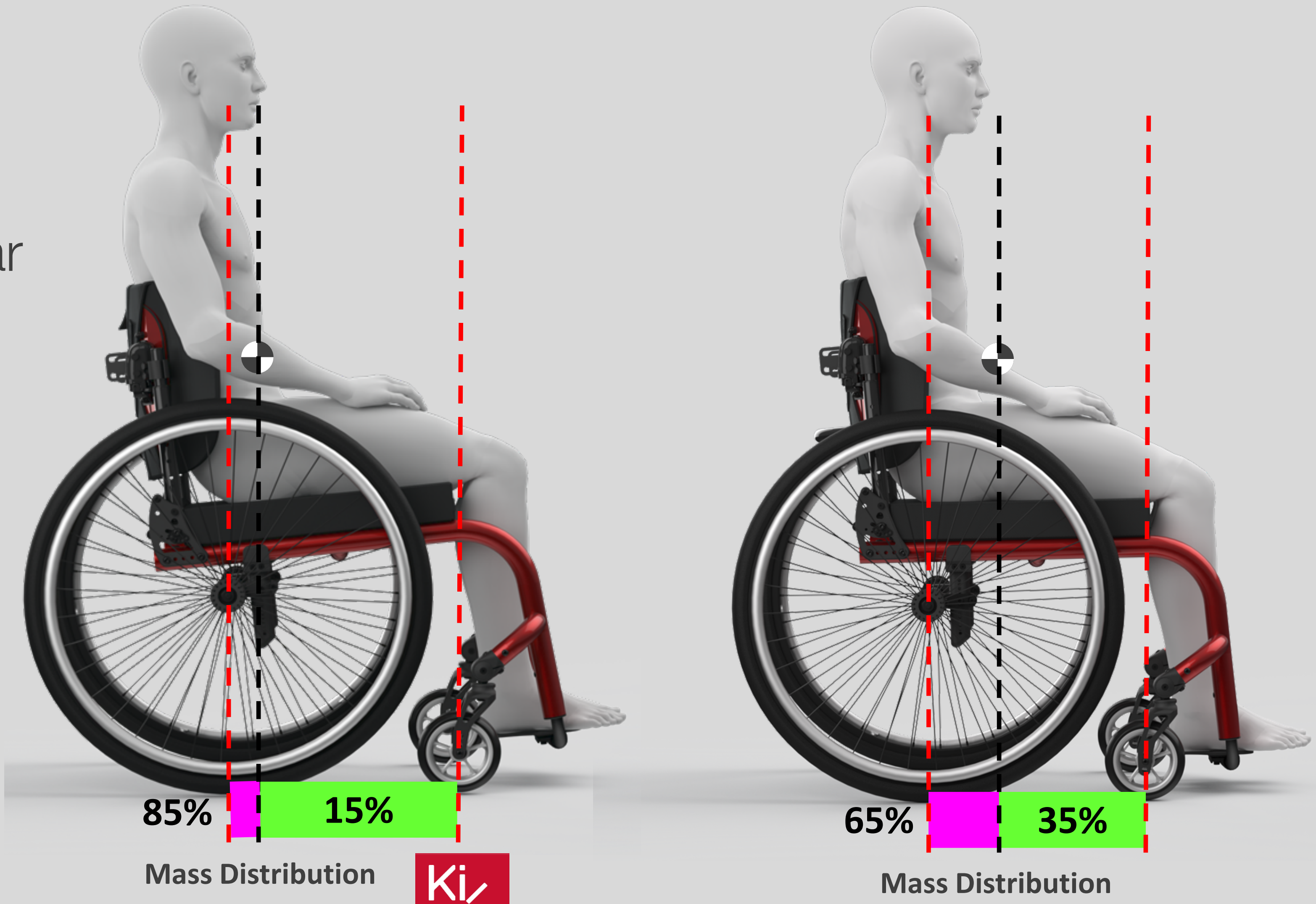
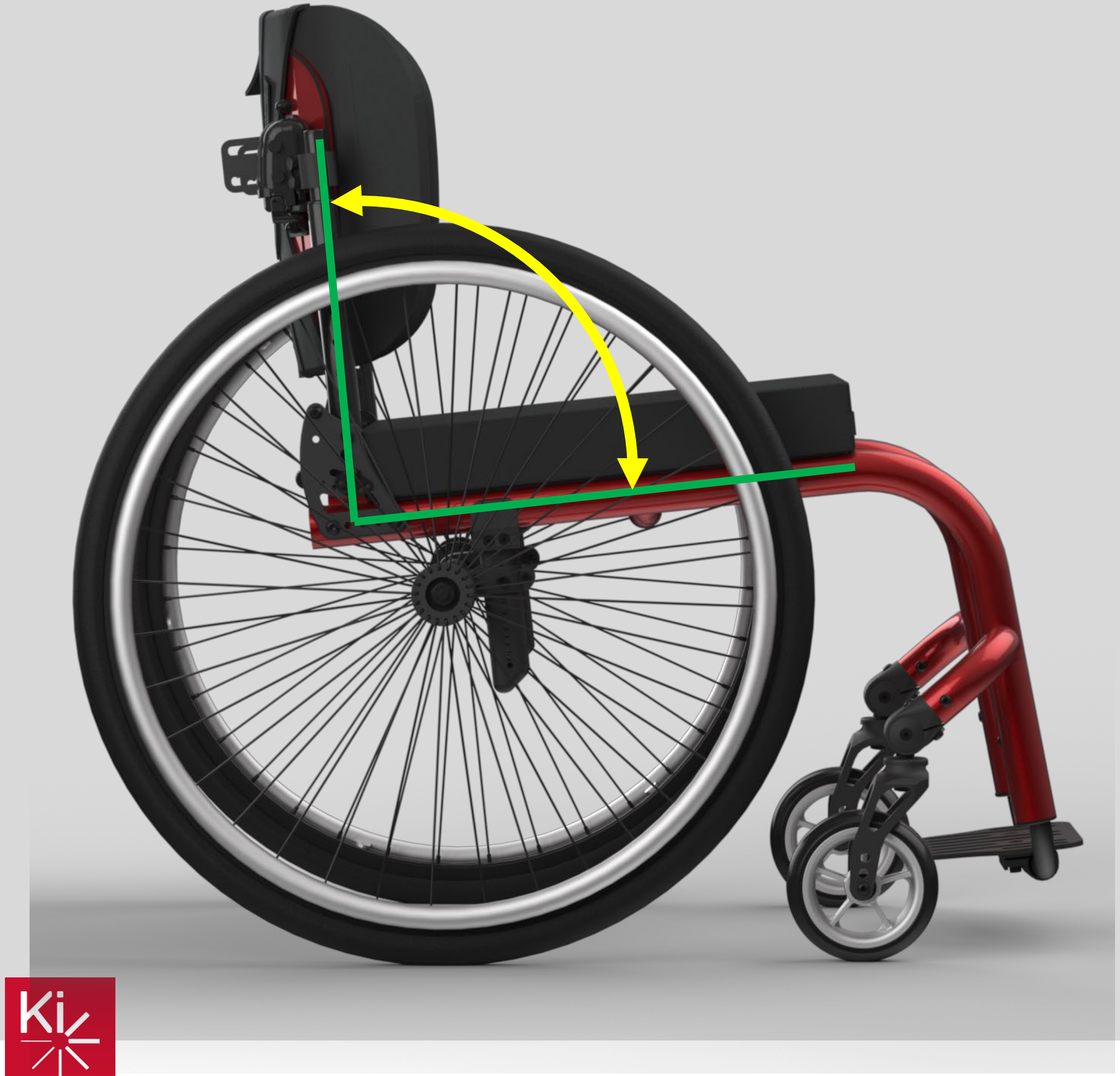
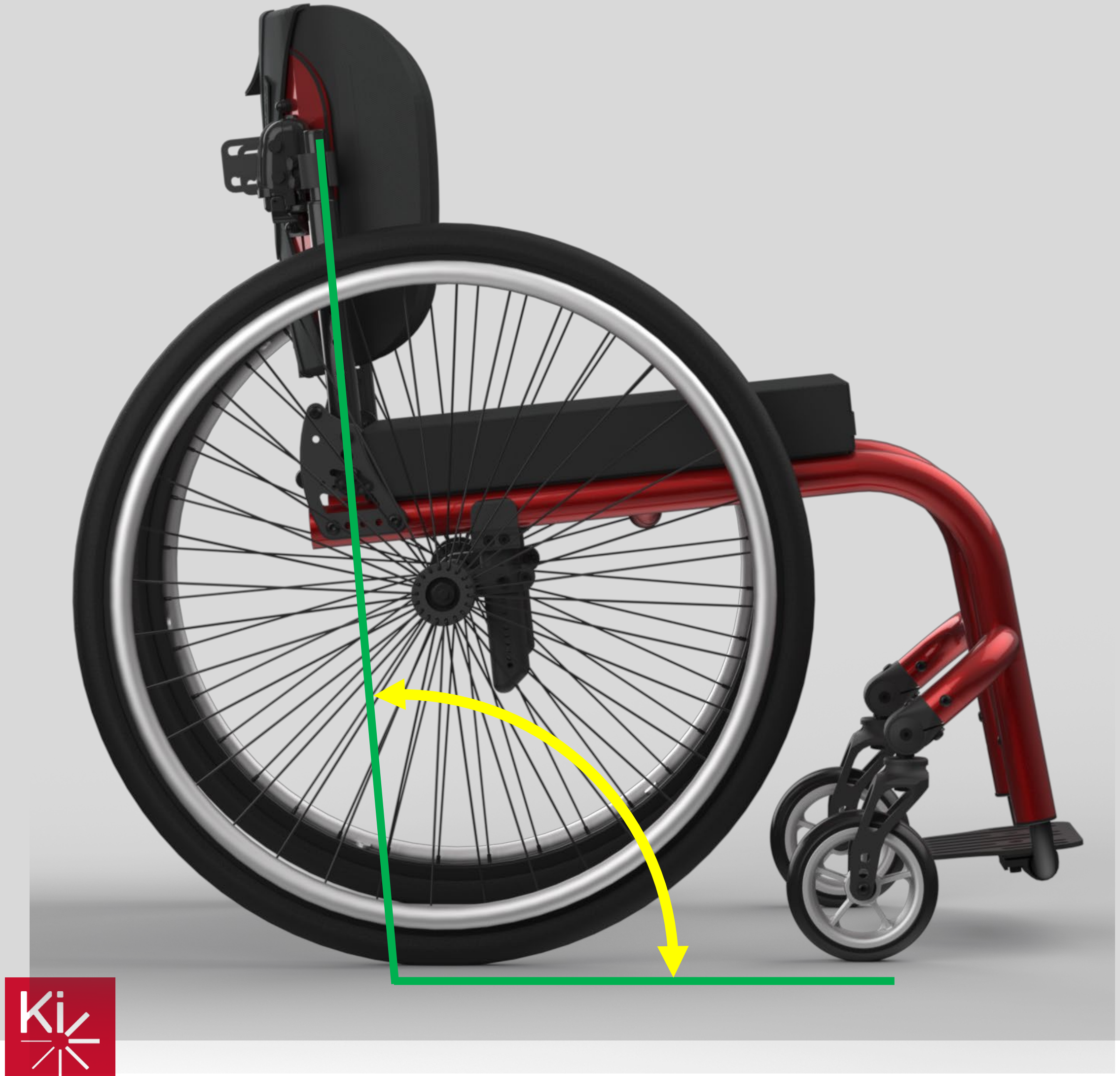


BACK ANGLE

Measurement of back cane angle in relation to seat rail



BACK ANGLE



BACK ANGLE

Like seat angle, often used to facilitate

- Improved seated stability
- Functional use of upper extremities

BACK ANGLE

- Can impact access to rear wheels for propulsion
- Can impact weight distribution over rear wheels

BACK ANGLE

May be altered throughout “life of the chair”

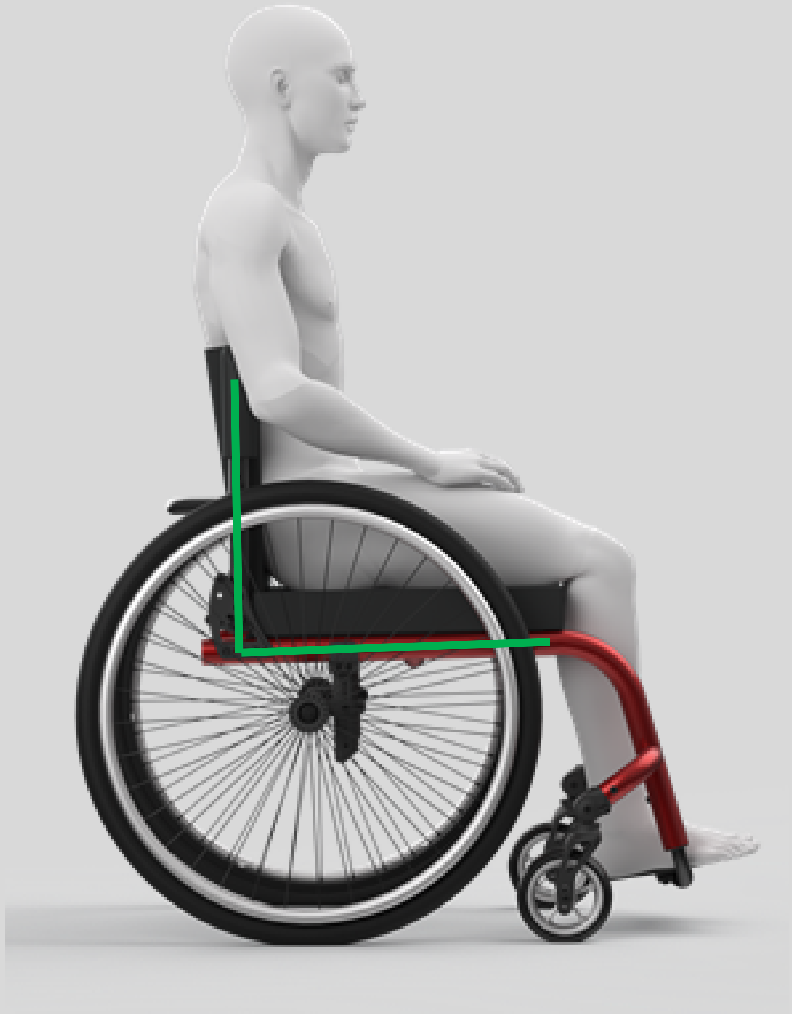
BACK ANGLE

May be altered throughout “life of the chair”

BACK ANGLE

Back Upholstery

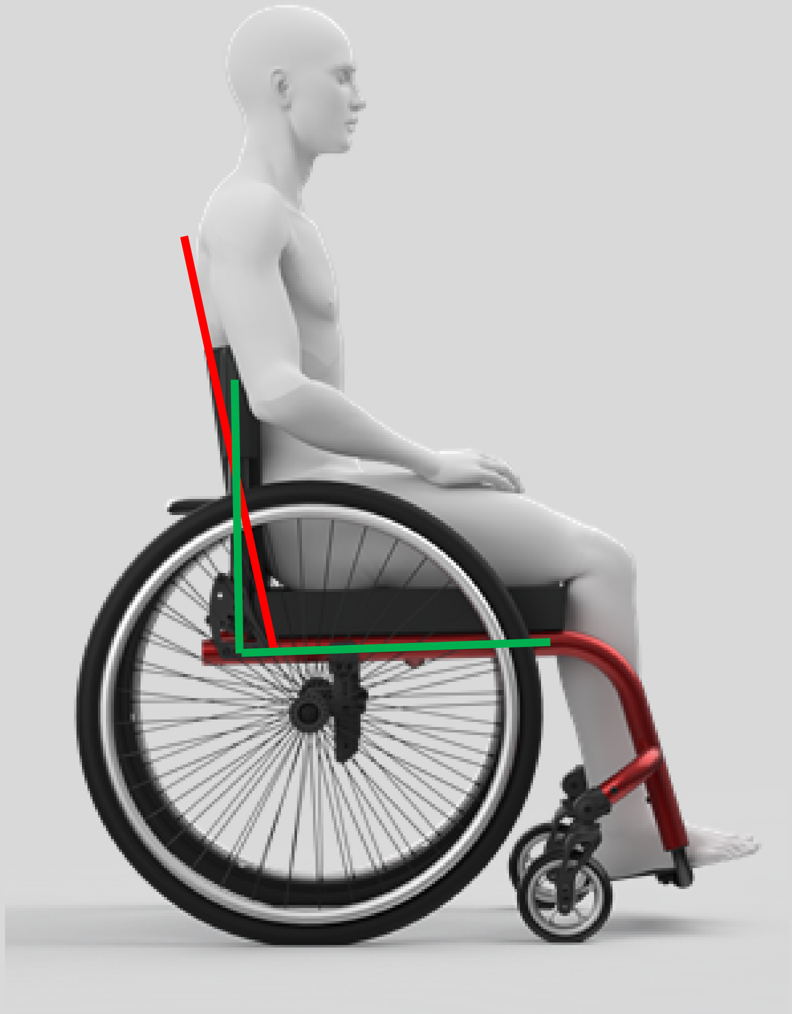
- Back Angle



BACK ANGLE

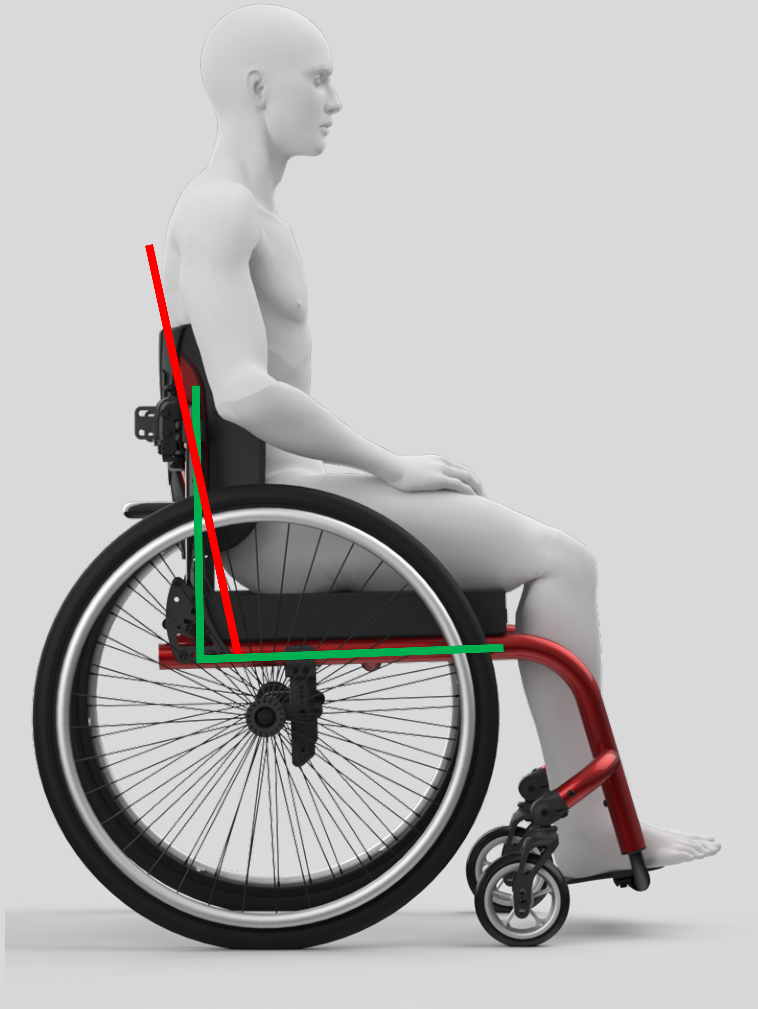
Back Upholstery

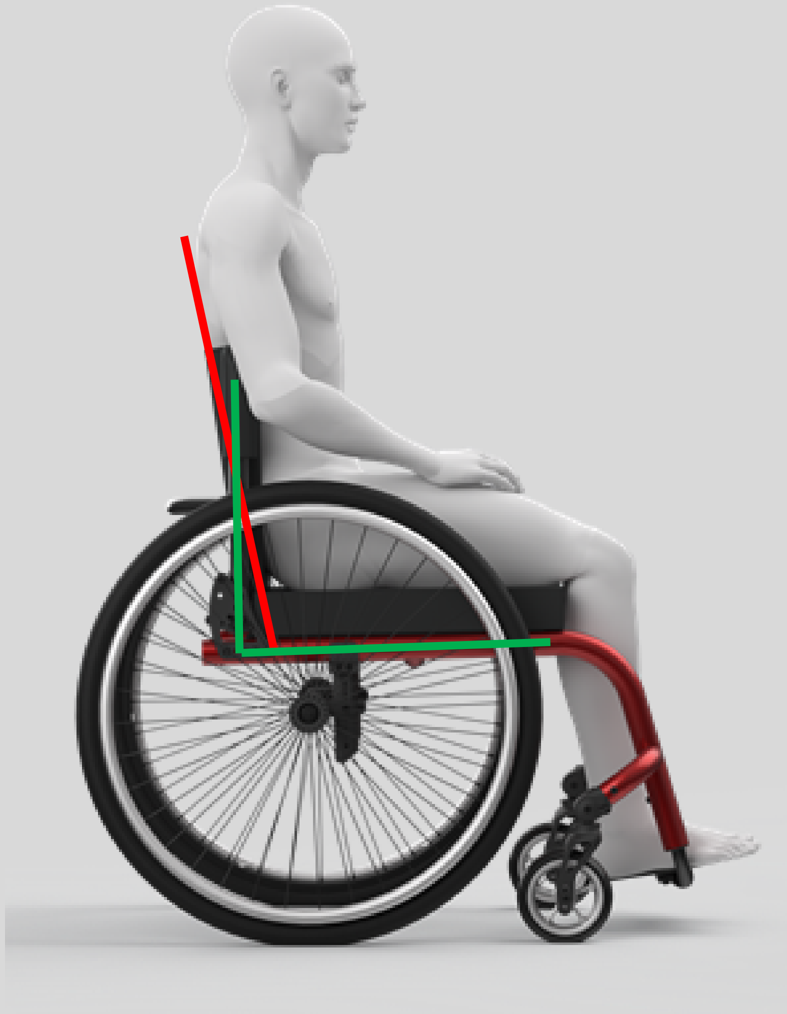
- Back Angle vs. Support Angle



BACK ANGLE

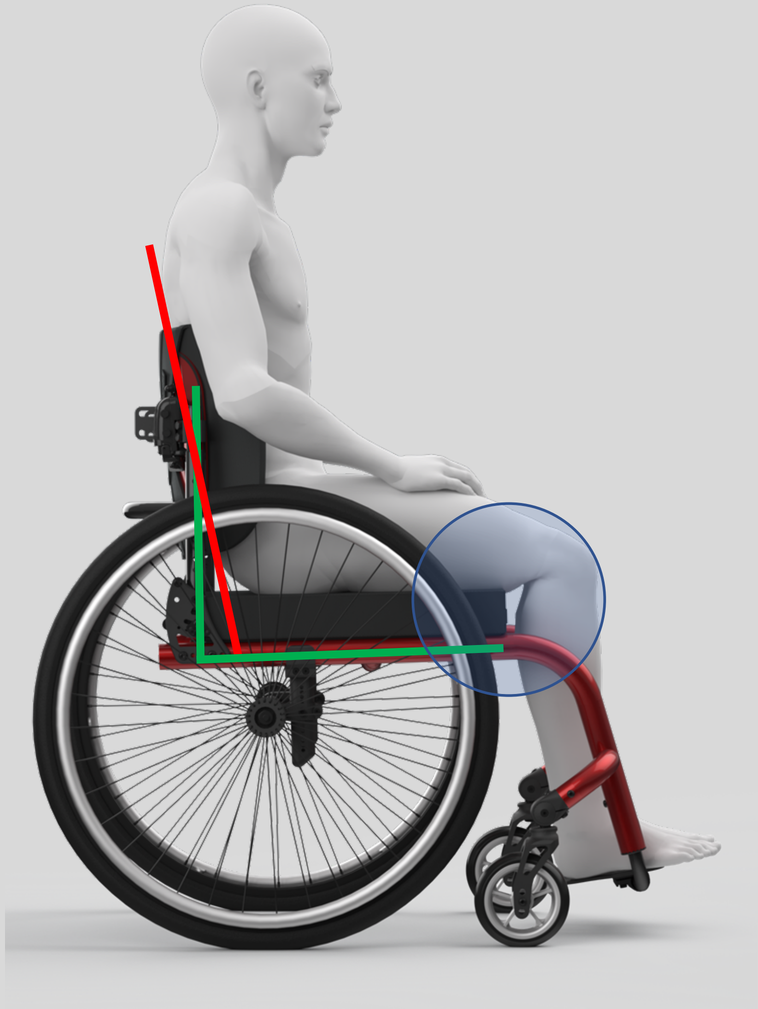
Solid Backrest

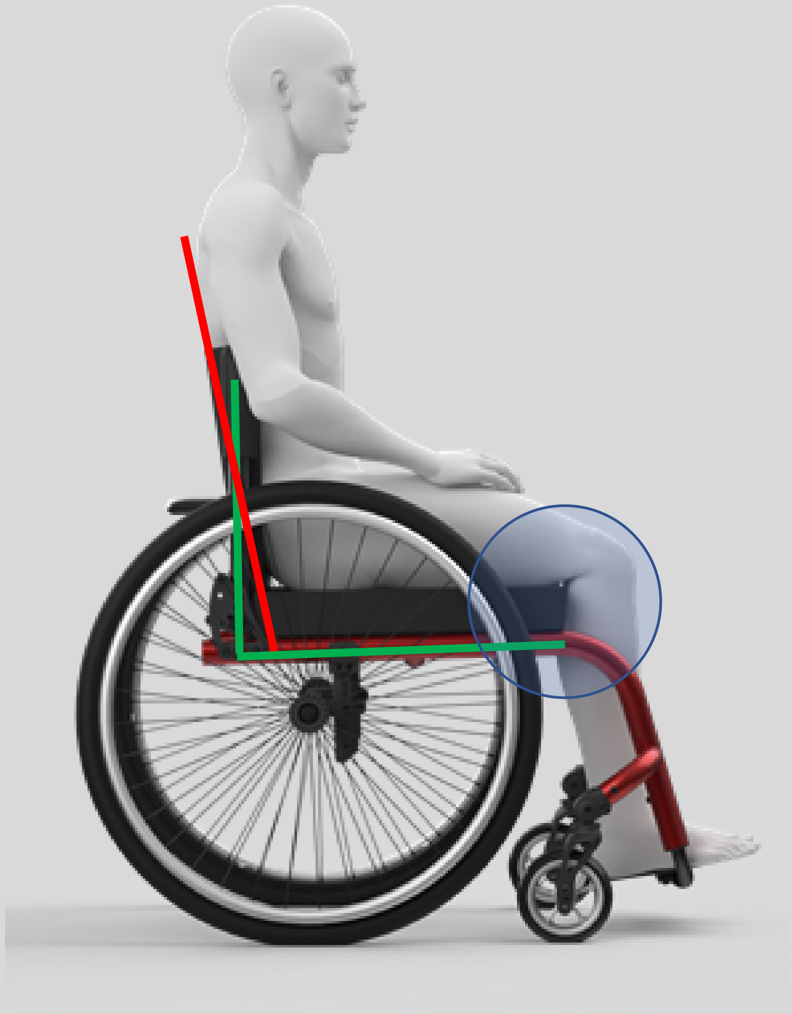




BACK ANGLE

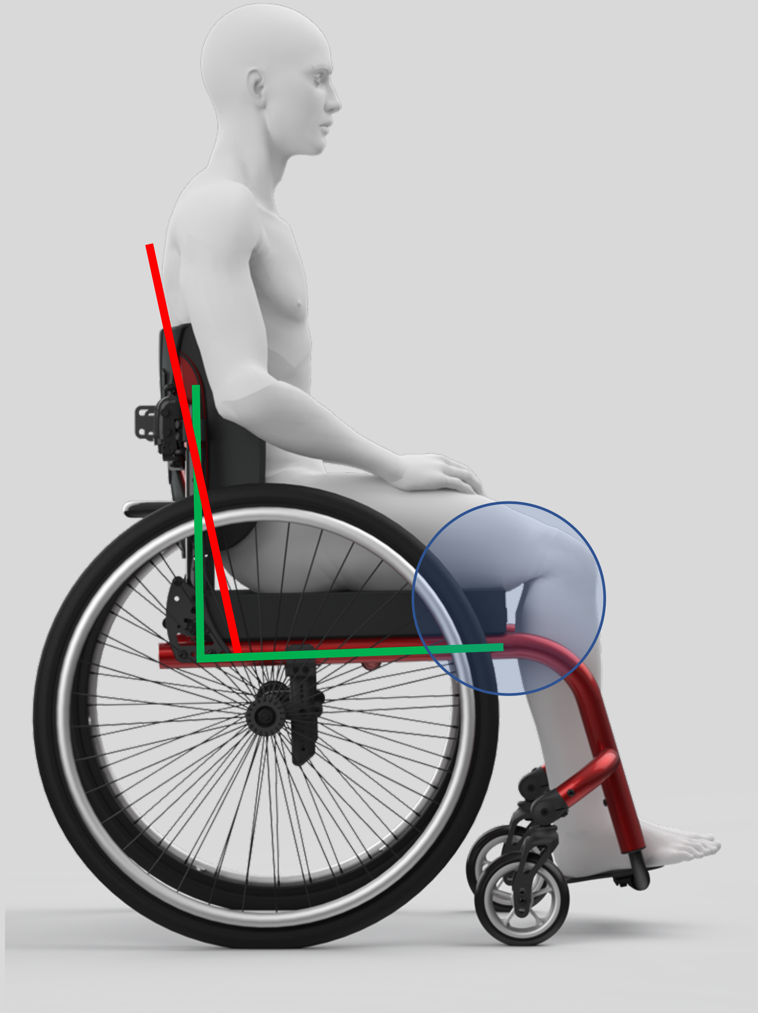
Solid Backrest





BACK ANGLE

Solid Backrest



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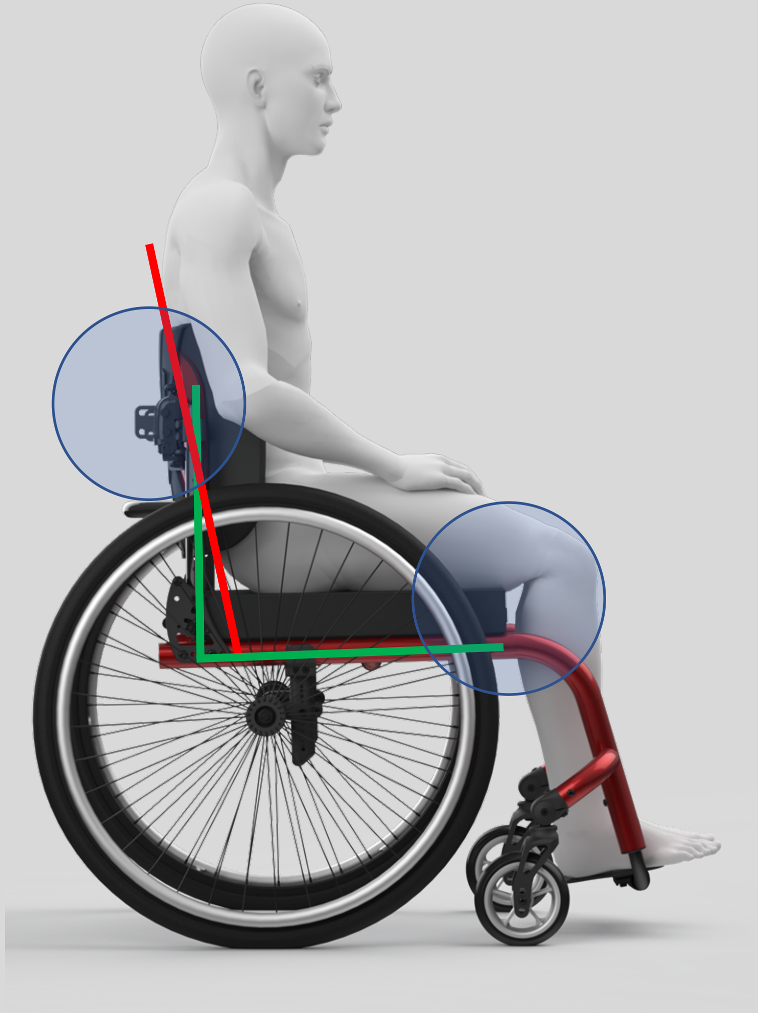
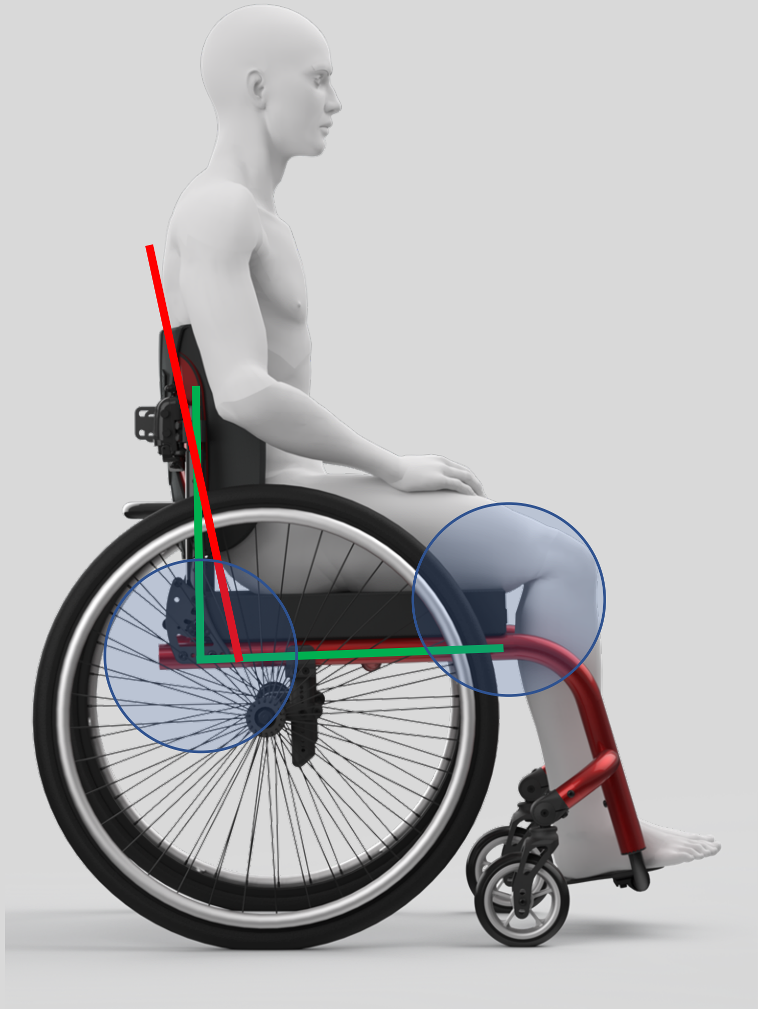
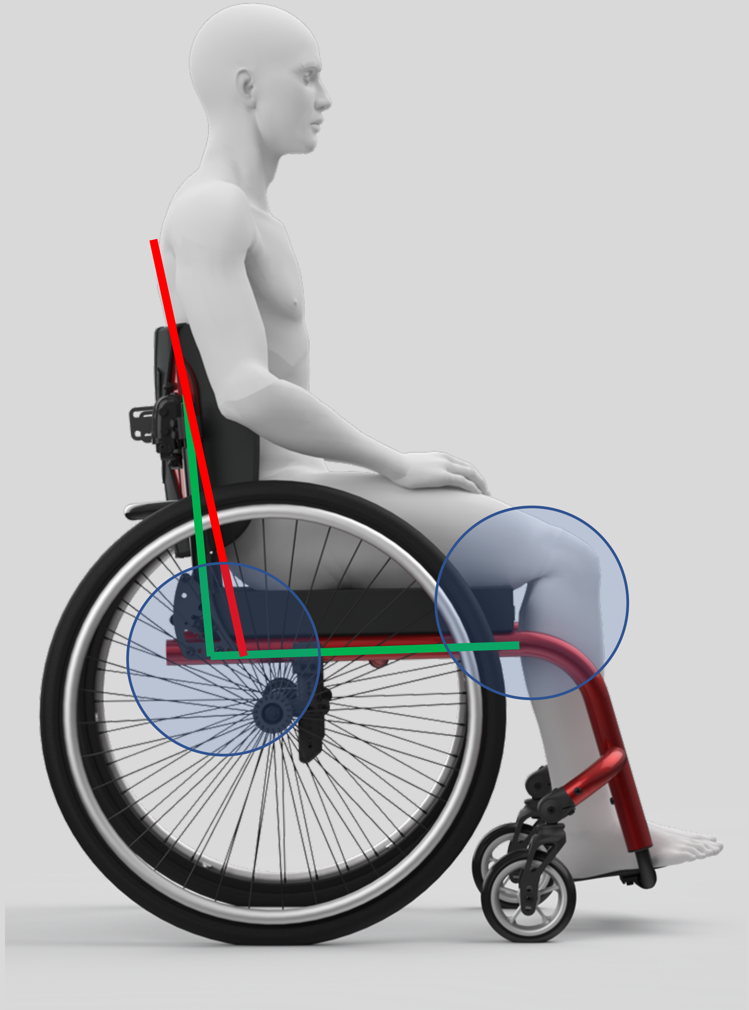


BACK ANGLE

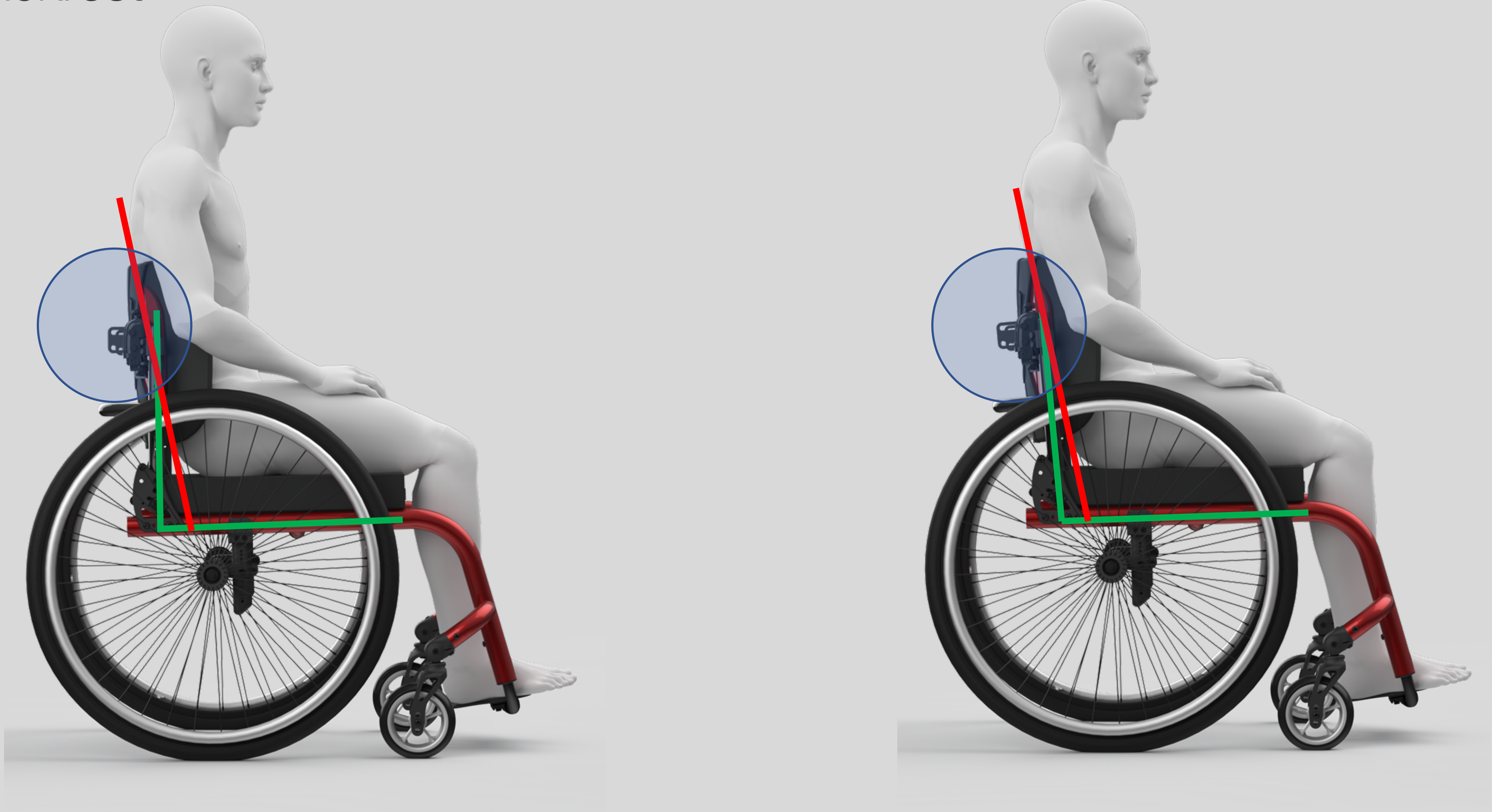
Solid Backrest





BACK ANGLE

Solid Backrest



BACK HEIGHT

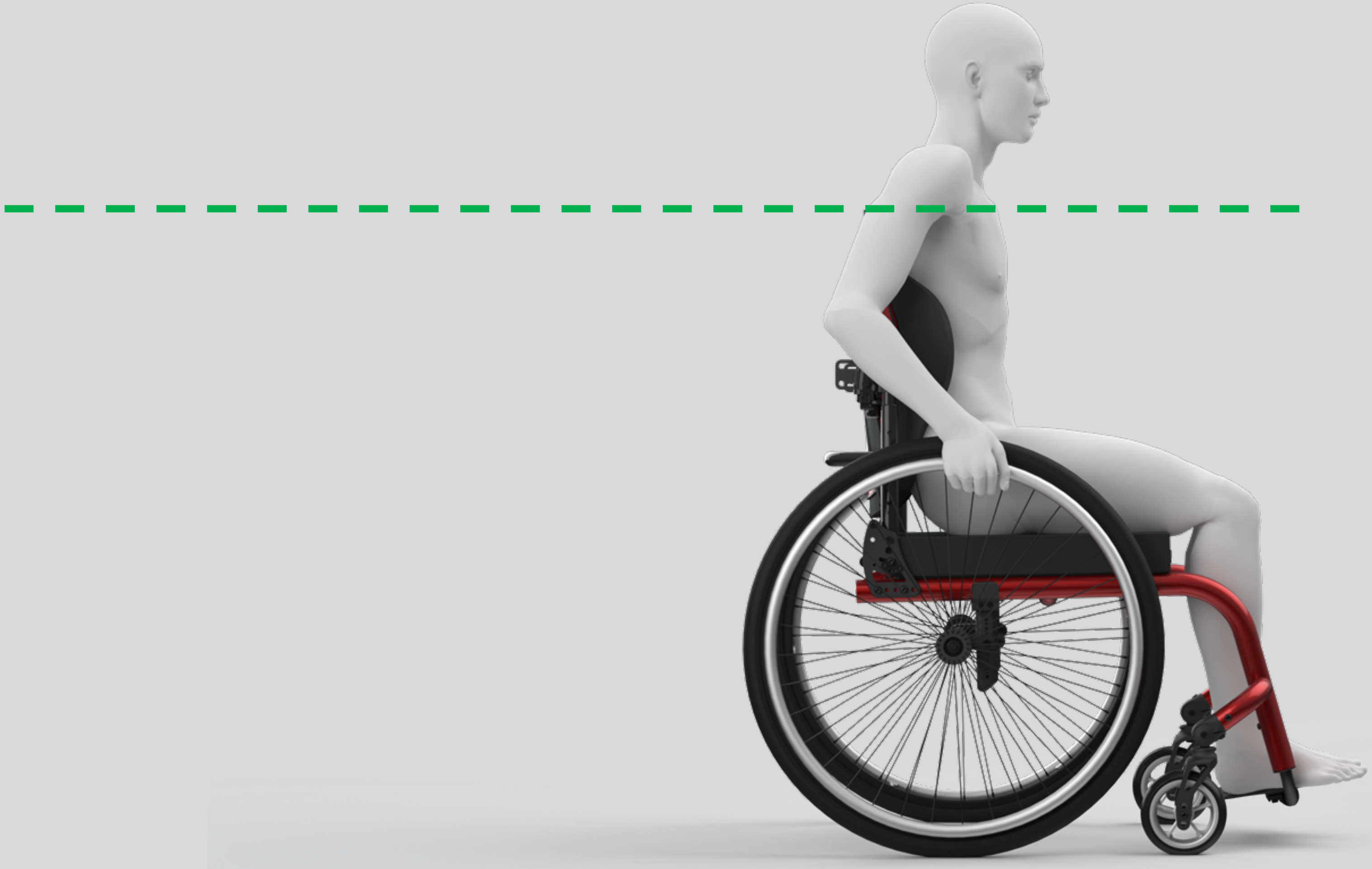
- Can impact postural stability

- Can impact upper extremity range of motion for function

BACK HEIGHT

Higher support

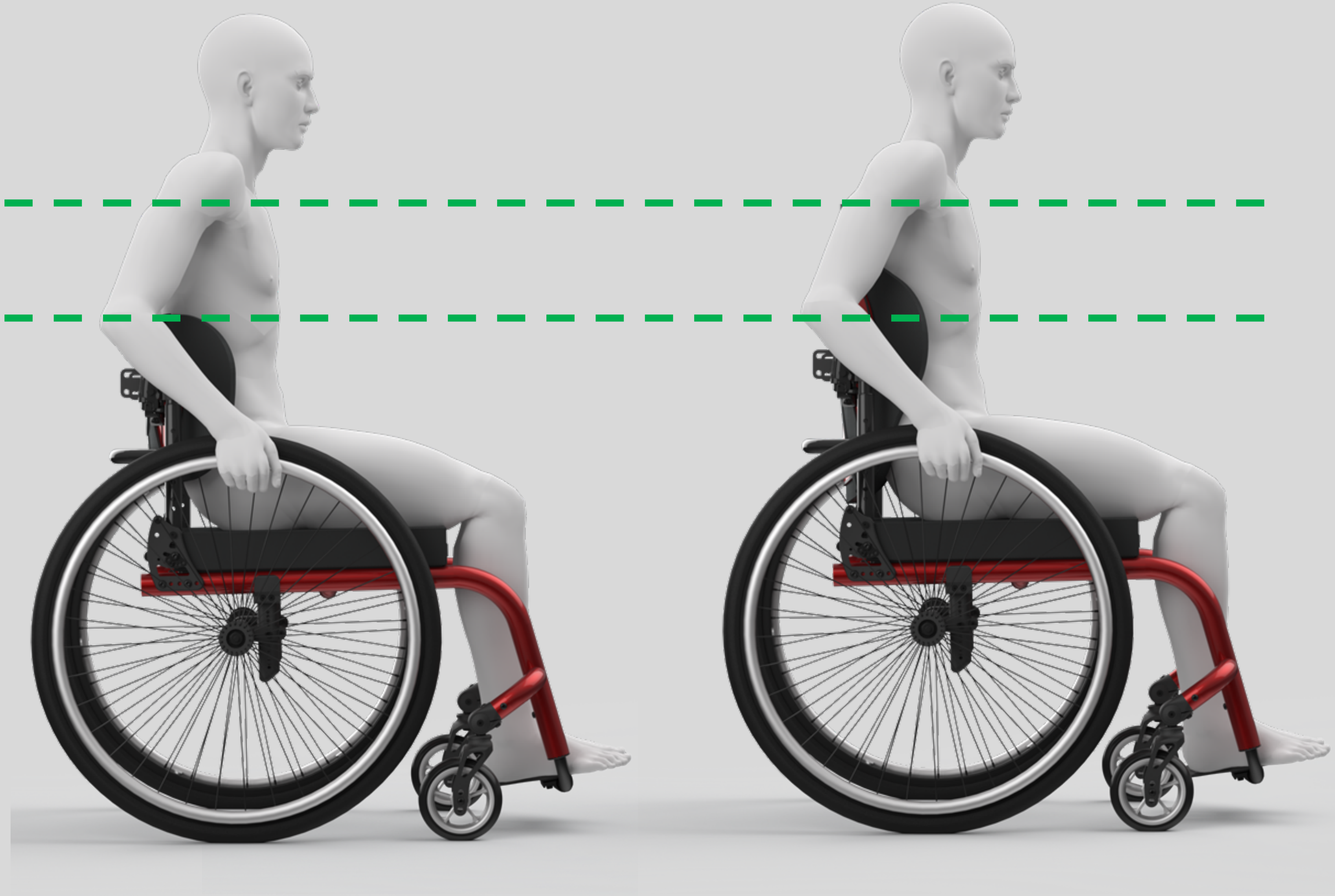
- Provides more posterior trunk stability
- May decrease shoulder extension range of motion



BACK HEIGHT

Lower support

- Provides less posterior trunk stability
- May increase shoulder extension range of motion



BACK HEIGHT

A pilot study on the impact of solid back support

- Higher vertical reach
- Longer one stroke push
- Faster 23 meter push
- Faster ramp ascent

Research Article

Wheelchair backs that support the spinal curves: Assessing postural and functional changes

Jessica Presperin Pedersen[1], Cynthia Smith[2], Margaret Dahlin[2], Molly Henry[1], Janell Jones[2], Kelly McKenzie[1], Mitch Sevigny[2], Lindsey Yingling[1]

[1]Center for Rehabilitation Outcomes Research, Shirley Ryan AbilityLab, Feinberg School of Medicine, Northwestern University, Chicago, Illinois, USA, [2]Craig Hospital, Denver, Colorado, USA

Objective: To compare outcomes using a wheelchair back designed to support the natural seated spinal curves versus an upholstered back that promotes posterior pelvic tilt and thoracolumbar kyphosis.
Design: Cross-over intervention.
Setting: Two free-standing spinal cord injury (SCI) model system hospitals.
Participants: Fifty adults with motor complete SCI C6-T4, between the ages of 18–60 years who use a manual wheelchair for mobility were recruited from a convenience sample.
Intervention: Each participant's wheelchair back support was removed and replaced by an upholstered back and a solid back in randomized order. Postural and functional outcomes, pain, and satisfaction were evaluated using each back.
Outcome measures: Seated postural measurements included pelvic angle, spinal angle of kyphosis and linear measurement of spine. Functional outcomes included vertical forward reach, one stroke push, timed forward wheeling, ramp ascent and descent. Numerical pain rating and a satisfaction survey provided input pertaining to both backs.
Results: The solid back demonstrated significance in seated postural measurements. Participants using the solid back trended to higher scores in functional outcome measures including vertical forward reach, one stroke push and timed ramp ascent. Participants reported increased satisfaction with comfort and stability with the solid back.
Conclusions: This pilot study demonstrated that a wheelchair back, which supports the seated spinal curves improves upright posture, functional reach, and wheelchair propulsion skills. Further research is necessary to demonstrate statistical findings as well as to assess back height and lateral support.

Keywords: Manual wheelchair, Wheelchair back supports, Functional outcomes manual wheelchair

Introduction

The interaction between a person's individual body structure, physical impairments, and their environment helps to determine their functional capabilities. A properly fit wheelchair and seating system can have a profound impact on the daily life of people with spinal cord injury (SCI) including independence, participation and quality of life.[1]

A seating system, comprised of a cushion and back dictates the pelvis and trunk positions. The integration of the seating system provides mobility in addition to postural support. An appropriate back support can also restore pelvic alignment.[2] Positioning in a wheelchair through a seating system including the backrest impacts stability, management of tone, optimization of skin protection, prevention of further postural asymmetry, participation in functional skills, as well as comfort.[2]

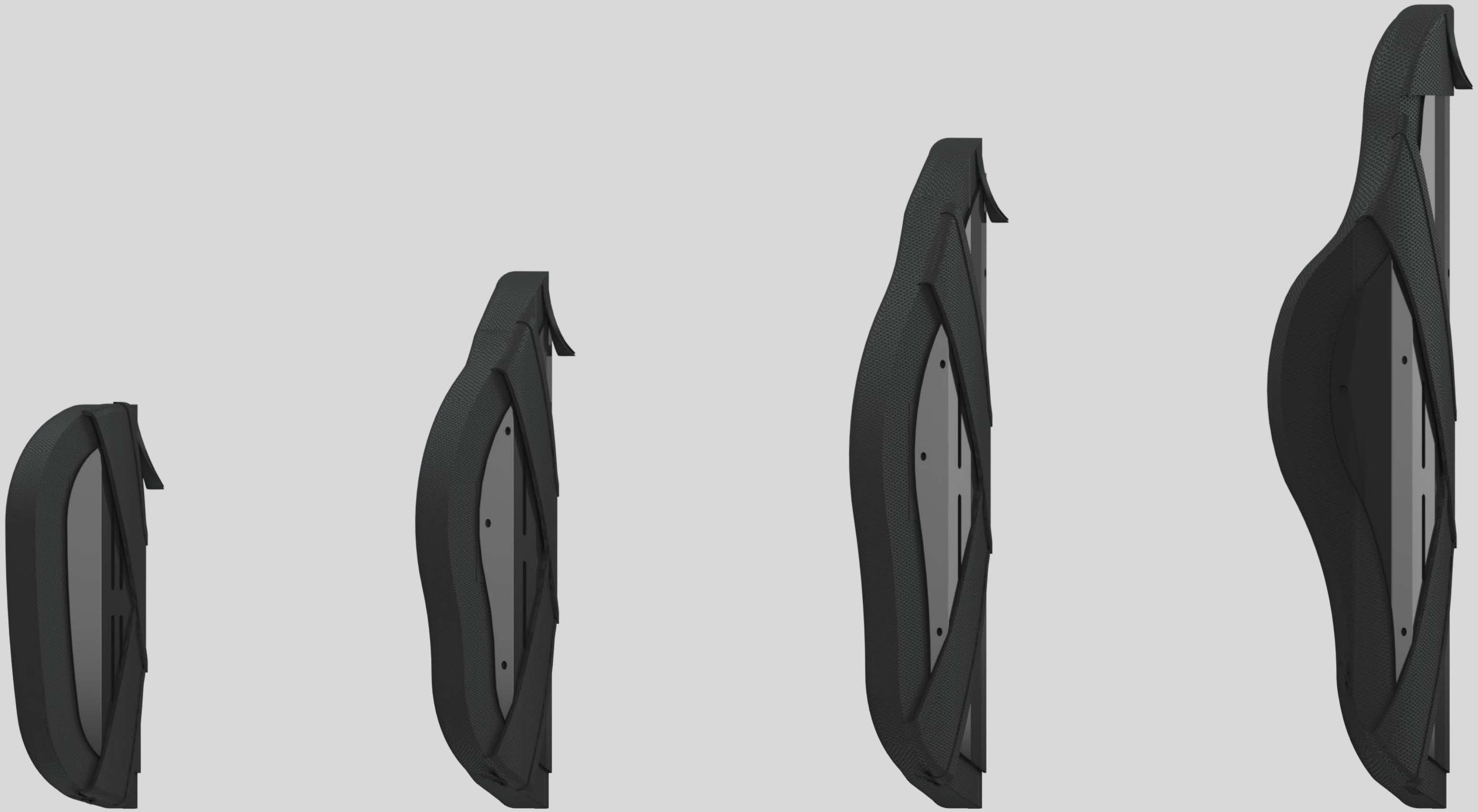
The pelvis provides a foundation for stability and affects spinal positioning, which in turn supports the upper limbs through interaction of the axial and appendicular skeleton.[3] Specific support for function is

(Pedersen, et al., 2019)

BACK HEIGHT

Lower backrest

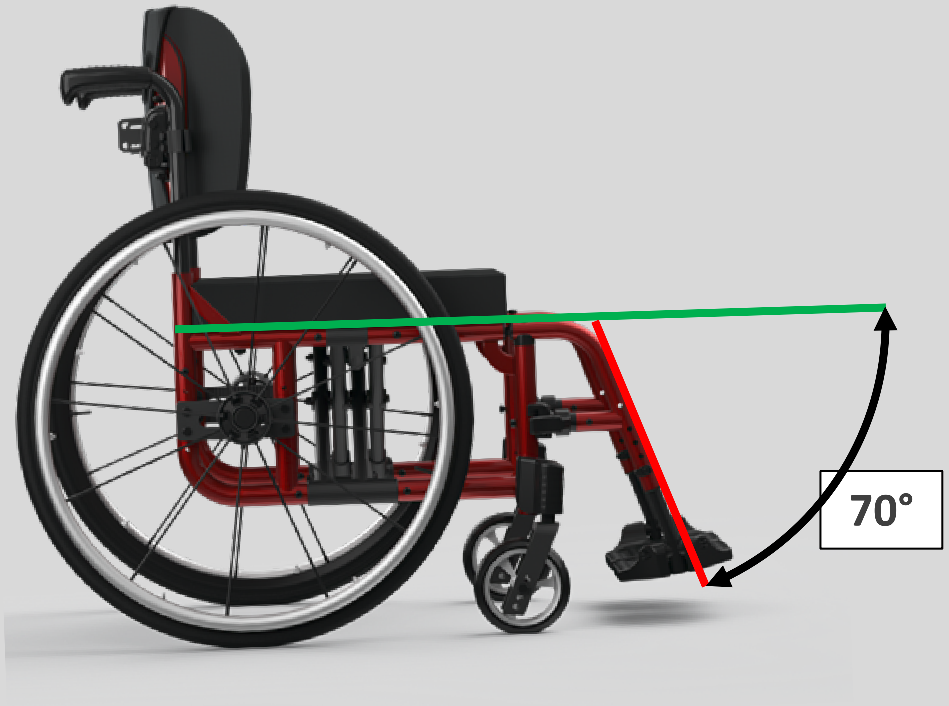
- Greater shoulder range of motion
- Longer push stroke
- Greater push time
- Reduced push frequency
- No significant impact on handrim forces



Yang et al., (2012)

FRONT FRAME ANGLE

Measurement of lower leg support angle



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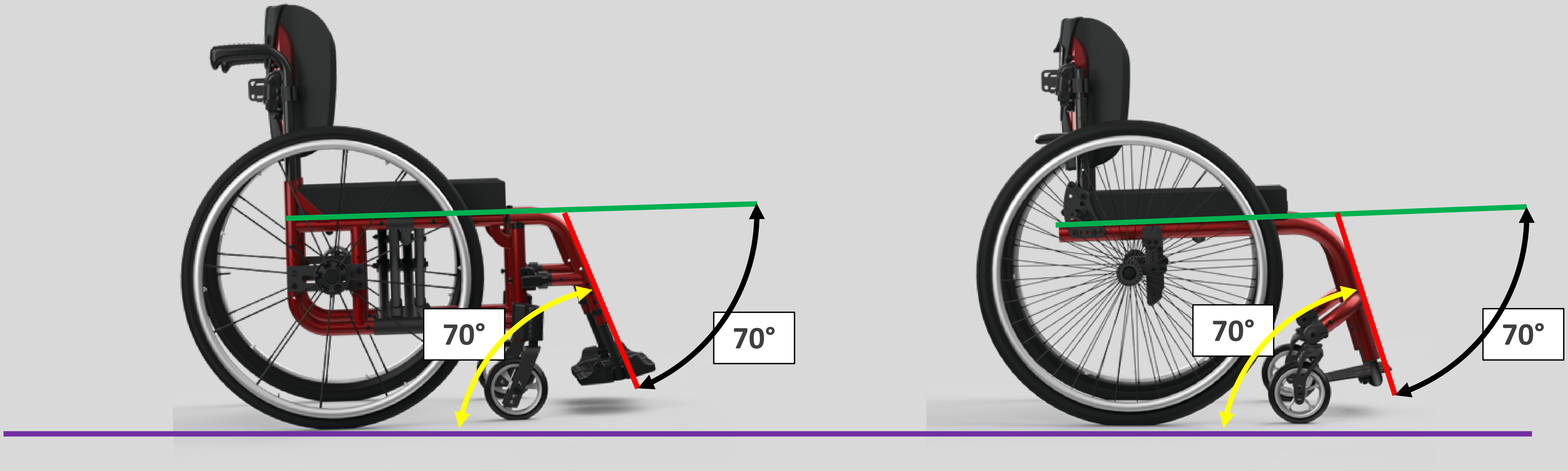

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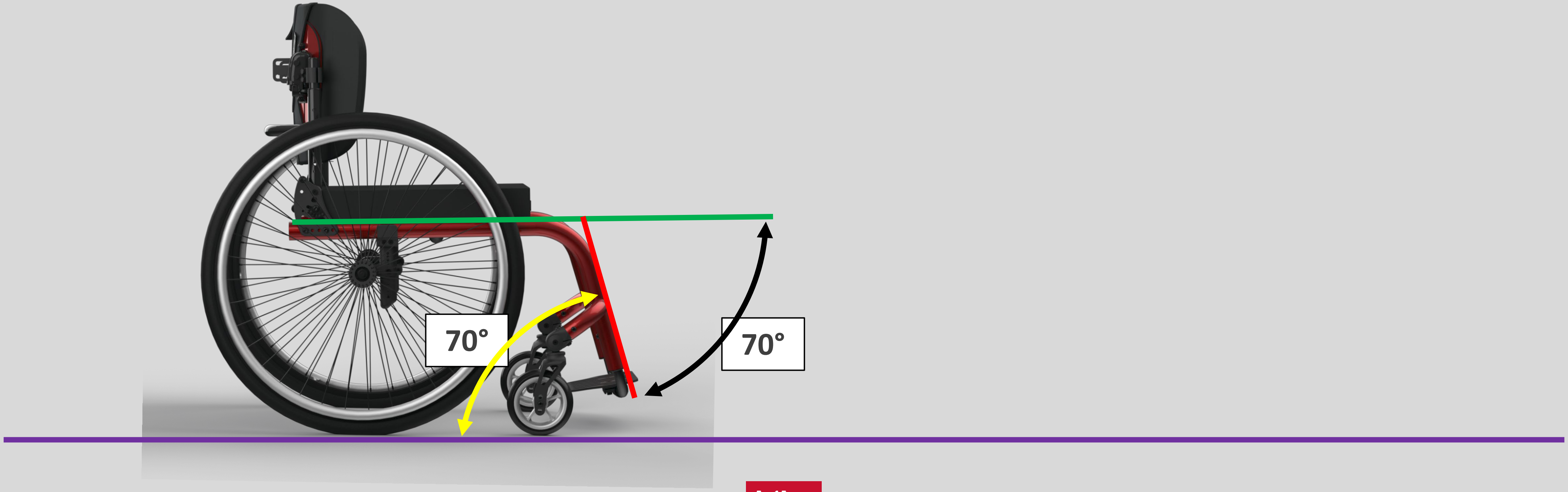

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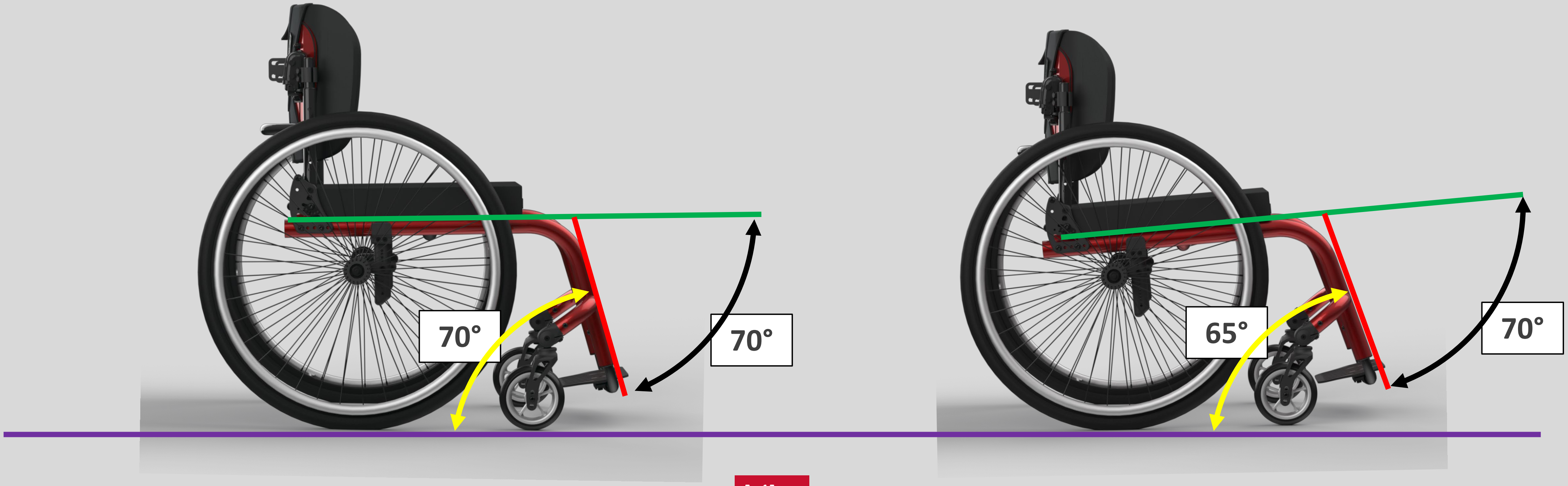

FRONT FRAME ANGLE

Considerations

- Hamstring length
- Range of motion (hip/knee/ankle)
- Spasticity/Tone
- Seated stability
- Maneuverability

PUTTING IT ALL TOGETHER

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A wheelchair needs to be set up for all the activities that a user performs from the device

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It requires adjustability to optimize the setup for changes in functional ability and need

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Adjustments to a single set up factor do not happen in isolation

PUTTING IT ALL TOGETHER

A wheelchair needs to be set up for all the activities that a user performs from the device

It requires adjustability to accommodate changes in functional ability and need

Adjustments to a single set up factor do not happen in isolation

Using Evidence Based Practice provides a framework to plan for potential changes in wheelchair setup

PUTTING IT ALL TOGETHER

Optimize the Wheelchair to Take Advantage of the Technology to Get Best Outcomes, Now and In the Future!

Questions

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