Dynamic Wheeled Mobility

The Future of Ultralight Wheelchairs for Active Users

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ACKNOWLEDGEMENT

Dynamic Wheeled Mobility

Gateway to the Future of the Ultralight Wheelchair

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DISCLOSURES

Jaimie Borisoff, PhD is the Canada Research Chair in Rehabilitation Engineering Design at the BC Institute of Technology and ICORD.

He receives funding for Dynamic Wheeled Mobility R&D from Canada Research Chairs, Canada Foundation for Innovation, and NSERC.

Jaimie Borisoff also works for PDG Mobility and has a financial interest in the Elevation Wheelchair – a product manufactured and sold by PDG.

DEFINITION

Dynamic Wheeled Mobility (DWM)

An alternative approach to ultralight wheelchair configuration that involves using "on the fly" adjustments and add-on components to give users the ability to quickly change the base configuration of their wheelchair for improved usability in multiple environments and activities.

What are we **NOT** talking about?

Power

(conventional dynamic seating)

e.g. from Permobil

Tilt & Recline

(conventional dynamic seating)

e.g. from PDG Mobility

PAPAWs

e.g. from Alber

Standing

e.g. from LEVO AG

DWM is for “Active” manual wheelchair users

History of wheelchairs

The cantilevered frame: introduced over 25 years ago!






Dynamic Wheeled Mobility

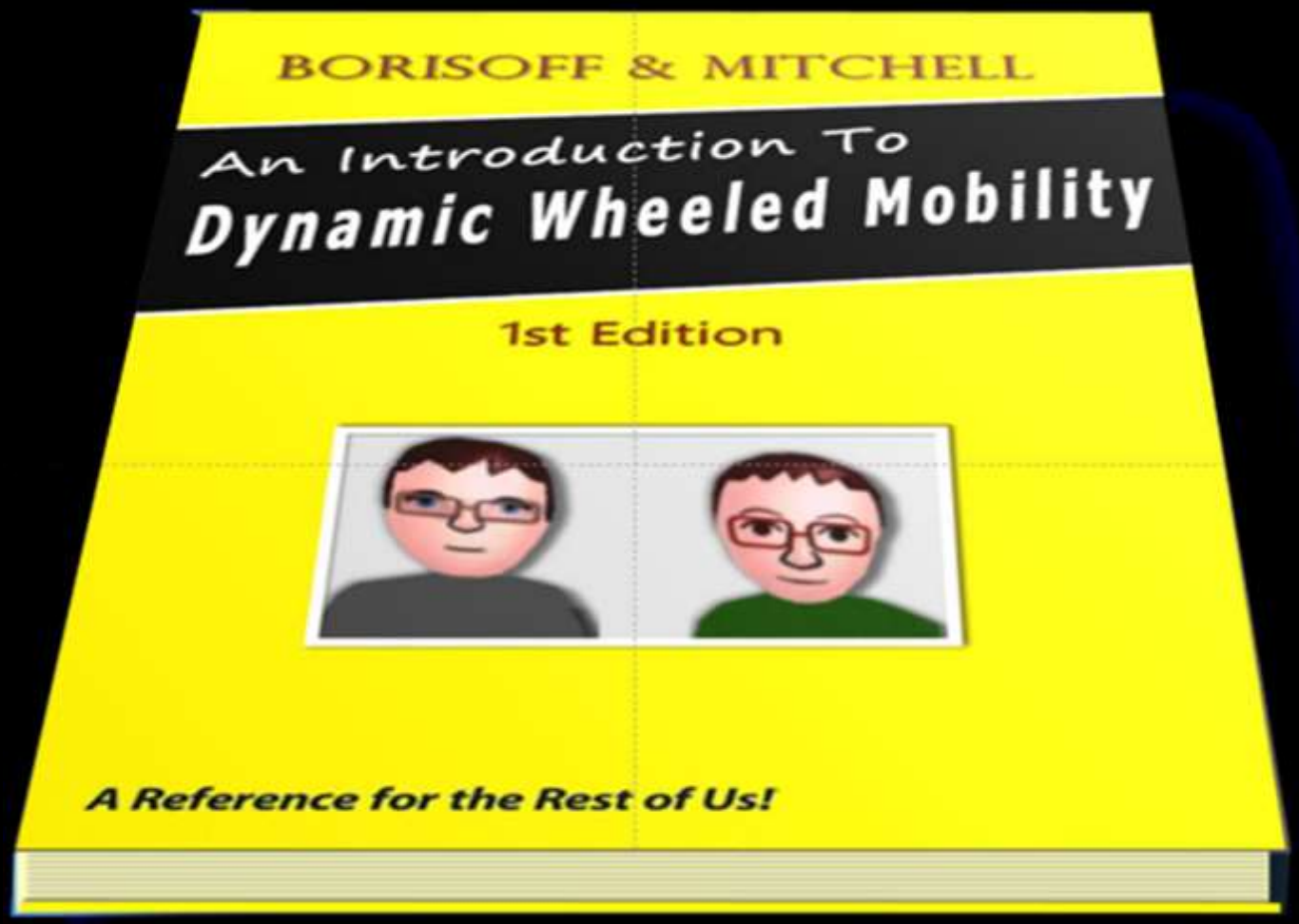
Can the ultralight wheelchair evolve beyond the lightweight static chair it is now?

And why would this be a good thing?

Dynamic Wheeled Mobility

The Future of Ultralight Wheelchairs for Active Users

DWM 101



DWM 101: Rules

- Rule 1: DWM adjustments must be easy to use - “On the fly”.
- Rule 2: Add-ons must be easily installed or removed by the end user.
- Rule 3: DMW features should be "transparent" when they are not used.
- Rule 4: True DWM features do not require significant changes to the "Base Configuration" to use.
- Rule 5: The user should not be dependent on a DMW feature for their day-to-day mobility.

DWM 101: Applications

- Propulsion
  - Inclines
  - Soft surfaces
- Transfers
- Functional Reach
  - Ergonomics, shoulder pain
- ADL's, Activities, and Participation
  - Ease, stability, comfort

DWM 101: Theory

- Guiding Framework: **Clinical Practice Guidelines (CPGs) for Preservation of Upper Limb Function Following Spinal Cord Injury**

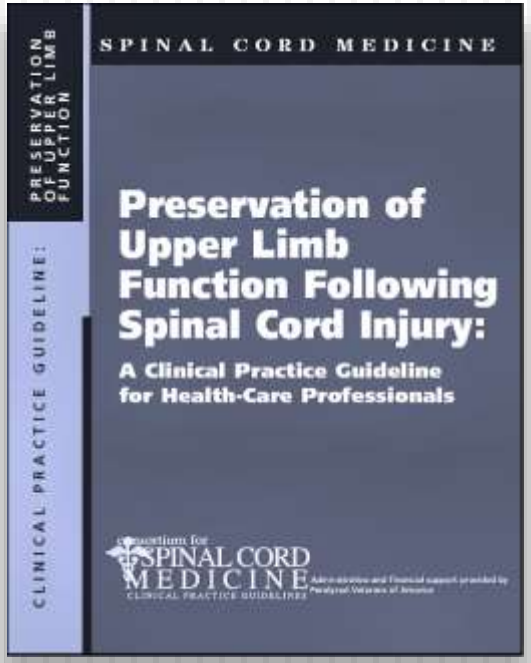
- Usability and the Ultralight Manual Wheelchair
- Designing Wheelchairs for Reasons Other than Propulsion

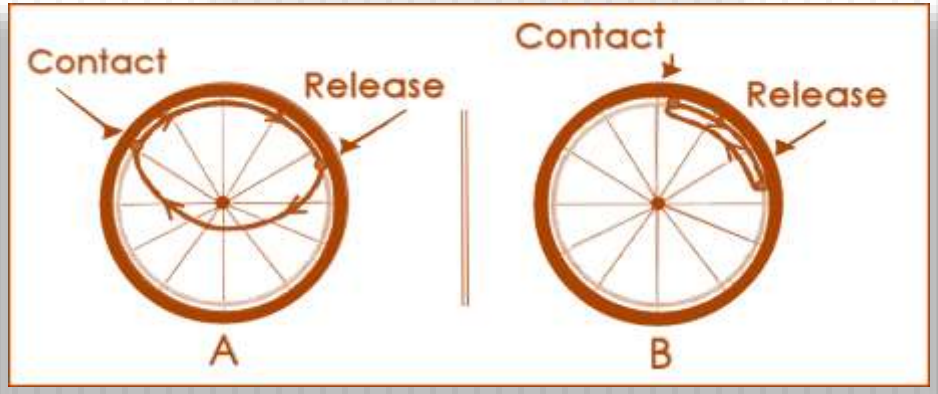
- The Law of Mutually Exclusive Configurations
- Conservation of Contextual Angles

- Question: DWM - Is It Worth the Weight?

DWM 101: Theory

Clinical Practice Guidelines





Paralyzed Veterans of America (PVA) Consortium for Spinal Cord Medicine (2005)

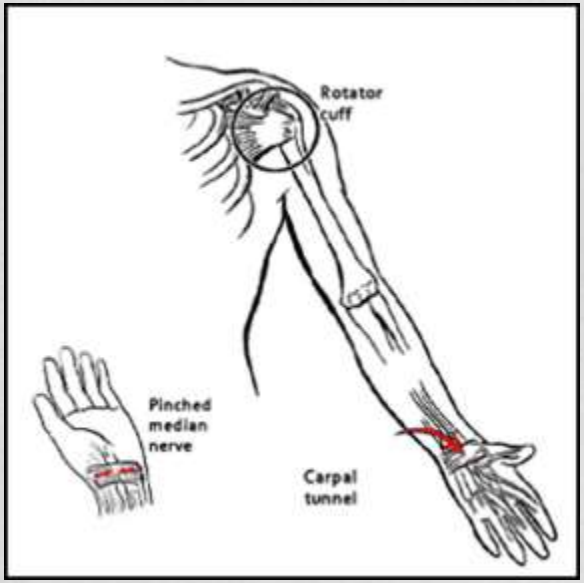
Clinical Practice Guidelines for Preservation of Upper Limb Function Following SCI
Ergonomics

Minimize the **Frequency** of Repetitive Upper Limb Tasks.

Minimize the **Forces** Needed to Complete Upper Limb Tasks.

Minimize **Extreme** or Potentially Injurious **Positions**.

- Avoid extreme positions of the wrist.
- Avoid positioning the hand above the shoulder.
- Avoid extreme positions at the shoulder--including extreme internal rotation & abduction.



Clinical Practice Guidelines for Preservation of Upper Limb Function Following SCI
Equipment selection & Training

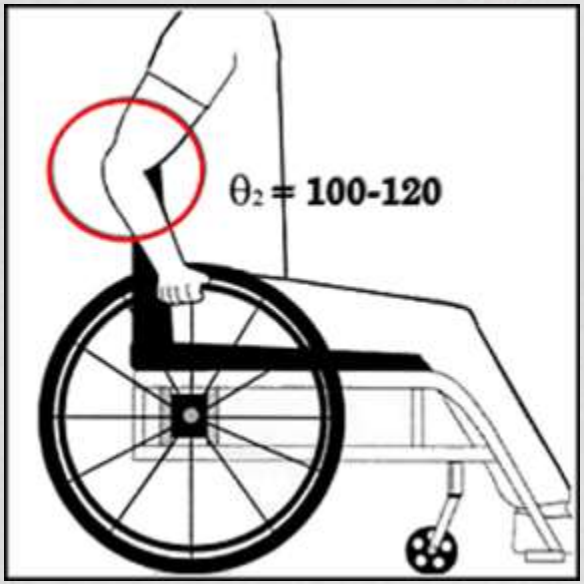
Provide Manual Wheelchair Users with SCI a High Strength, Fully **Customizable**, Wheelchair Made of the **Lightest** Possible Material.

- Lighter Wheelchairs Require Less Force to Propel.
- Lighter Wheelchairs are Adjustable.
- Lighter Wheelchairs are Made with Better Components.

The Wheelchair Should be Configured so That:

- The Rear Axle Is Located as Far Forward as Possible Without Compromising the Stability of the User.

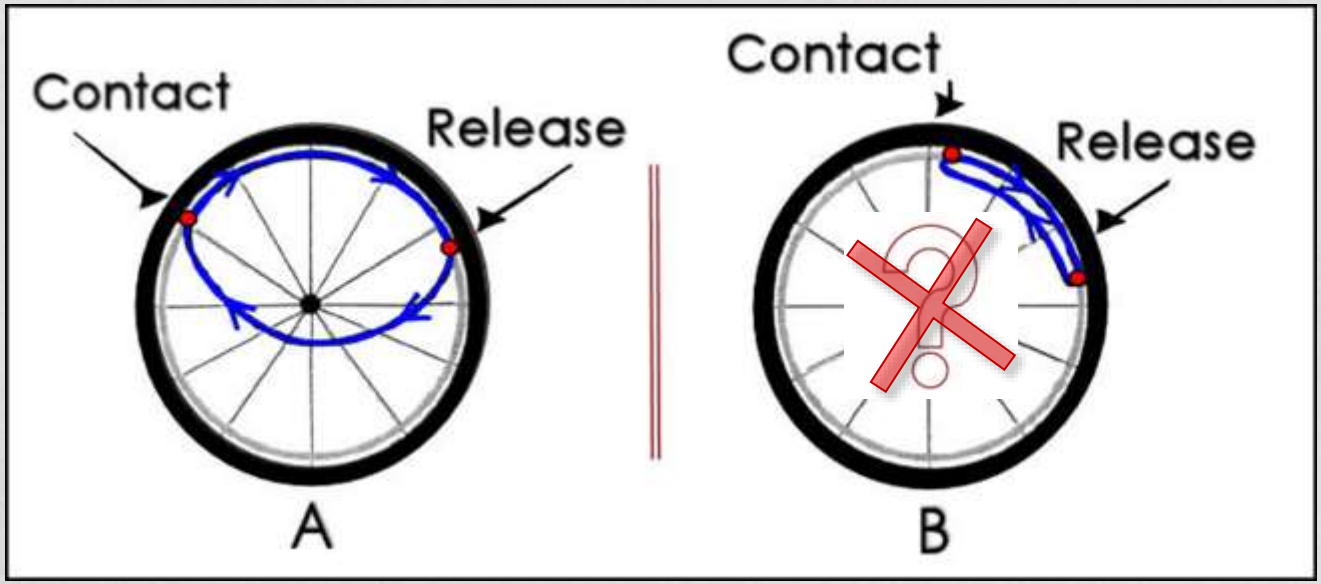
- the Rear Axle Is Positioned so That the Hand is at the Top Dead-Center of the Pushrim and the Angle Between the Upper Arm & Forearm is 100 -120 Degrees.



Instruct Manual Wheelchair Users With SCI to:

- Use Long, Smooth Strokes that Limit High Impacts on the Pushrim.
- Use a Semicircular pushing pattern.

SEMICIRCULAR ARC PATTERN



Clinical Practice Guidelines for Preservation of Upper Limb Function Following SCI
Equipment selection & Training

Instruct Individuals with SCI who Complete Independent Transfers to:

- Perform Level Transfers When Possible.
- Avoid Positions of Impingement When Possible.
- Vary the Technique Used and the Arm that Leads.

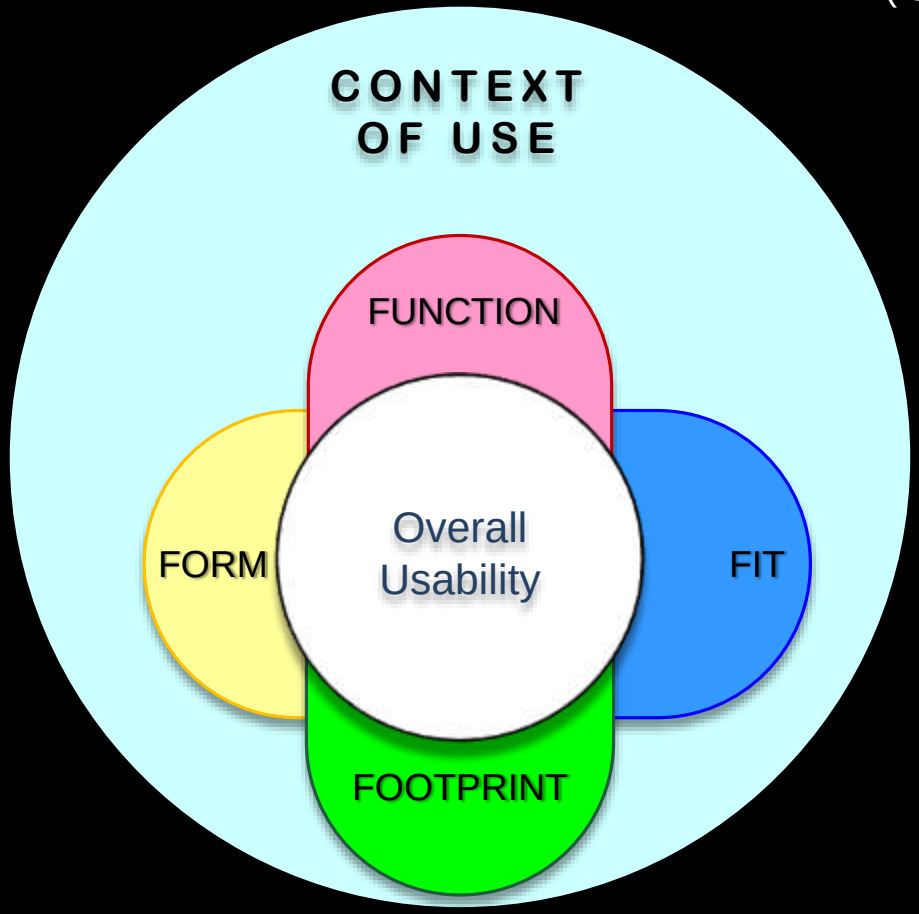
CPG's and ultralights – what are missing?

- The role of an ultralight's configuration and setup in minimizing Frequency, Forces, & Extreme Positions of the upper extremities during ***activities*** **not** involving **propulsion** on level smooth surfaces is limited.
  - Transfers
  - Reaching
  - Other ADL's
  - Propulsion on non-level surfaces
  - Surfaces with higher rolling resistance

The Concept of Usability and the Ultralight Manual Wheelchair

"The extent to which a product can be used by specified users to achieve specified goals with Effectiveness, Efficiency, and Satisfaction in a specified Context of Use."

(*ISO 9241-11*)



Static Configuration and “Optimal” Setup

While most conventional ultralight designs provide sufficient adjustability to be customized for an individual user, the configuration itself is inherently "static".

A static configuration can never provide optimal usability during every functional task & environment in which the user with SCI routinely uses their wheelchair.

As a result, optimizing an ultralight's configuration has primarily focused on propulsion and positioning in the user's primary environment of use.
(We refer to this as the user's "Base Configuration")

Ensuring the individual can safely use their chair in other environments and activities is usually addressed by deciding what concessions & trade-off's need to be made to the user's base configuration.

Static Configuration: Concessions and Trade-off's

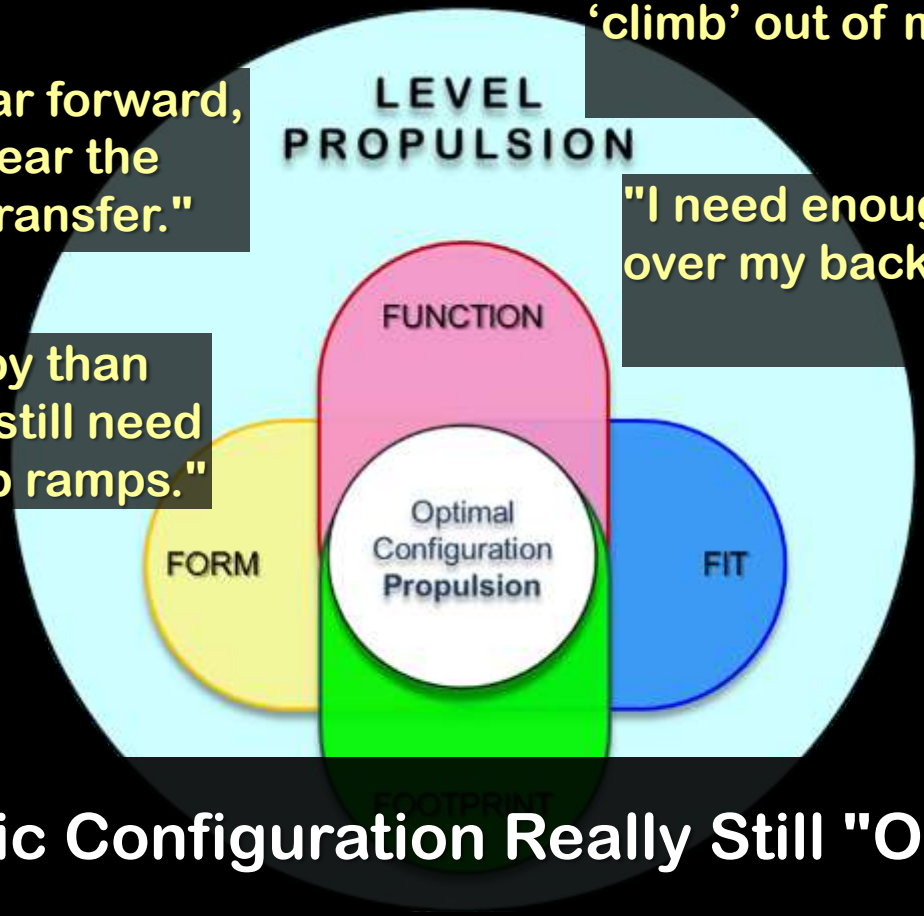
These concessions & trade-off's frequently result in a base configuration to be less than optimal for any single context of use…

"With that much dump, I can't 'climb' out of my seat."

"If the axle is that far forward, I won't be able to clear the rear wheel when I transfer."

"I need enough stability to bridge over my backrest to get dressed.

"My chair is less tippy than I'd prefer because I still need to be able to push up ramps."



Is a Static Configuration Really Still "Optimal"?

Designing Wheelchairs for Functions Other Than Propulsion

…

WHY?

How do people use wheelchairs?

Propulsion during the day: **Daily Means**

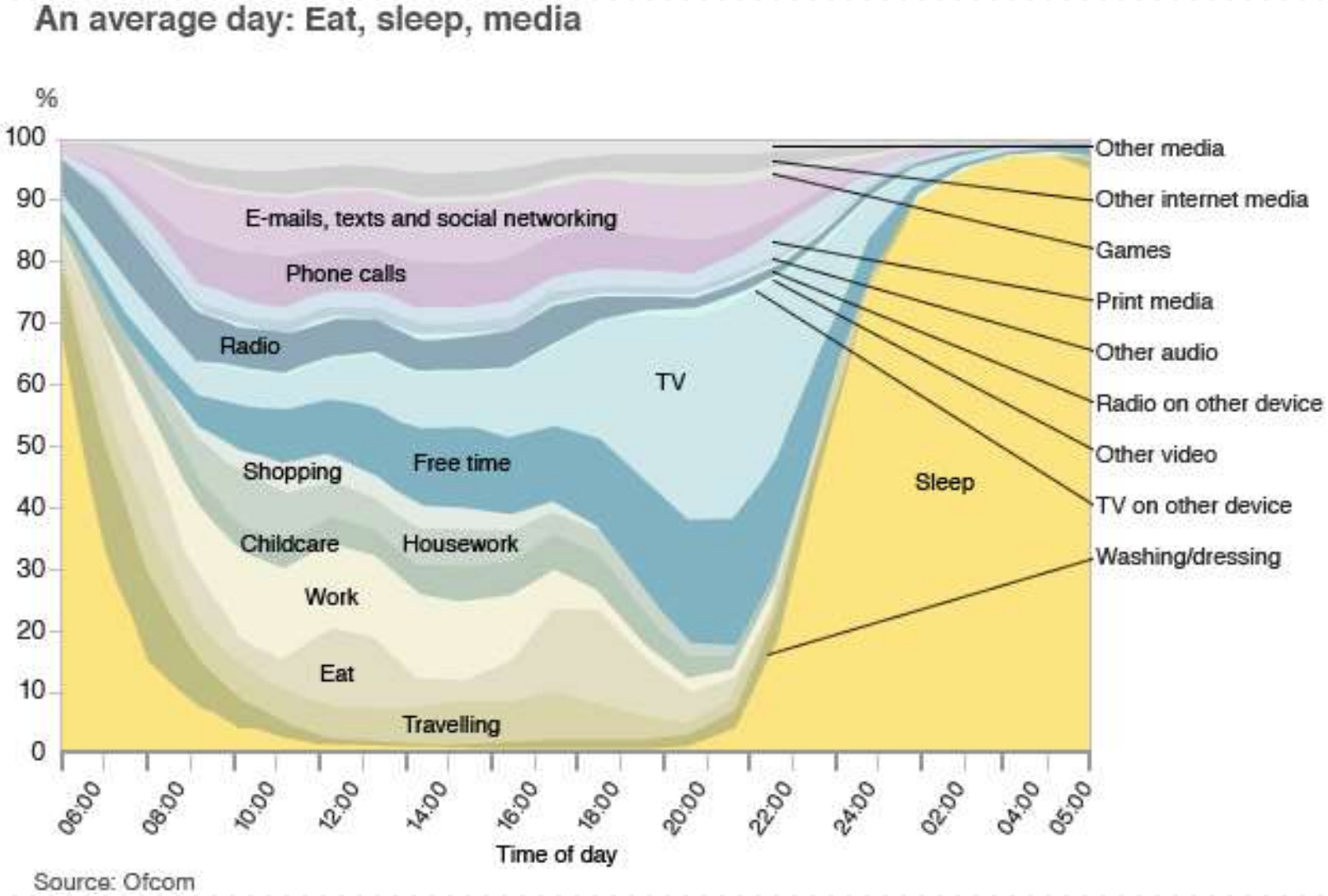
Distance	Time	Bouts	Occupancy
1.5 km	58 min	96	11 hrs

~ 10%

"Bouts of Mobility"

Sonenblum and Sprigle, Georgia Tech

Daily Activities



http://www.bbc.co.uk/news/technology-11012356 via Gary Moulton

Chairs for everyone else are “dynamic”

DWM - Is It Worth the Weight?

For Propulsion?

- Wheelchairs for sports are often significantly heavier than an athlete's everyday wheelchair

- Wheelchair rugby chairs average mass = **41 lbs.** [1]

[1] B. S. Mason, L. H. van der Woude and V. L. Goosey-Tolfrey, "Influence of glove type on mobility performance for wheelchair rugby players," Am. J. Phys. Med. Rehabil., 88:559-570, 2009.

DWM - Is It Worth the Weight?

How important is 3 lbs. on 200 lbs. system?

"Additional mass (up to 5kg) loaded on a manual wheelchair does not seem to have any effect on energy expenditure, heart rate, or performance"

Arch Phys Med Rehabil. 2010 Aug;91(8):1248-54. doi: 10.1016/j.apmr.2010.05.011.

Effects of wheelchair mass on the physiologic responses, perception of exertion, and performance during various simulated daily tasks.

Sagawa Y Jr[1], Watelain E, Lepoutre FX, Thevenon A.

Where is weight important?

- Lifting the chair into a car

DWM 101: Concepts & Applications

DWM: Concepts

- MODULAR DESIGNS
- ADD-ON COMPONENTS
  - Products That Reduce Rolling Resistance
  - Mechanical Alternatives to Traditional Propulsion
  - Power Add-On Systems
- DYNAMIC “on the fly” RECONFIGURATION
  - For Function / ADLs
  - To Improve Propulsion
  - To Facilitate Transfers

DWM – Modular Designs

- Lasher BT-X

- Icon A1

MODULAR DESIGNS – Lasher BT-X

DWM – Add-On Components

- Power Add On Systems

In contrast to PAPAWs, these add-on components do not change the base configuration of an ultralight chair, yet provide similar propulsion assistance.

- Mechanical Alternatives to Traditional Propulsion

Non-electrical add-ons such as lever drives or geared rear wheels.

- Products That Reduce Rolling Resistance

Front attachments or alternate rear wheels to make propulsion easier on soft terrain such as grass, dirt, or snow.

ADD-ON COMPONENTS - Power Add-On Systems

- SmartDrive

- Rio Mobility Firefly

ADD-ON COMPONENTS - SmartDrive

- Weight – 8lb battery, 11lb motor

ADD-ON COMPONENTS - Mechanical Alternatives

- Lever Drives
- Manual geared wheels

ADD-ON COMPONENTS - Mechanical Alternatives

- Clip-on handcycles

ADD-ON COMPONENTS - Reduce Rolling Resistance

- Freewheel

ADD-ON COMPONENTS - Reduce Rolling Resistance

- Wheelblades

DWM – DYNAMIC RECONFIGURATION

- Dynamic Repositioning For Function & ADL's

Real time adjustments which change the user's posture or orientation (and seated stability, i.e. Active Stability Management) in the wheelchair to perform self-care, ADLs, and other functional tasks with greater ease.

- Dynamic Repositioning To Improve Propulsion

On the fly adjustments which change the user's: posture or pushrim orientation or COG to improve biomechanical efficiency and minimize extreme joint positions during propulsion under specific conditions (e.g. ramps, obstacles, going downhill).

- Dynamic Repositioning To Facilitate Transfers

Adjustments to facilitate safe and efficient transfers by reducing transfer gaps, improving clearance with the rear wheel, leveling the seat, or matching surface heights.

DWM Chair Examples

- Modified Icon A1

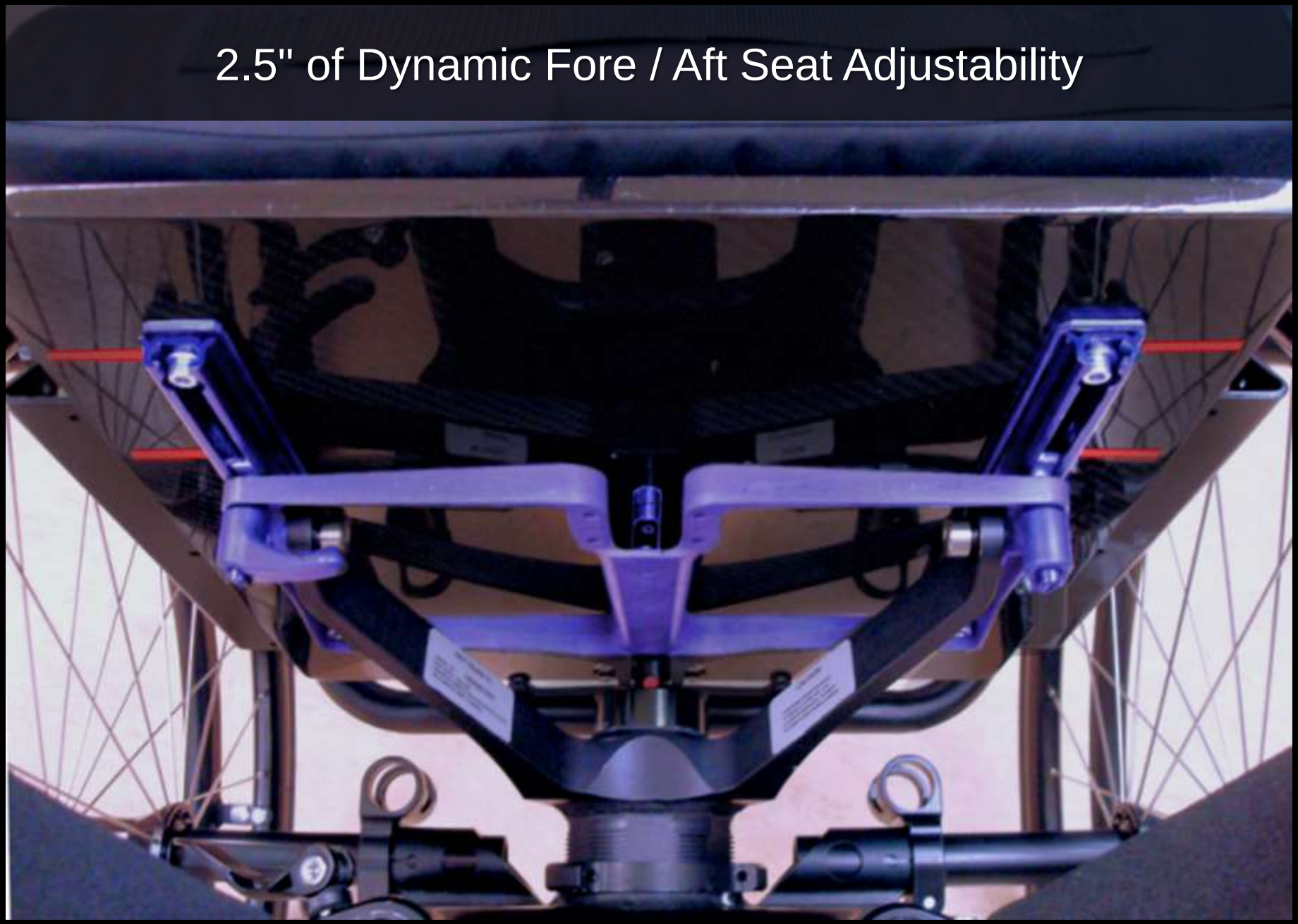
- Elevation by PDG

Modified Icon A1

2.5" of Fore/Aft Seat Adjustability

2.5" of Dynamic Wheelbase Adjustability

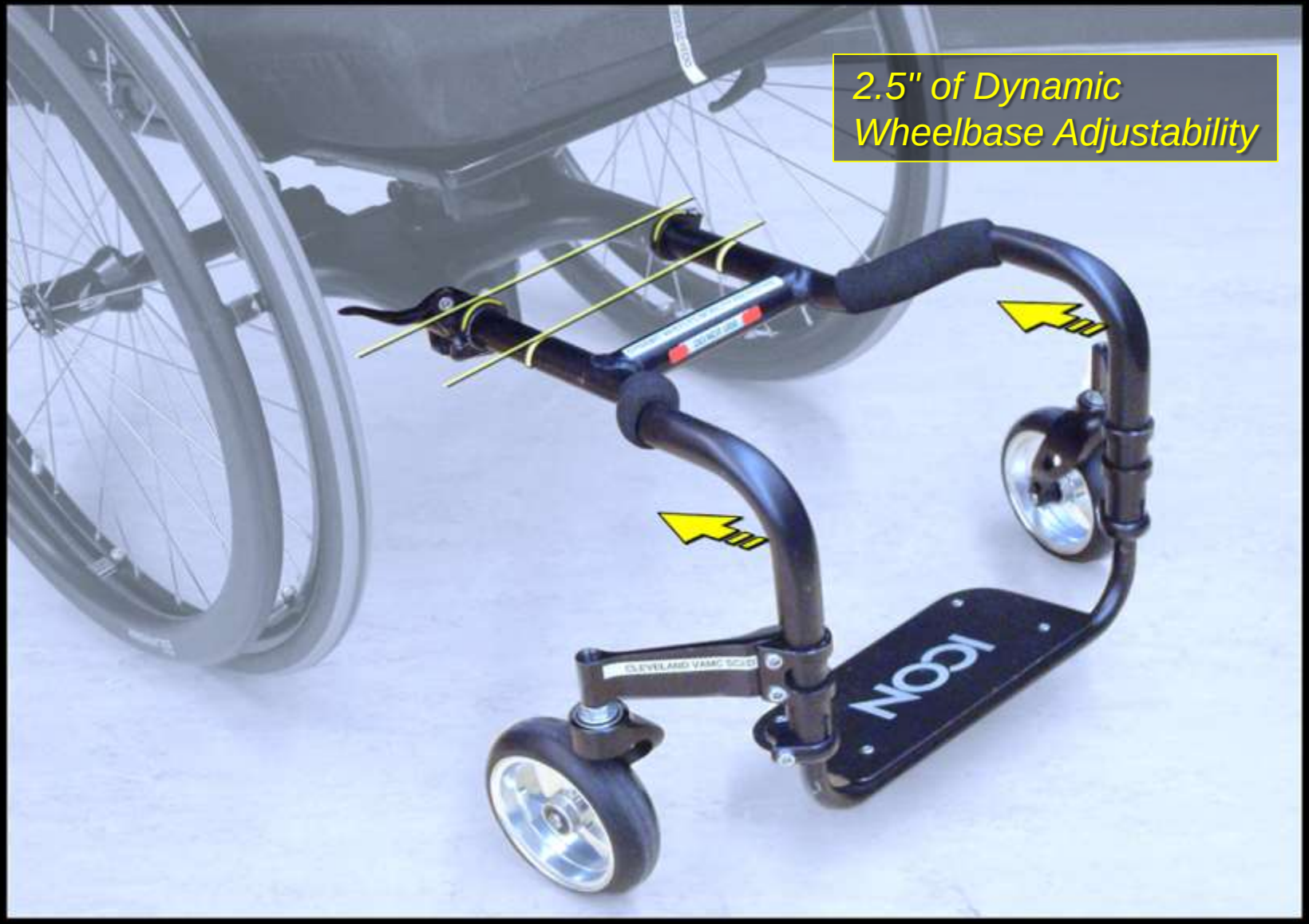
Modified Icon A1



Modified Icon A1

2.5" of Fore/Aft Seat Adjustability

Modified Icon A1



A Commercially Available DWM Wheelchair

Dynamic Seat Height

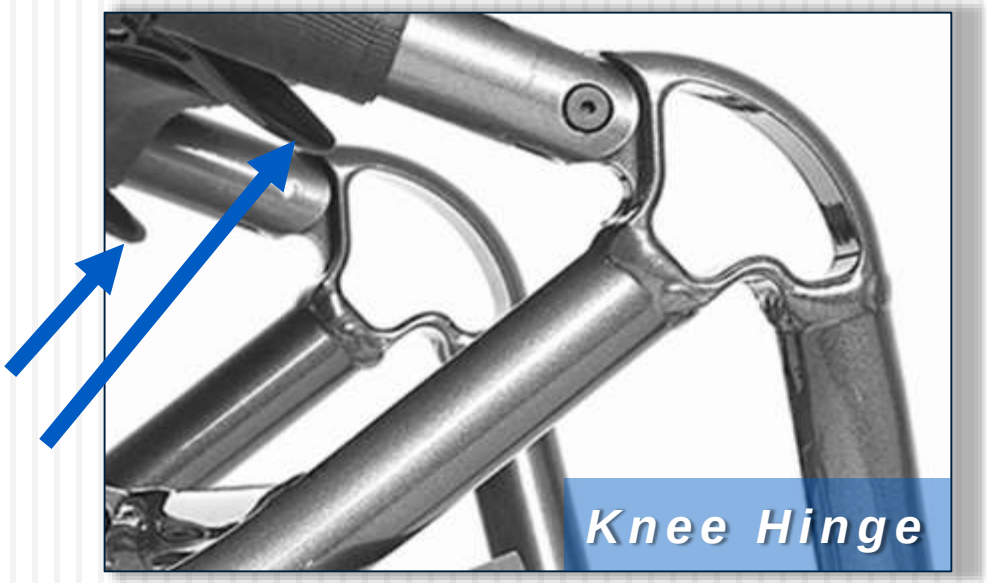
(10” or > 30°) of On-The-Fly Seat Height Adjustment

Dynamic Recline

30° of On-The-Fly Back Angle Adjustment

ELEVATION

(PDG Mobility Technologies)



DWM rule: <u>easy to use</u>
"On the fly" adjustability

Elevated seating stability

“lifting” side guards

ELEVATION

(PDG Mobility Technologies)

Dynamic Wheeled Mobility

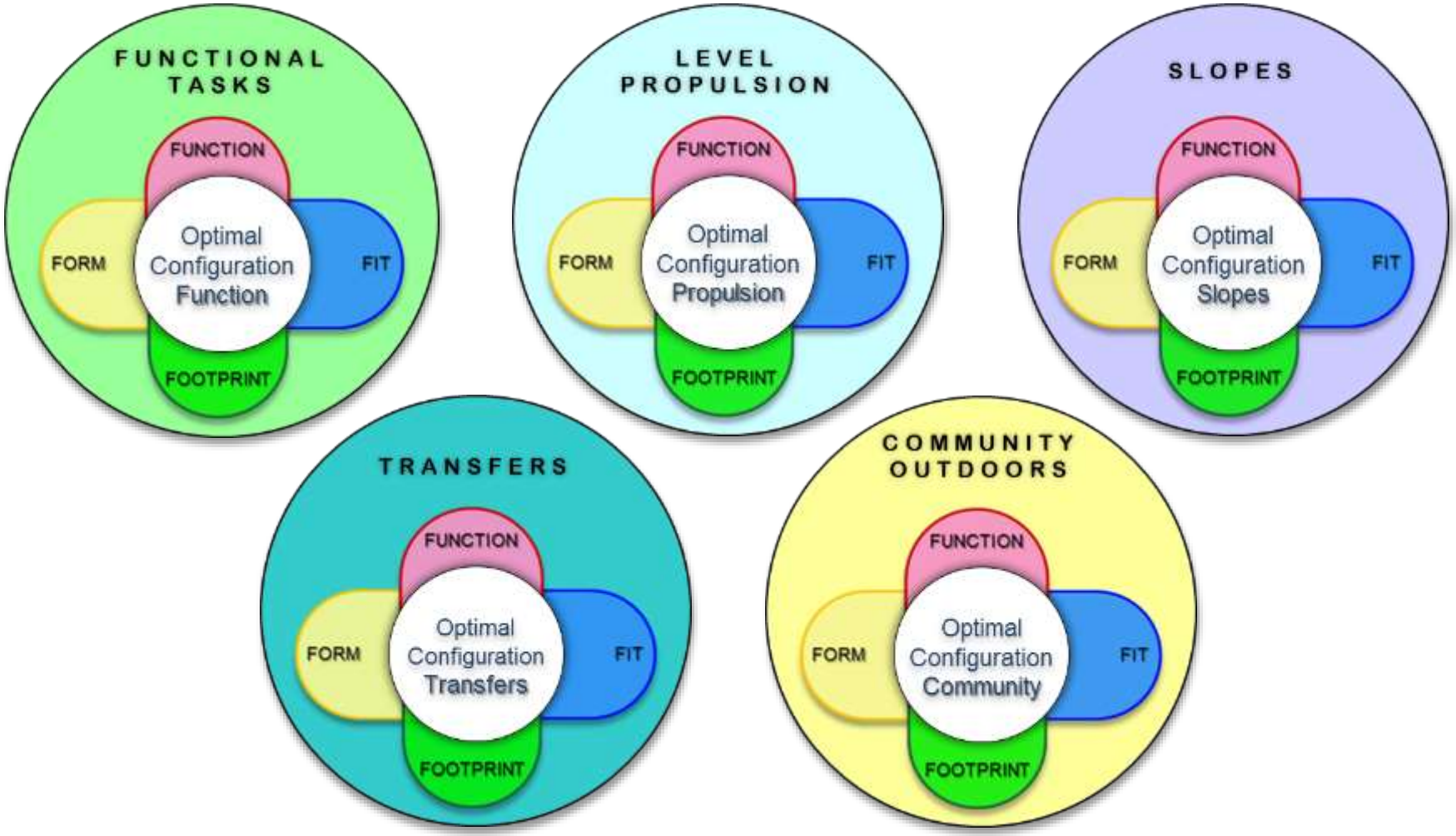
DWM 101: Theory

The last bit, I promise…

The Law of Mutually Exclusive Configurations

The Law of Mutually Exclusive Configurations

There Is an Inverse Relationship Between the Optimal Configuration for Smooth Level Propulsion and Most Other Functional Tasks



The Law of Mutually Exclusive Configurations

There Is an Inverse Relationship Between the Optimal Configuration for Smooth Level Propulsion and Most Other Functional Tasks

Optimal Propulsion on Smooth Level Surfaces Requires The User To *Sit Lower & Further Back* In The Chair.

Functional Reach Is Maximized When The User Is Sitting *Higher & Toward The Front* Of The Chair.

Transfers are easiest when The User Is Level and/or both surfaces are matched in height.

The Law of Mutually Exclusive Configurations

There Is an Inverse Relationship Between the Optimal Configuration for Smooth Level Propulsion and Most Other Functional Tasks

Conservation of Contextual Angles

Conservation of Contextual Angles

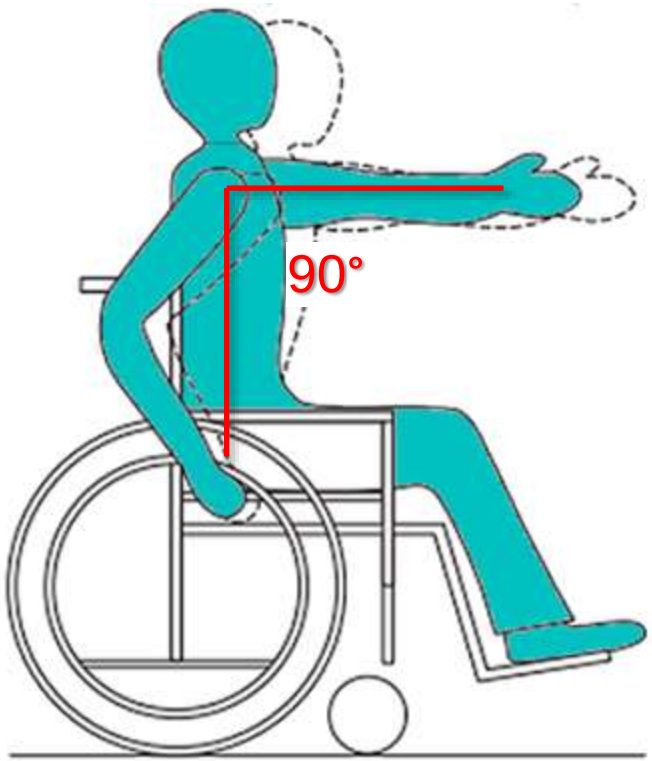
Changing key angles of the ultralight, its user, or the environment will result in changes to other angles in order to offset that change.

$$\sum \Delta\ \text{angles}^{\text{COMBINED}} = \Delta\ \text{angles}^{\text{DEVICE}} + \Delta\ \text{angles}^{\text{USER}} + \Delta\ \text{angles}^{\text{ENVIRONMENT}}$$

Conservation of Contextual Angles

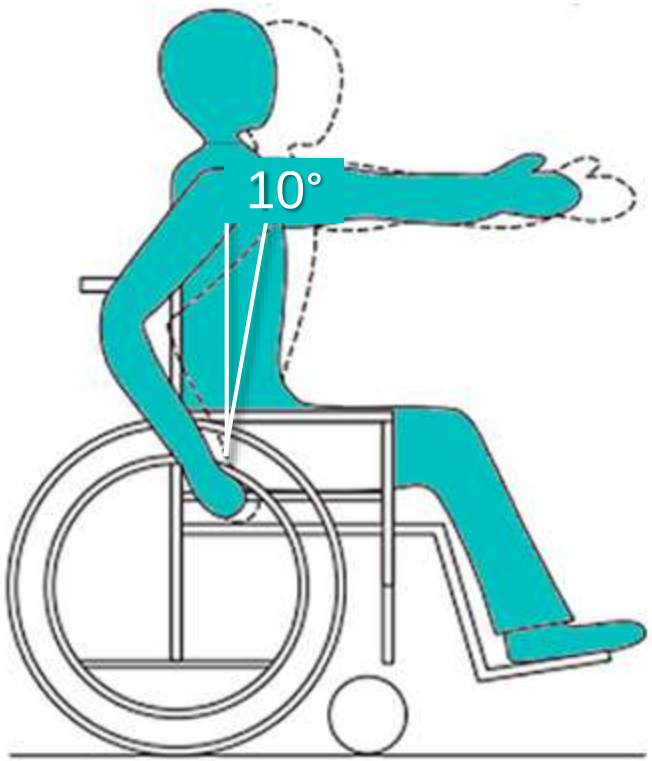
USER

Δ angles



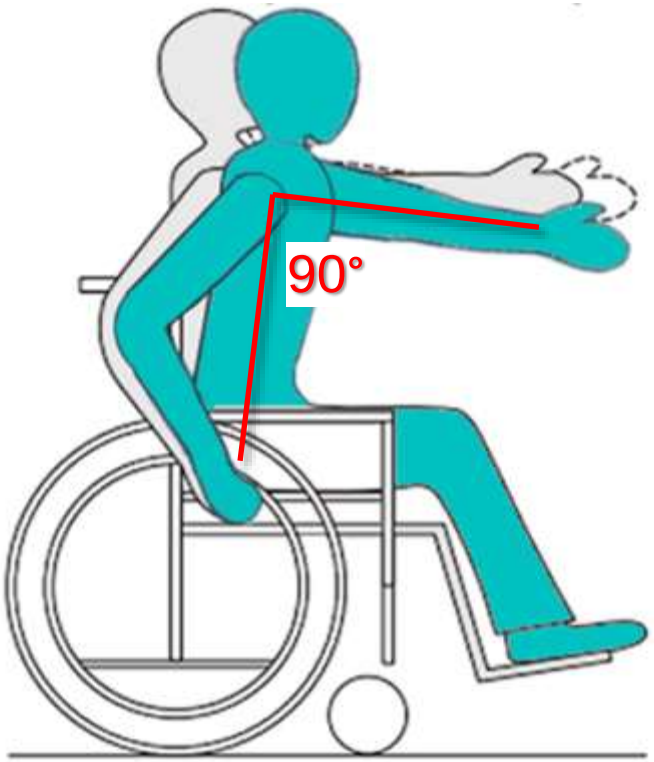
Conservation of Contextual Angles

Δ angles USER



Conservation of Contextual Angles

Δ angles USER



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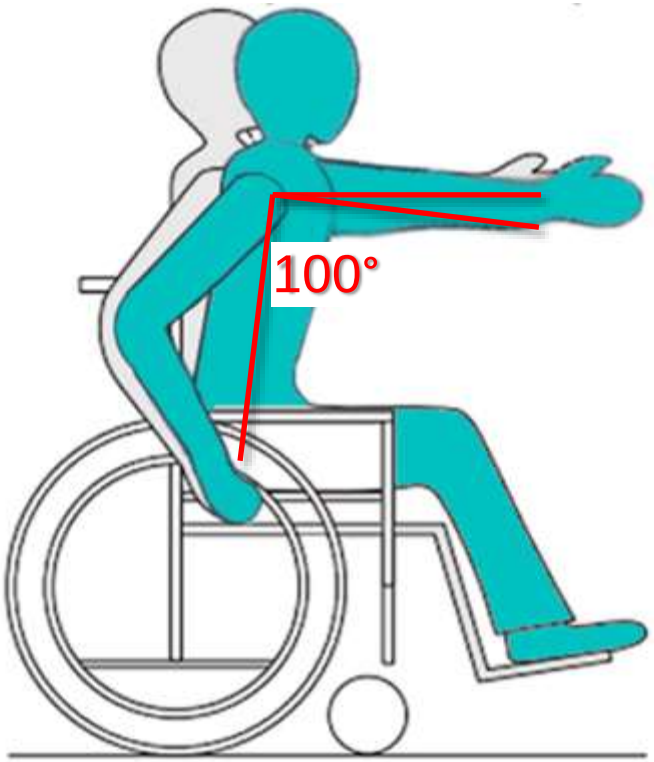
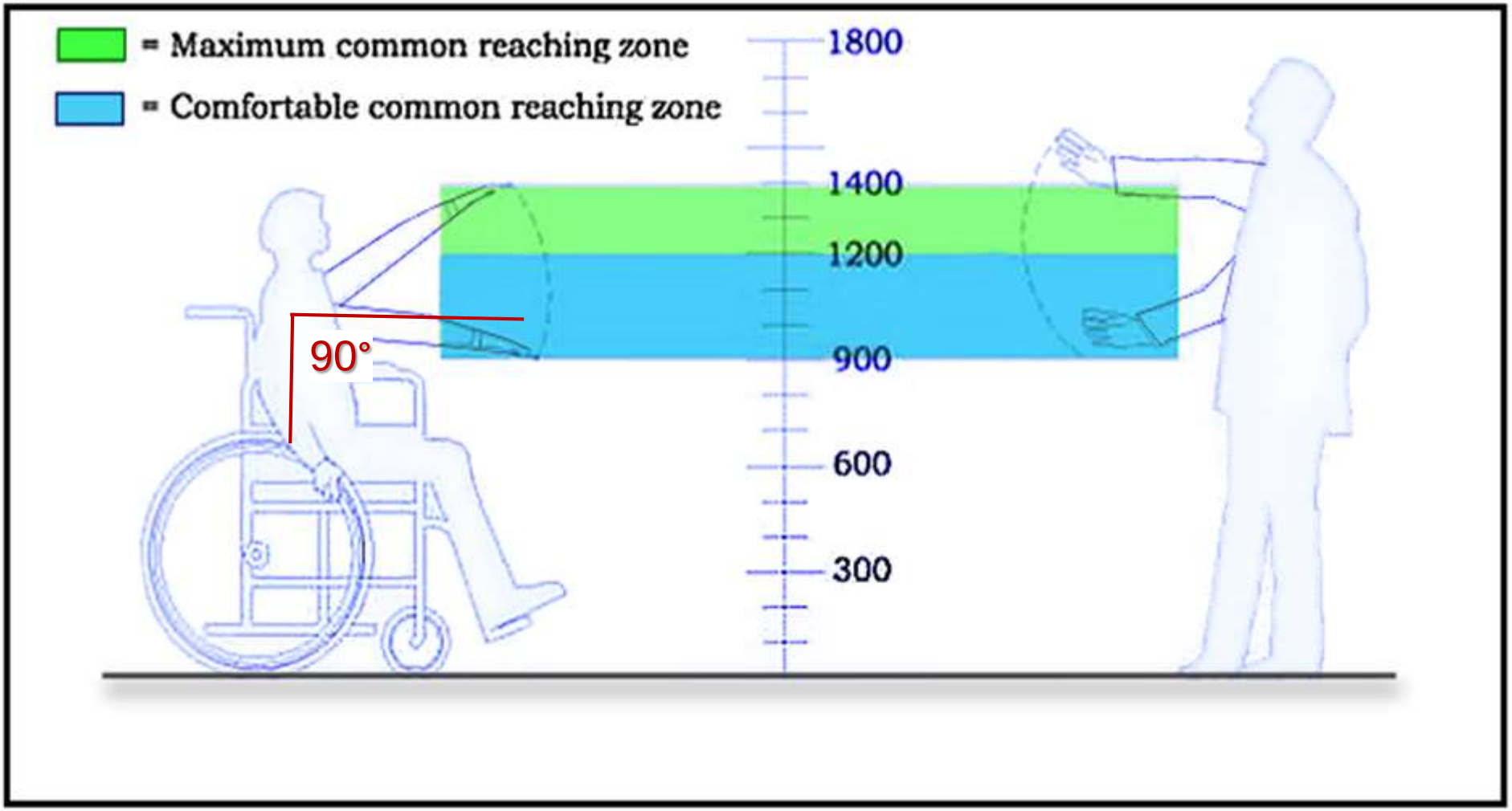
Δ angles USER



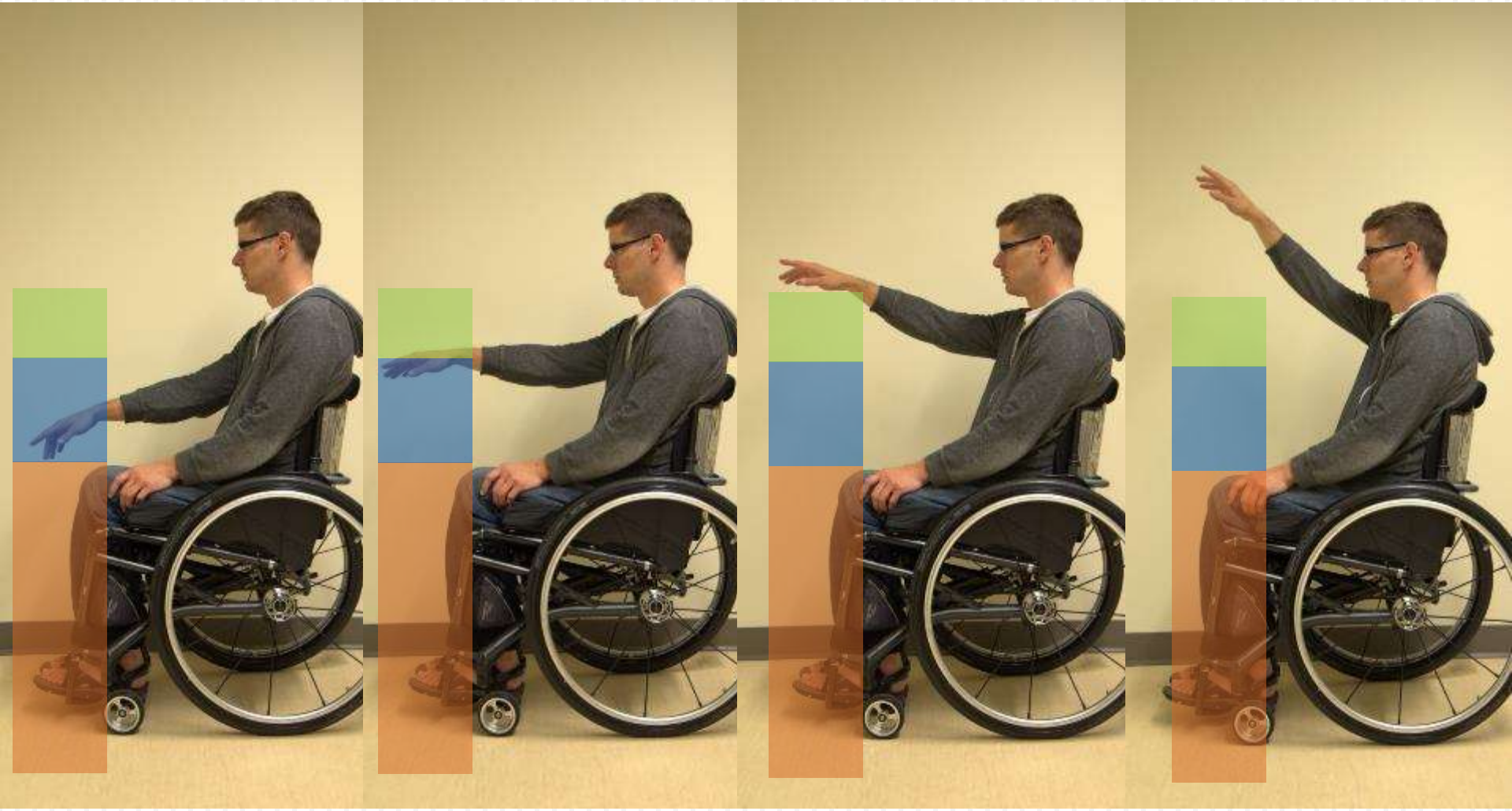
DWM Applications: Reach

"Avoid positioning the hand above the shoulder"

"Avoid positioning the hand above the shoulder"

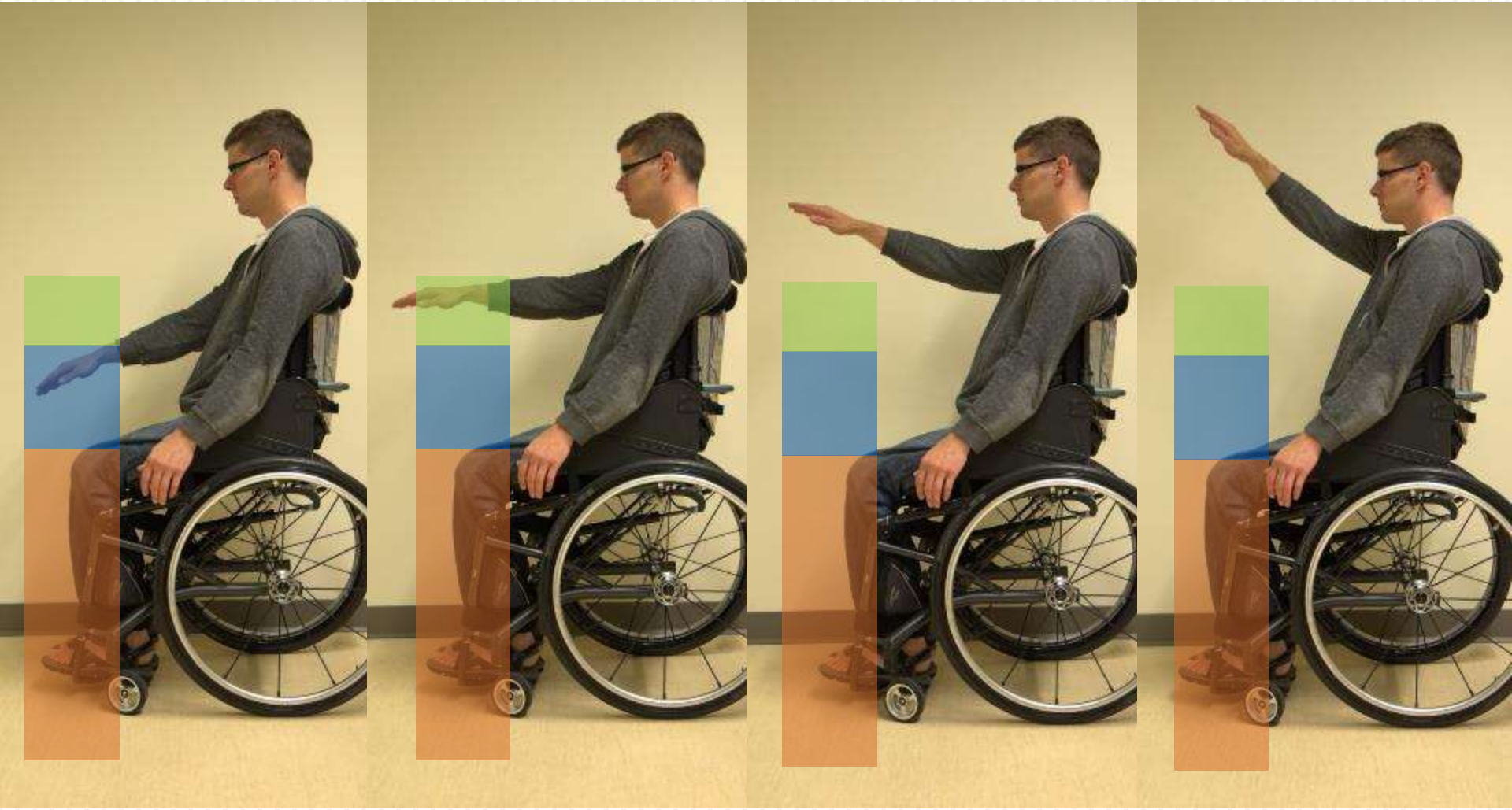


"Avoid positioning the hand above the shoulder"



How?

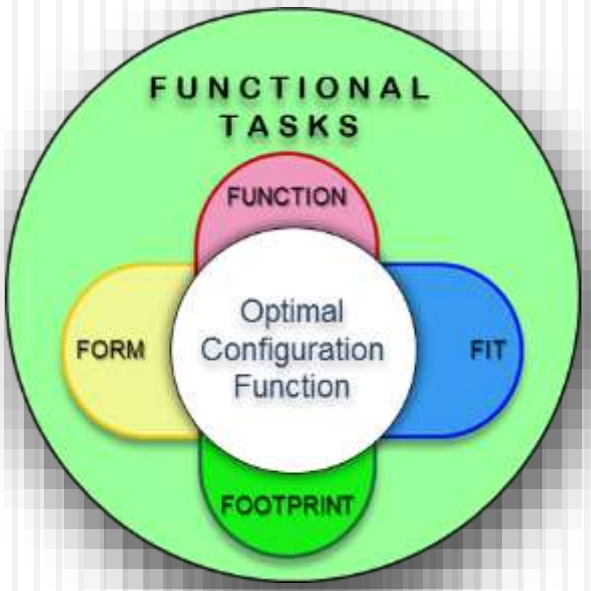
"Avoid positioning the hand above the shoulder"



That’s How!

A NEW WAY THAT THE ULTRALIGHT CAN EFFECTIVELY IMPLEMENT A CPG!!

DYNAMIC REPOSITIONING FOR FUNCTION



FUNCTIONAL REACH

What about the Ground? Reaching Down?

- **Reaching to grab objects**
- **Tasks "on your lap"**

DWM Applications: Propulsion

"Minimize the Forces Needed to Complete Upper Limb Tasks“

"Minimize Extreme or Potentially Injurious Positions“

…SLOPES!

DYNAMIC REPOSITIONING TO IMPROVE PROPULSION

SLOPES

ADA Standard for a for a New Construction is 4.8° (12:1).

ADA Maximum for an *Existing Building* is 7° (8:1).

Minivan Ramps Angles Range from 8-12°.

CASE STUDY

Why Is Steve Anxious About Going Up Minivan Ramps If His Chair Has Really Been "Optimally Configured"?

17x16+0 85 Degree TiLite ZRc

17x16+0 85 Degree TiLite ZRc

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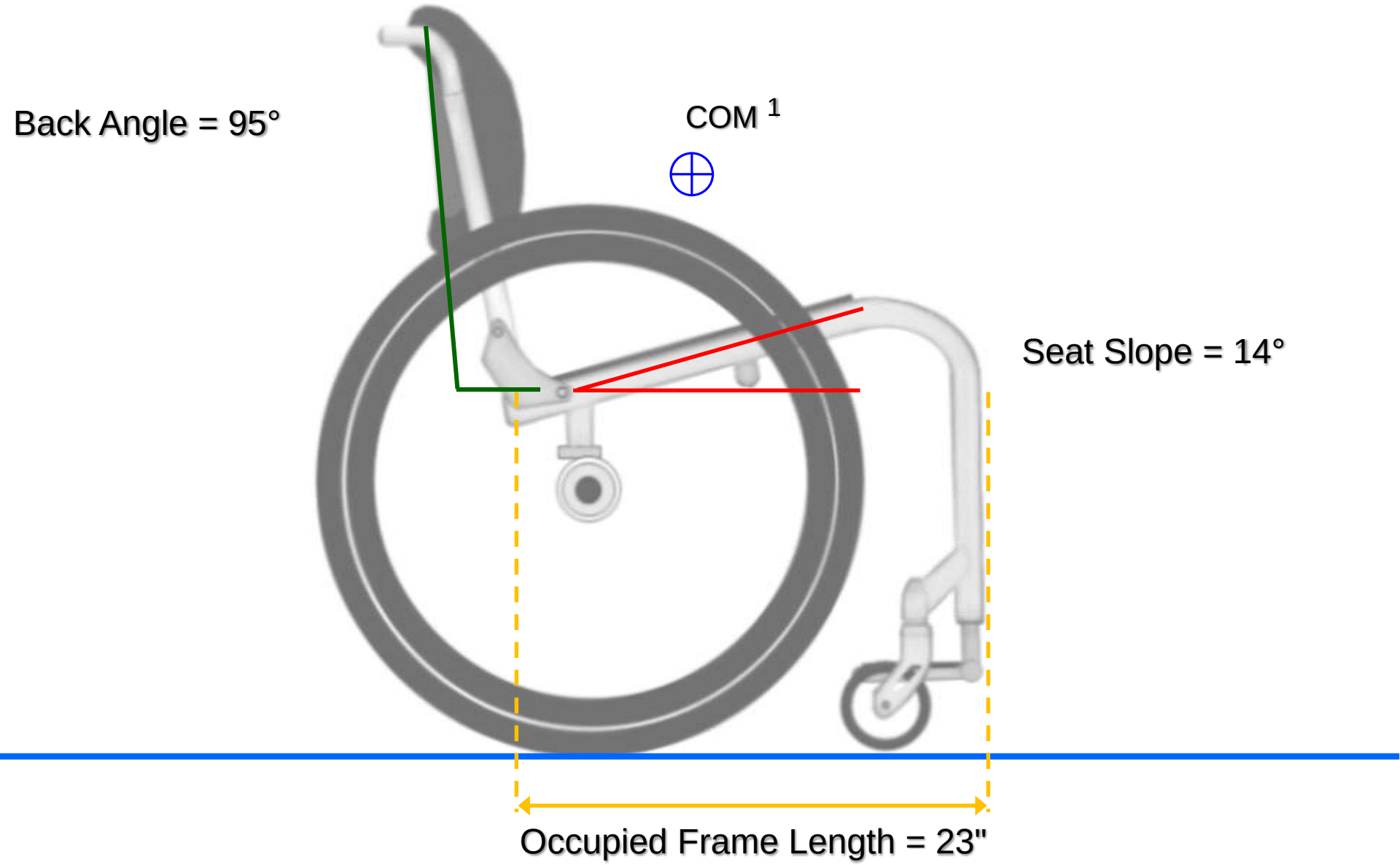
An Optimal Configuration for Smooth Level Surfaces

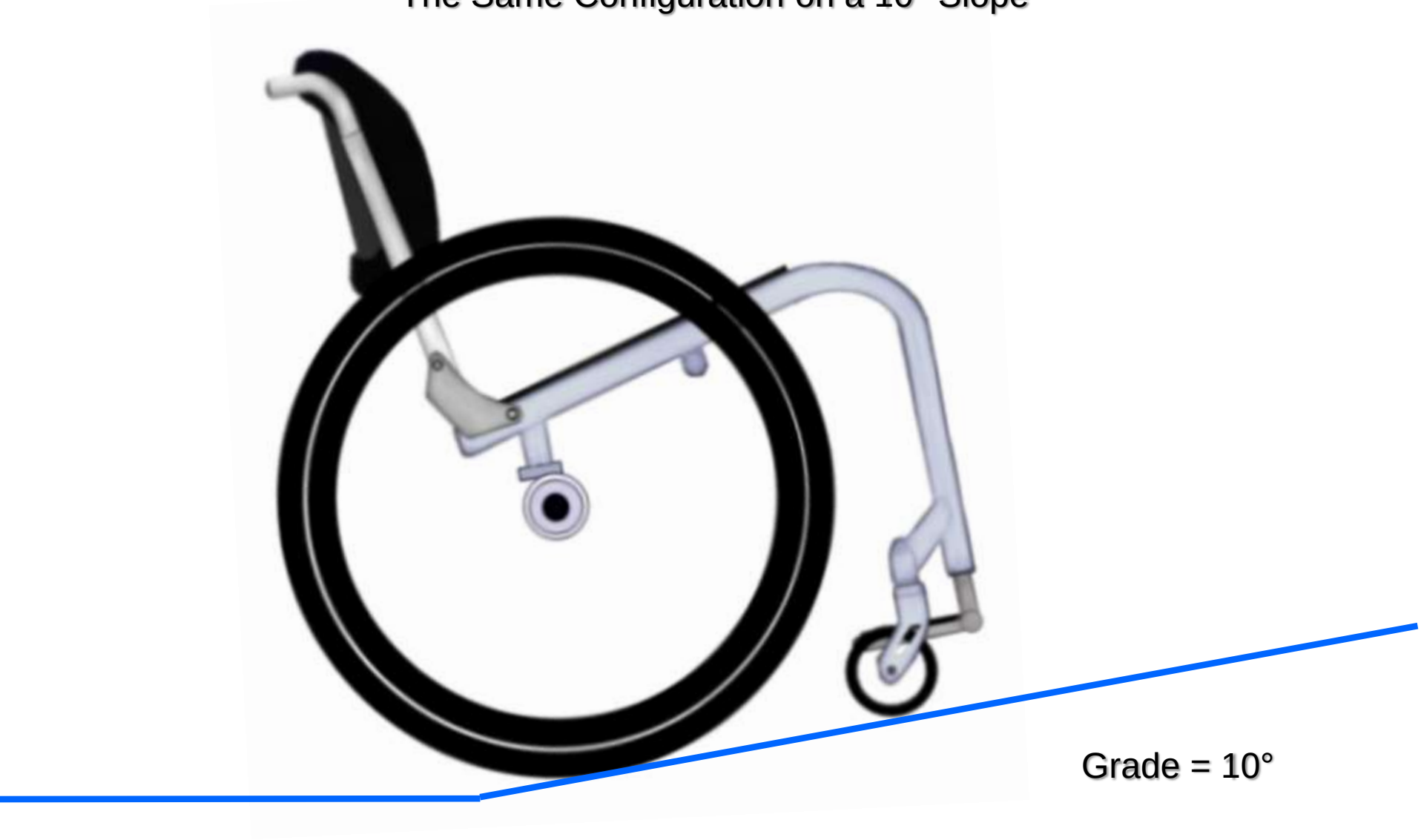
17x16+0 85 Degree TiLite ZRc

An Optimal Configuration for Smooth Level Surfaces



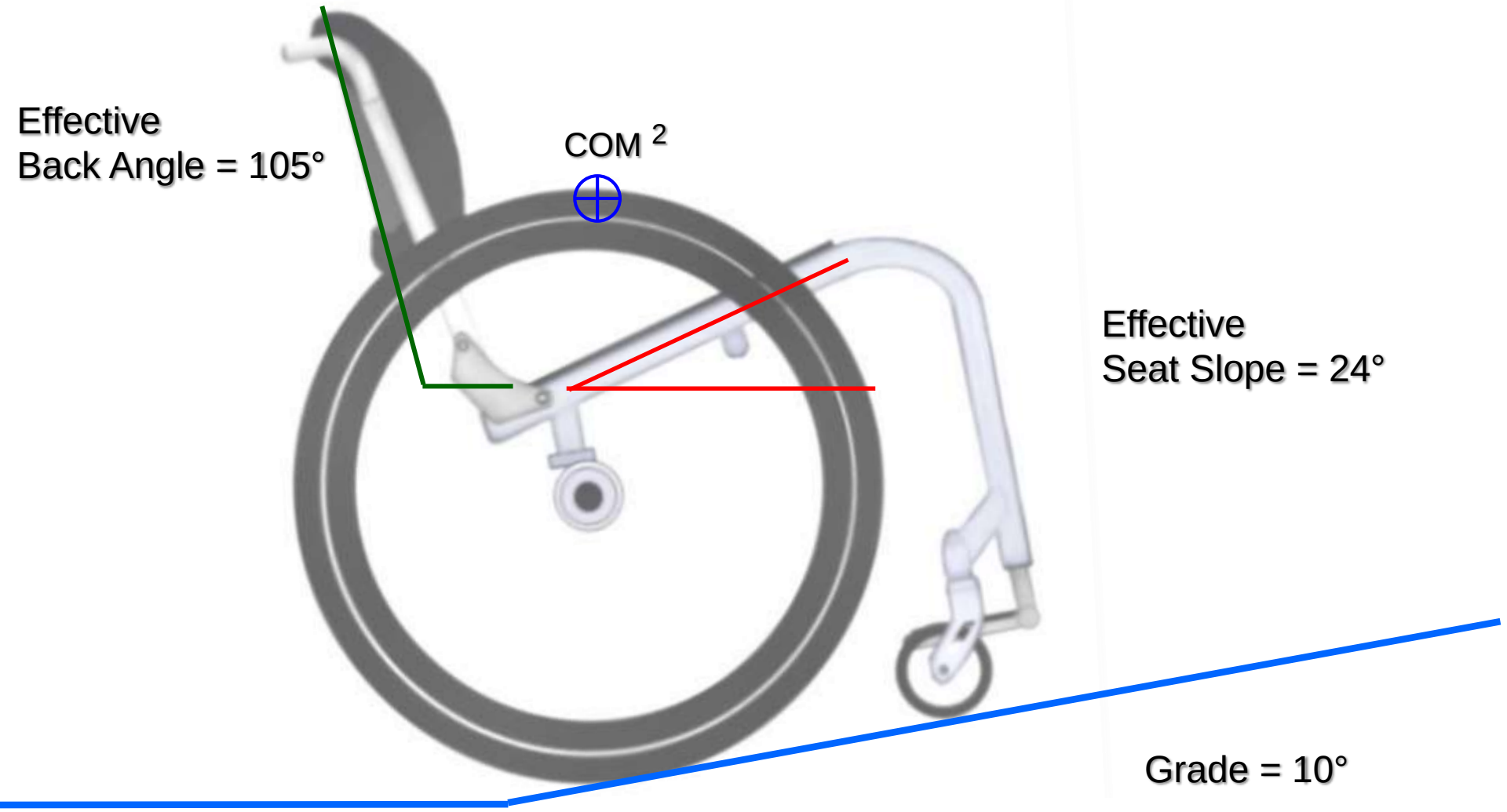
17x16+0 85 Degree TiLite ZRc

The Same Configuration on a 10° Slope



17x16+0 85 Degree TiLite ZRc

Configuration on a 10° Slope



Conservation of Contextual Angles

Analysis

$\Delta\ angles^{DEVICE} = D$

$\Delta\ angles^{USER} = U$

$\Delta\ angles^{HILL} = H$

$\Sigma\ \Delta\ angles^{COMBINED} = \Sigma\ \Delta$ **DUH!**

Conservation of Contextual Angles

Now how can we fix the problem?

Conservation of Contextual Angles

We Can Change the Angles of the Seating...

and / or

...We Can Change The Center of Mass or Pushrim Orientation by Moving the Seat Forward

Effect of Dynamic Reconfiguration

14° SEAT slope **(4” seat dump)**
95° BACK recline

“Optimal” Configuration for Steve

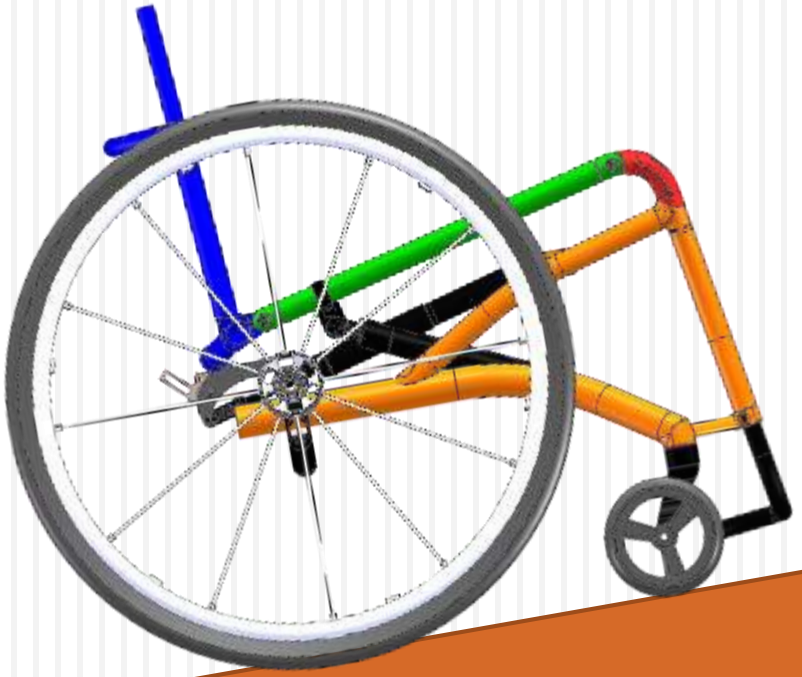
Dynamic Repositioning For Function: PROPULSION – LEVEL WHEELING

14° SEAT slope (4” seat dump)
95° BACK recline

Dynamic Repositioning For Function: PROPULSION – UP HILL (10 degrees)

14° SEAT slope
95° BACK decline

Effective
Back Angle = 105°

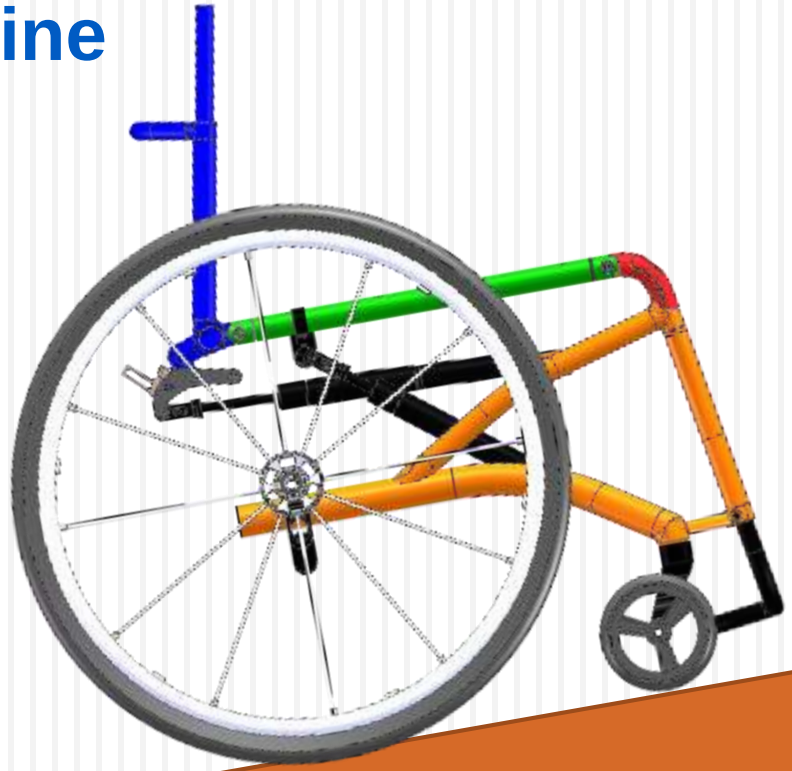


Effective
Seat Slope = 24°

Dynamic Repositioning For Function: PROPULSION – UP HILL (10 degrees)

0° SEAT slope (flat seat)
80° BACK decline

Effective
Back Angle = 0°



Effective
Seat Slope = 10°

Dynamic Repositioning For Function: PROPULSION – DOWN HILL

Dynamic Repositioning For Function: PROPULSION – LEVEL WHEELING

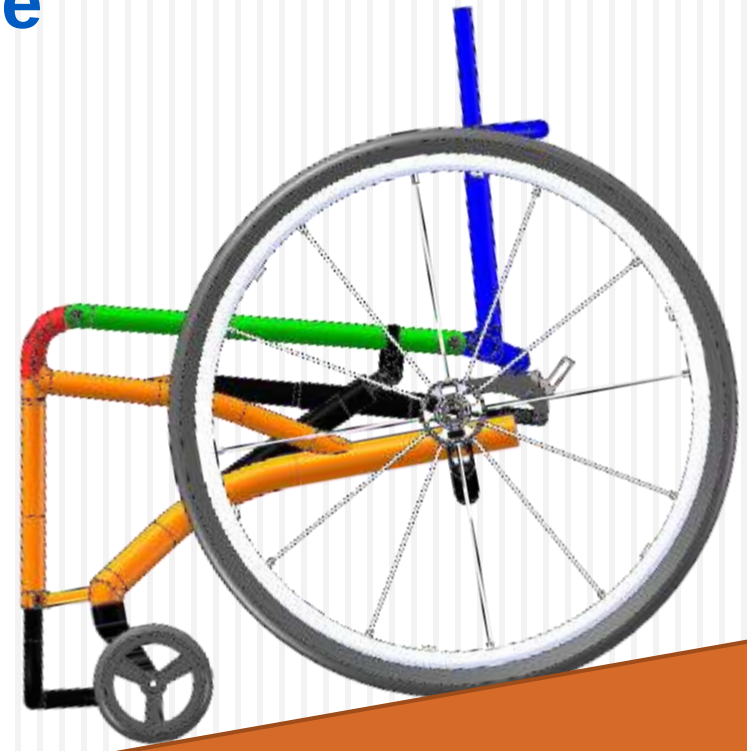
14° SEAT slope
95° BACK recline

Dynamic Repositioning For Function: PROPULSION – DOWN HILL (10 degrees)

14° SEAT slope
95° BACK recline

Effective
Back Angle = 85°

Effective
Seat Slope = 4°

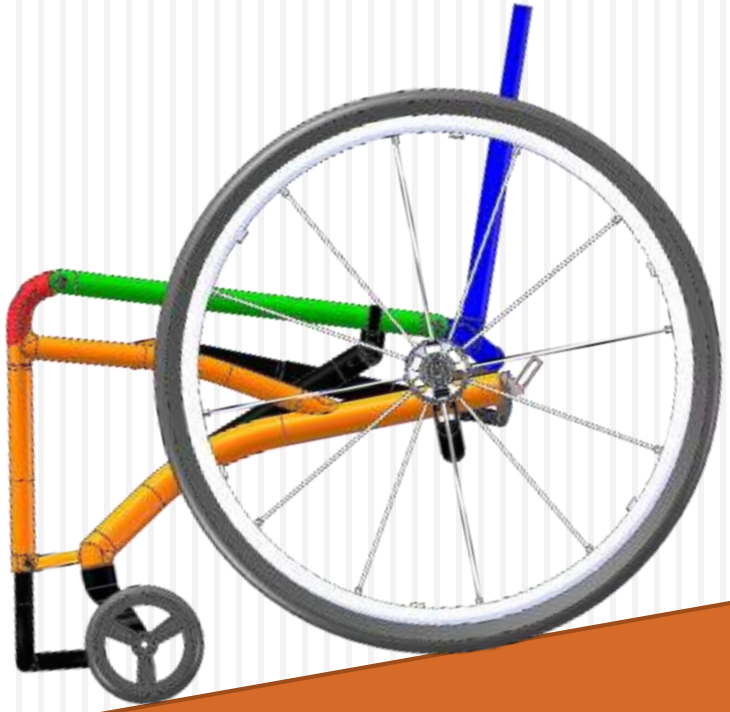


Dynamic Repositioning For Function: PROPULSION – DOWN HILL (10 degrees)

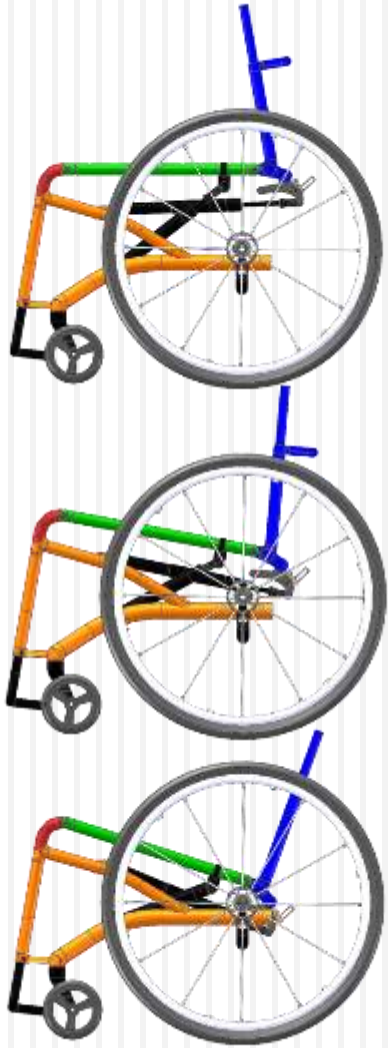
18° SEAT slope (5” seat dump)
110° BACK recline

Effective
Back Angle = 100°

Effective
Seat Slope = 8°

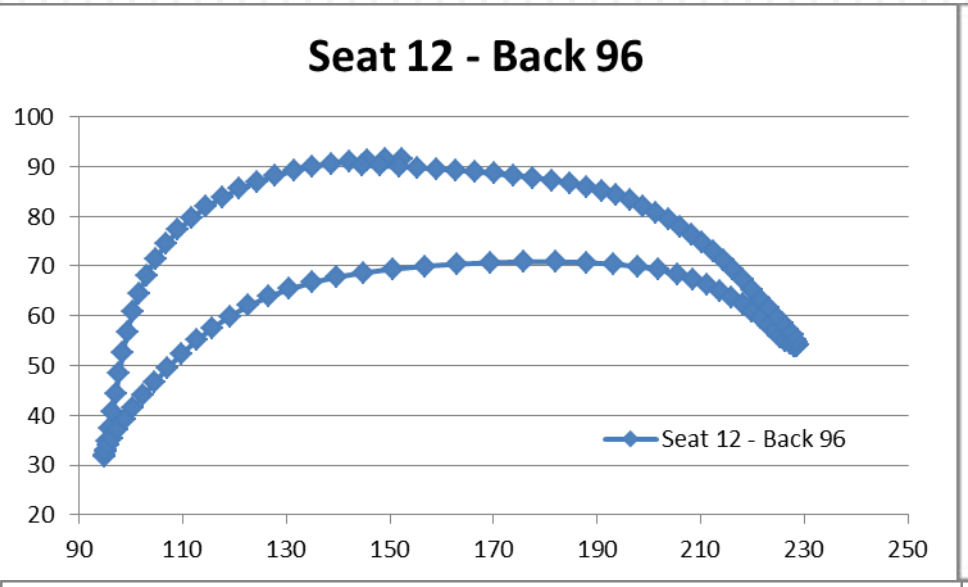


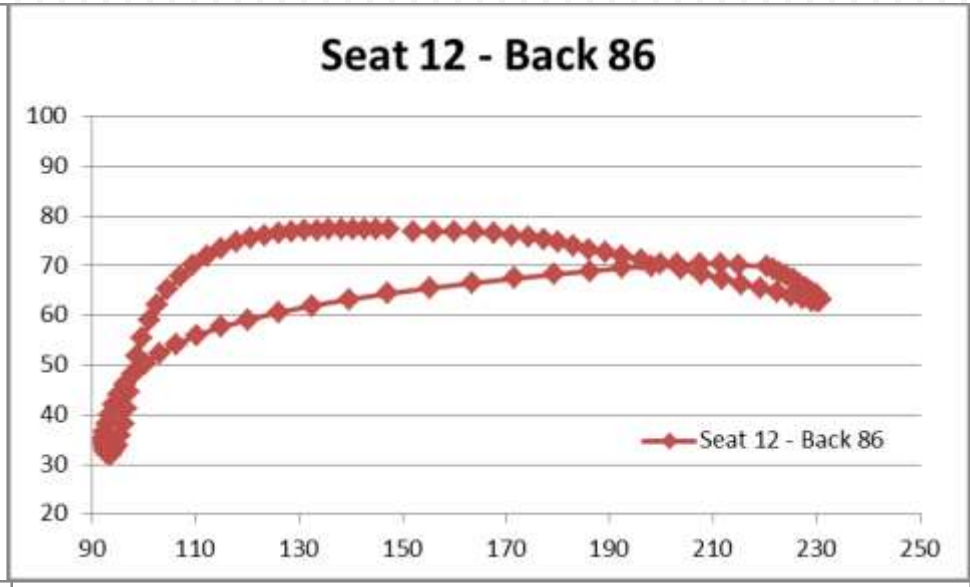
Dynamic Repositioning For Function: PROPULSION – COG changes (relative in mm)

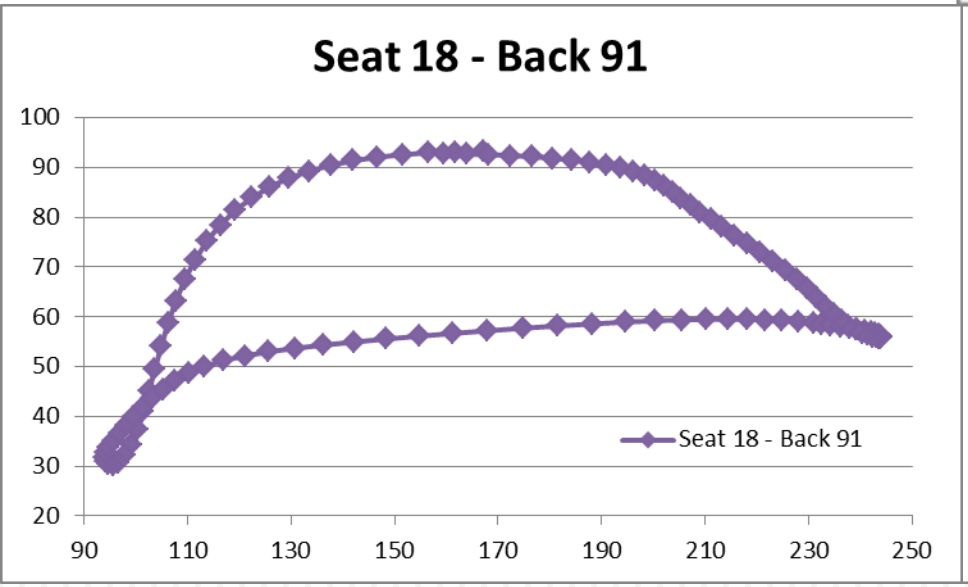


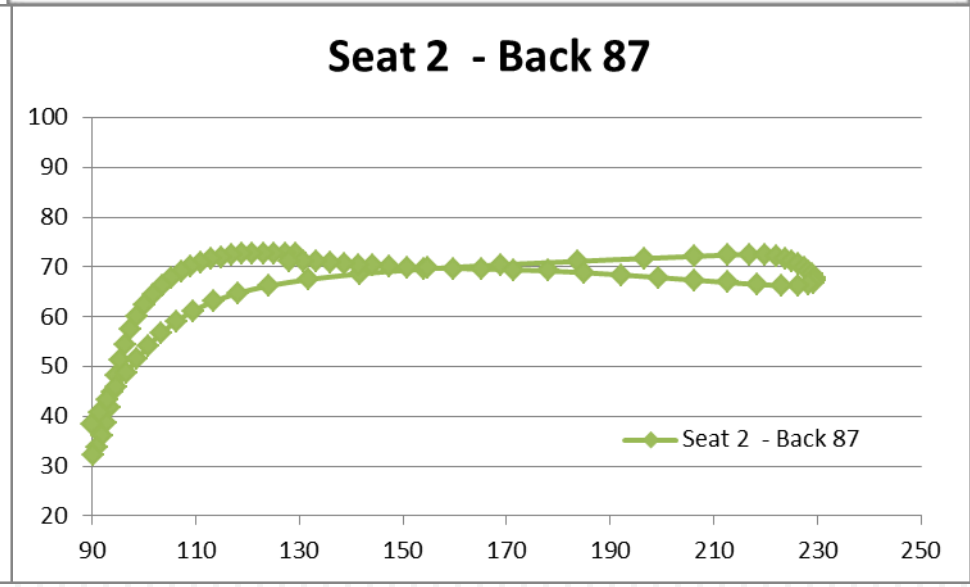
	Seat	Back	CoG
Up hill	0	80	-25
Level ground	10	95	0
Down hill	18	110	21

Shoulder vs Elbow Angle









Modified Icon A1

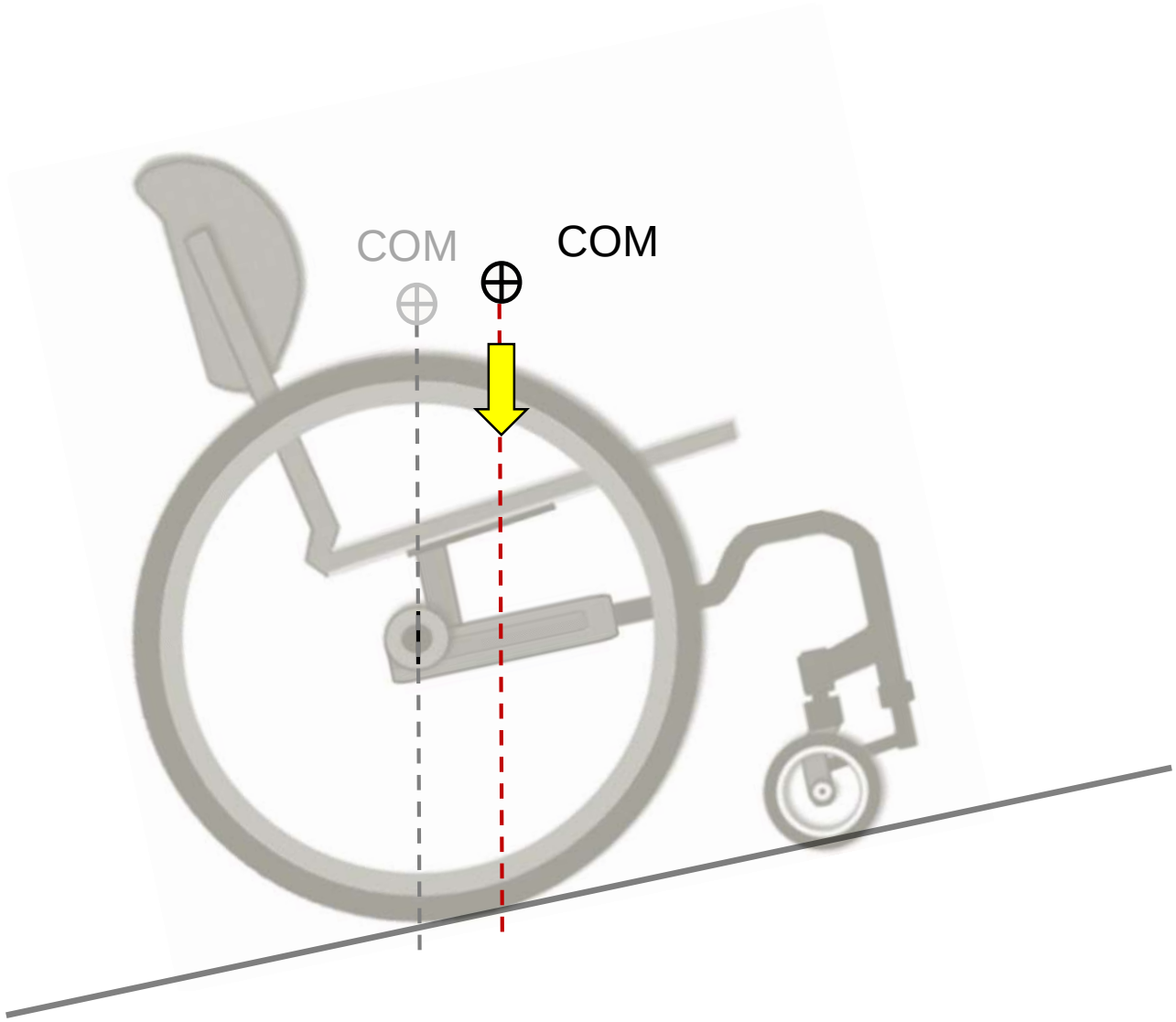
2.5" of Fore/Aft Seat Adjustability

2.5" of Dynamic Wheelbase Adjustability

EFFECT OF DYNAMIC RECONFIGURATION

Use of a Sliding Seat On a 7° Incline

HOW IT WORKS



Question:

Which Configurations Will Enable The User To Ascend A 3 1/2" Platform With Less Upper Extremity Strain?

(and with less skills needed than possessed by Dr. Lee Kirby)

Seat Forward With Long Wheelbase on 3 1/2" Platform

DWM Applications: Transfers

"Perform Level Transfers When Possible "

"Avoid Positions of Impingement When Possible"

Dynamic Reconfiguration

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

TRANSFER **ONE SETUP**

Dynamic Reconfiguration

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

TRANSFER TWO SETUP

Dynamic Wheeled Mobility

Dynamic Reconfiguration

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

Dynamic Wheeled Mobility

Dynamic Reconfiguration

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

Dynamic Wheeled Mobility

Dynamic Reconfiguration

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

DYNAMIC REPOSITIONING TO FACILITATE TRANSFERS

CPGs that apply to DWM (even if they don't know it)

DWM has GREATER BENEFITS than with FIXED CONFIGURATIONS

- 4. Minimize the force required to complete upper limb tasks.
  - e.g. Overhead reaching; reaching the ground (lowering seat + steep dump which is easier to sit in when reaching down with chest on lap, or reaching sideways); reclining with butt forward for doing tasks in front with both hands; transferring; using the Freewheel;
- 5. Minimize extreme or potentially injurious positions at all joints.
  - e.g. wheeling on level ground; wheeling up ramps (changing seat position first); Overhead reaching; transferring;
- 9. Position the Rear Axle so that when the Hand is Placed at the Top Dead-Center Position on the Pushrim, the Angle Between the Upper Arm and Forearm is Between 100 and 120 Degrees.
  - E.g. Changing your seat height or COG to suit wheeling tasks
- 11. Promote an appropriate seated posture and stabilization relative to balance and stability needs.
  - e.g. wheeling downhill with reclined back; wheeling up ramps; dumped sitting;
- 15. Instruct individuals with SCI who complete independent transfers to: Perform level transfers when possible
  - e.g. flatten seat to transfer; raise seat to transfer to higher surface

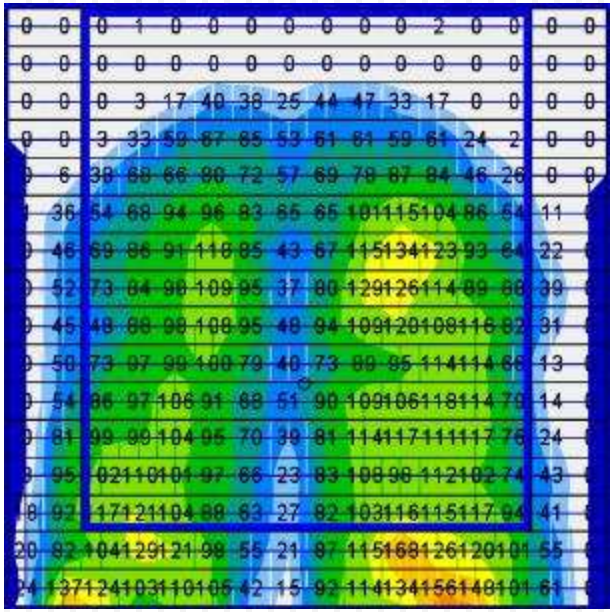
WHERE ULTRALIGHTS CAN PLAY LARGER ROLE

- 13. Provide seat elevation … (for power mobility)
  - yes, but why not manual ultralight chairs?
- 6. and 34. Encourage manual wheelchair users to consider Power wheelchair systems
  - e.g. yes, but with a SmartDrive.

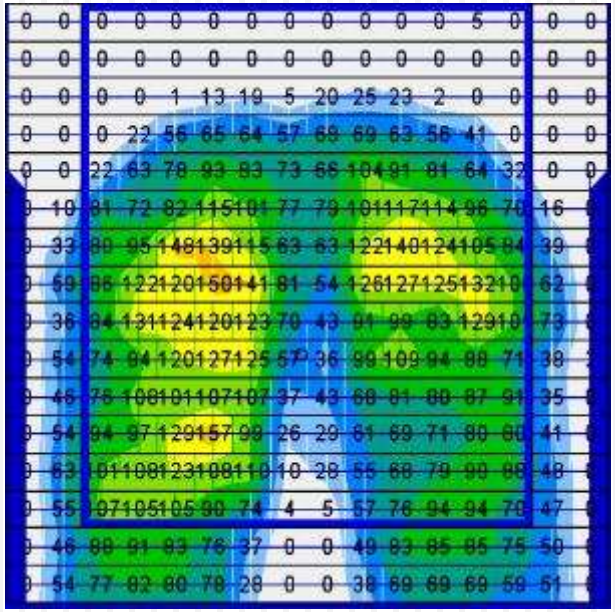
Some other benefits of changing seat position? (non – CPG)

- Comfort
- Functional positioning (other ADL's)
- Pressure re-distribution
- Joint mobility (e.g. S-I joints)
- Cardiovascular health?

  (HR, BP, and stoke volume changes between dumped, level, and elevated sitting)

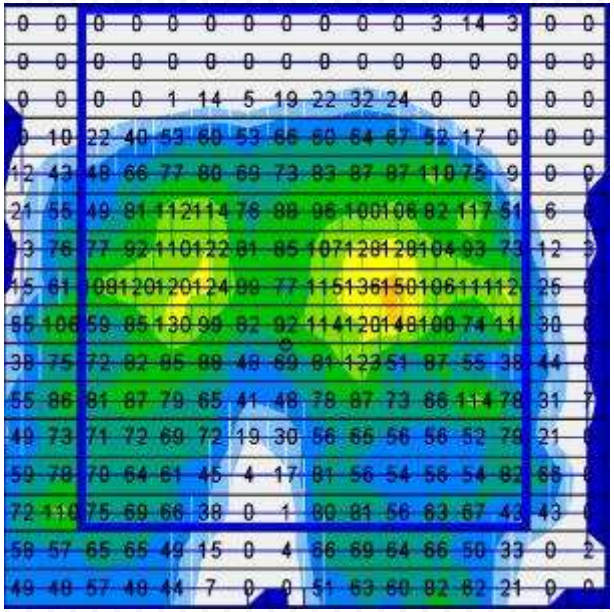


Subject 1



Subject 2

-15°



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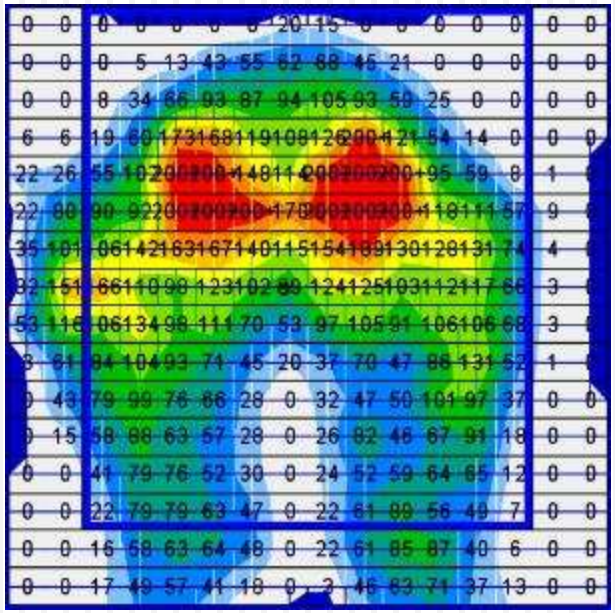
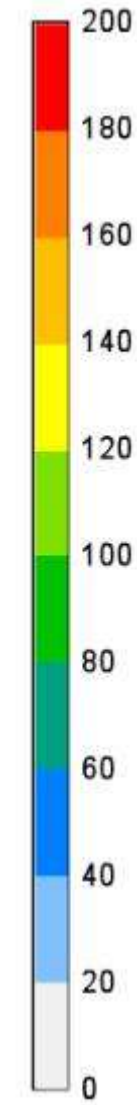
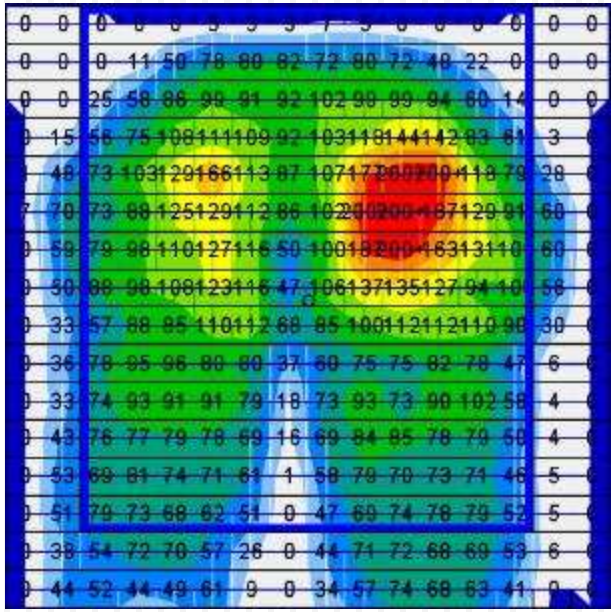


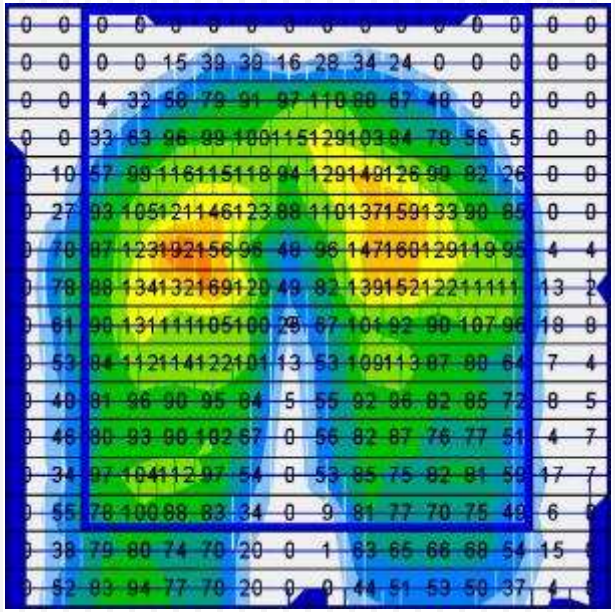
Subject 4*





Subject 1

0°



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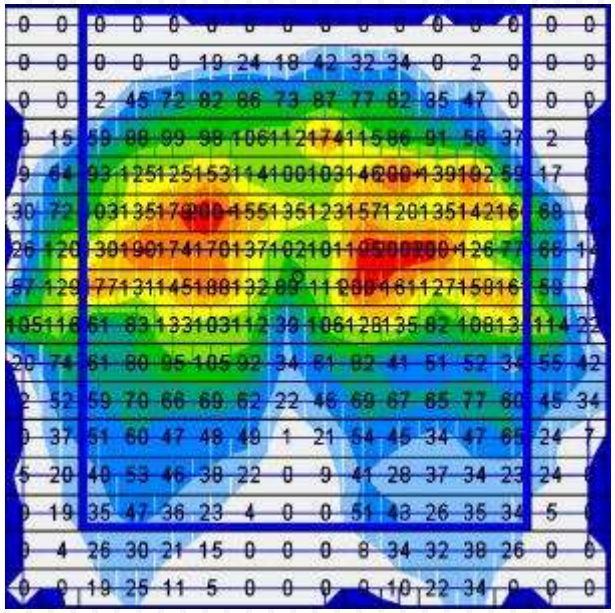

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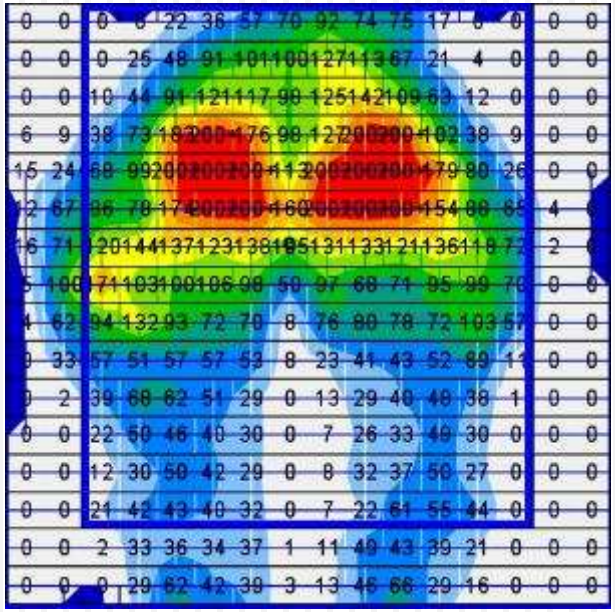

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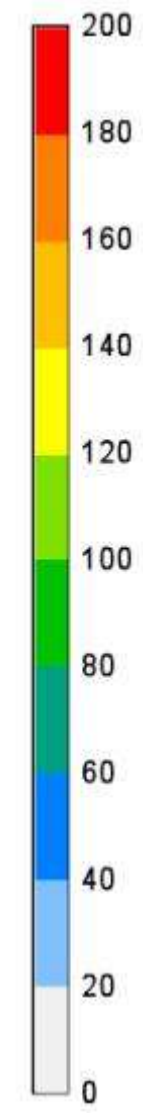
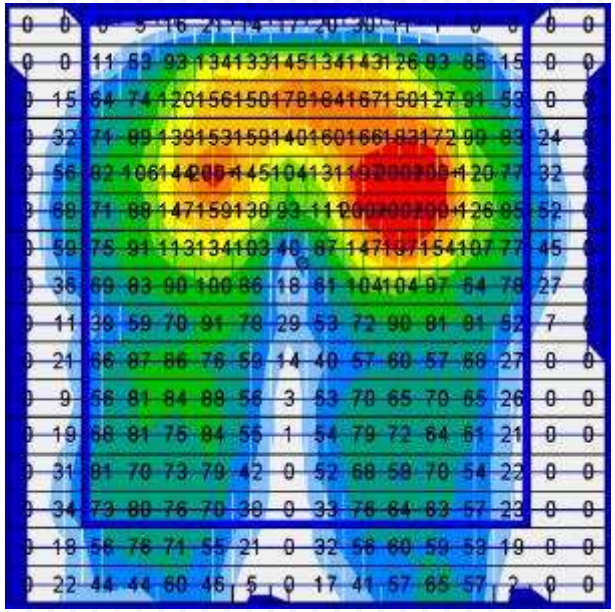
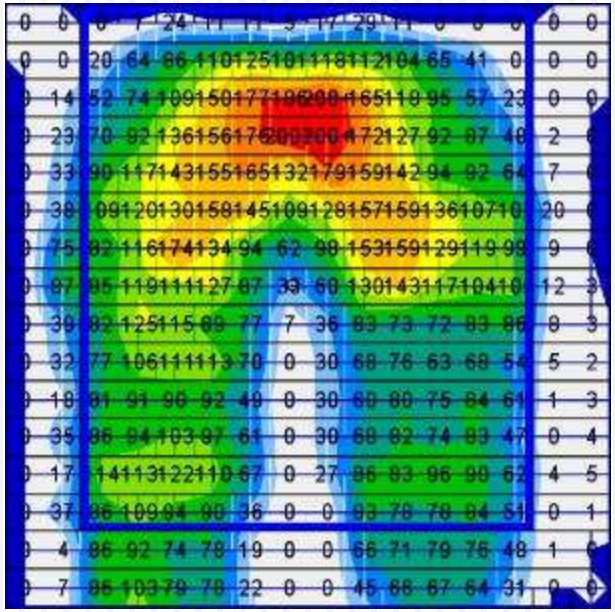




Subject 1

+15°



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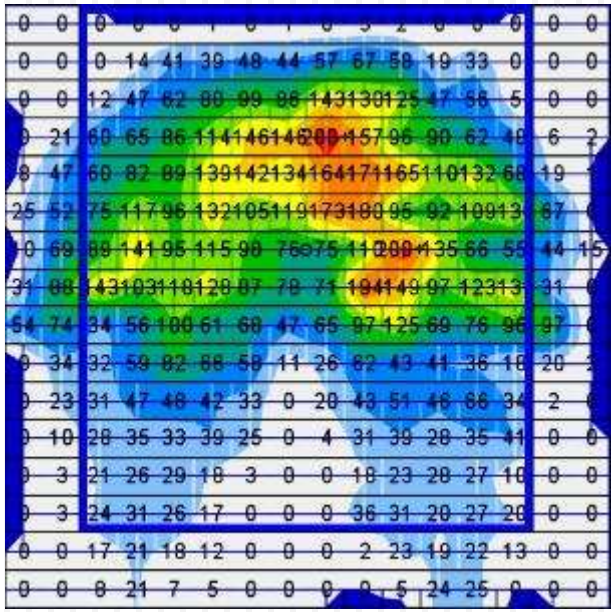

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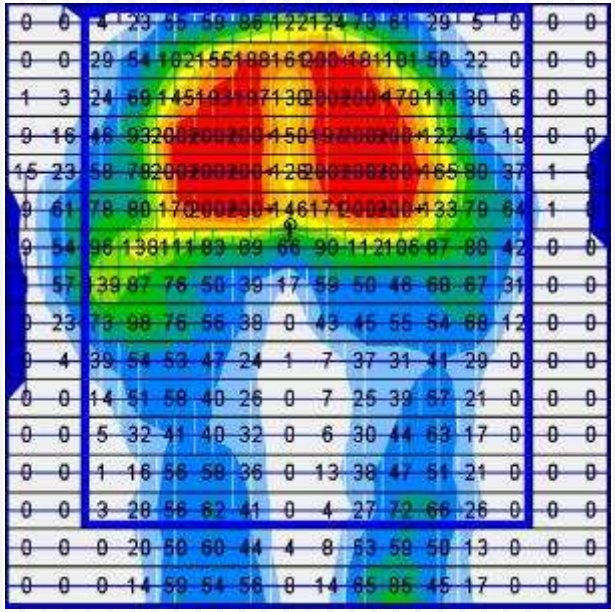

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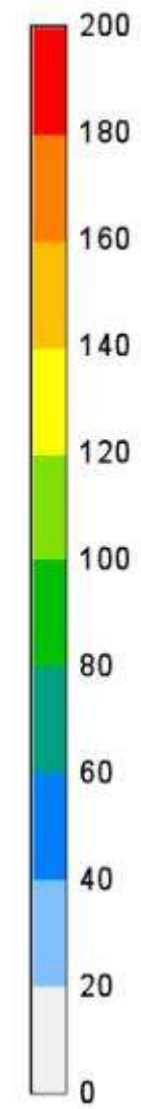
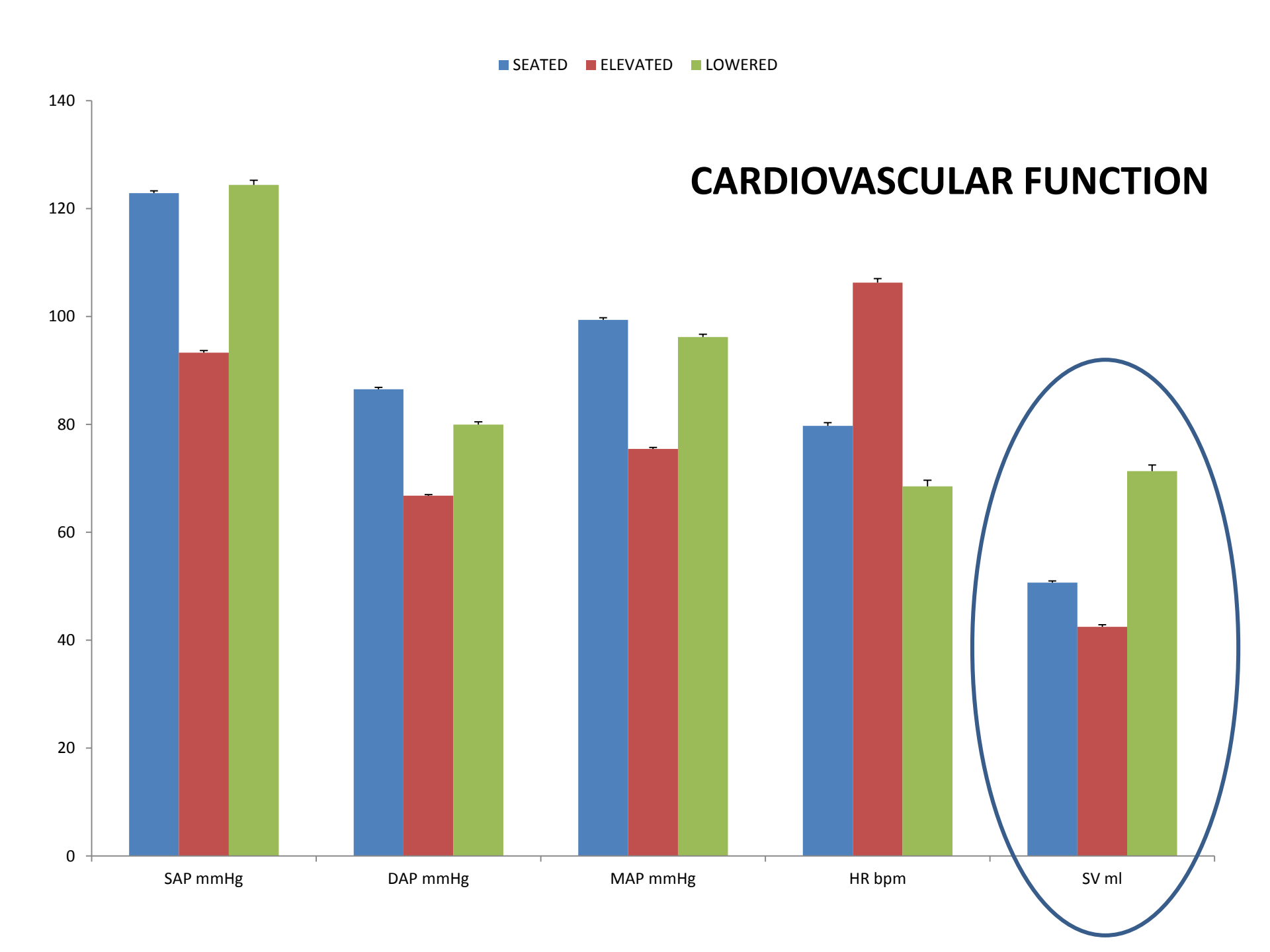



SEATED
ELEVATED
LOWERED
CARDIOVASCULAR FUNCTION
140
120
100
80
60
40
20
0
SAP mmHg
DAP mmHg
MAP mmHg
HR bpm
SV ml

DWM Applications: ADL's

- Other Activities
- Participation

How do people use Elevation?

Dynamic Repositioning For Function ~ socialization

Dynamic Repositioning For Function ~ socialization

Employment

Children (Pediatrics)

Recreation

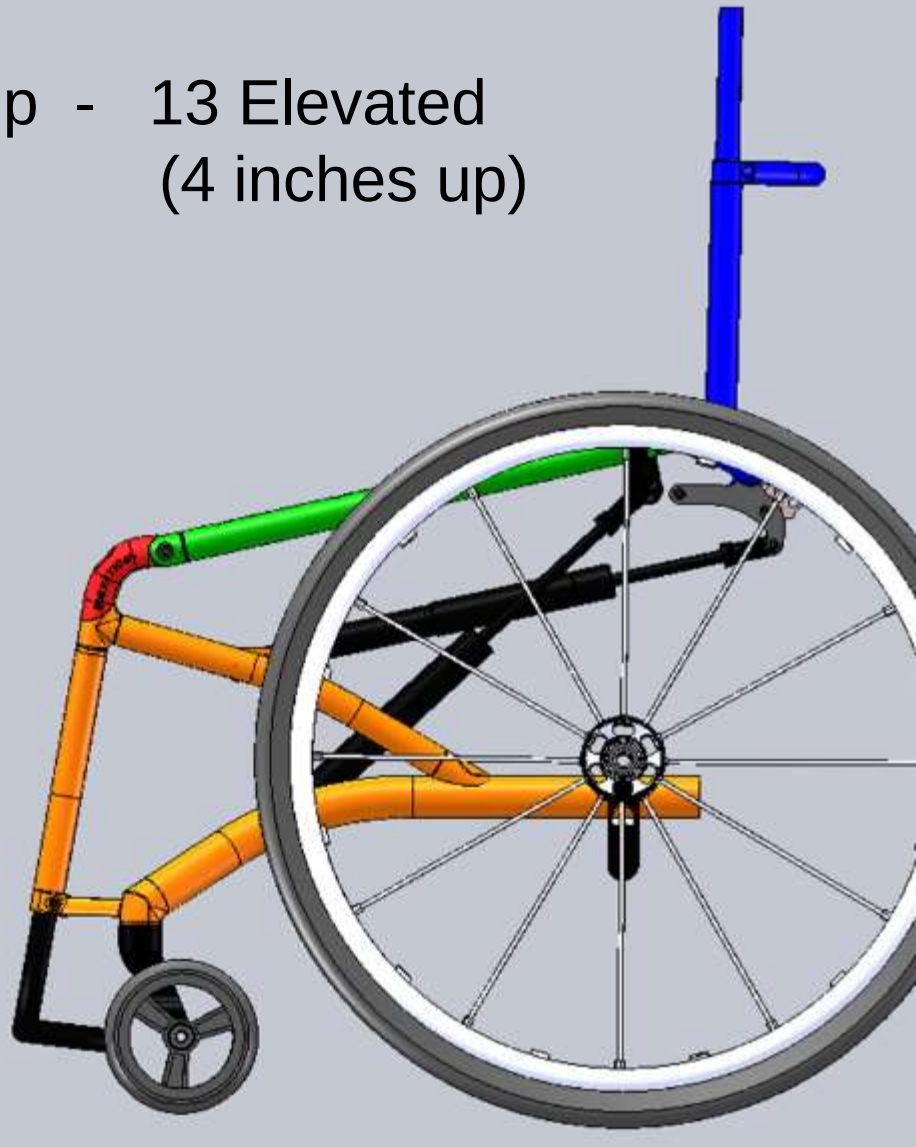
High reaching

Self care

Different Users, Different Uses

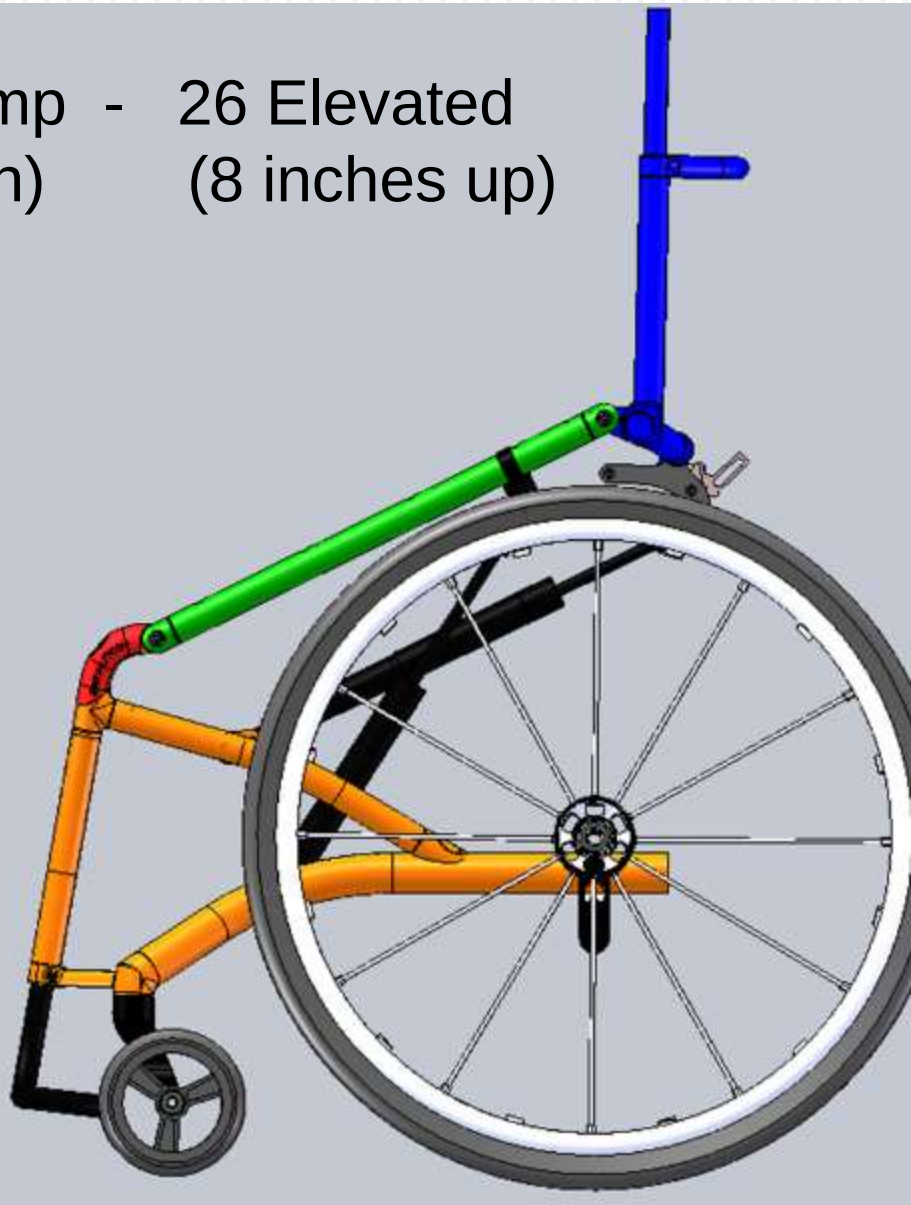
“Low” setup

19 degrees Dump - 13 Elevated
(6 inches down) (4 inches up)



“High” setup

7 degrees Dump - 26 Elevated
(2 inches down) (8 inches up)

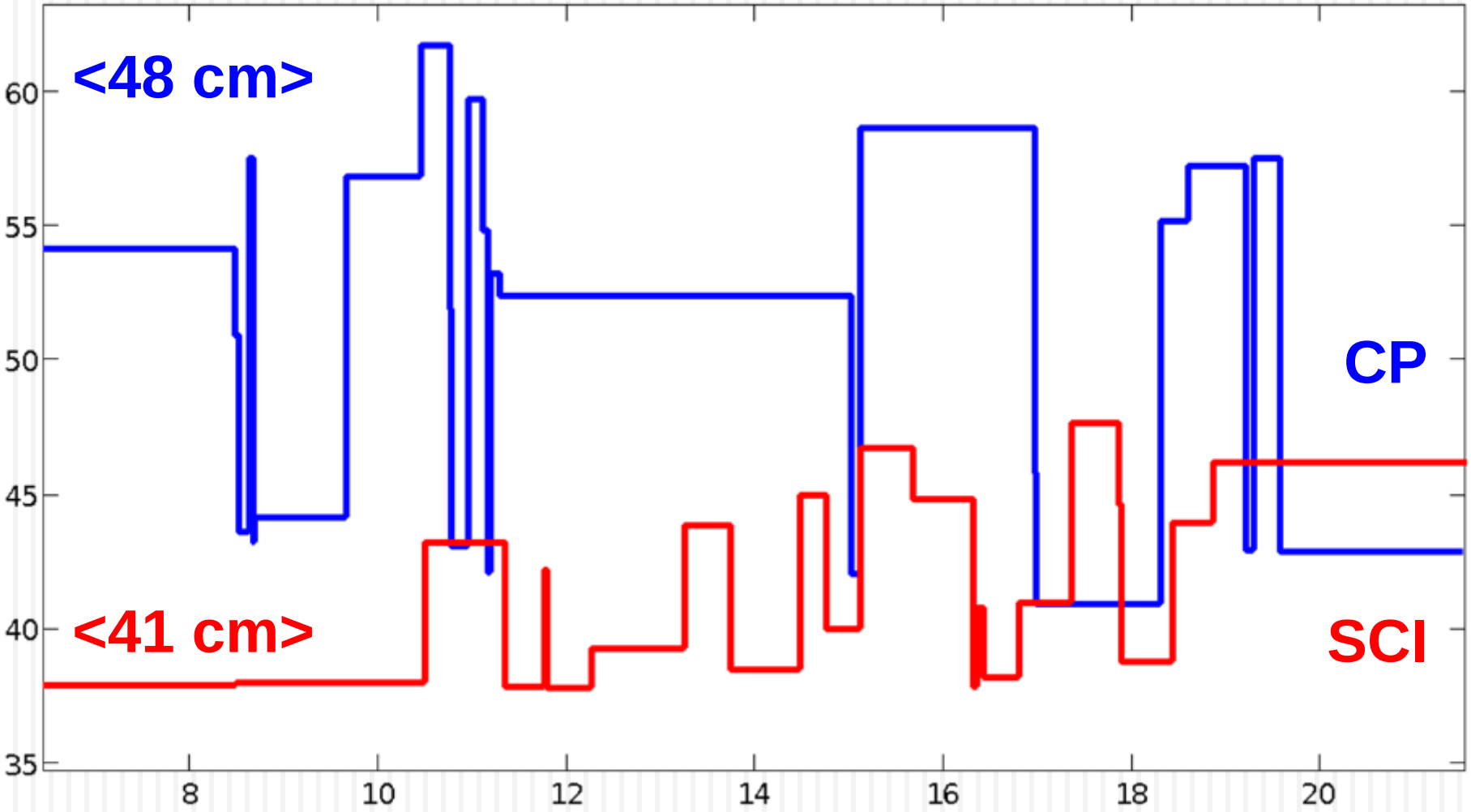


Different users, different uses

CP <48 cm>

SCI <41 cm>

Daily height chart – 2 people



Elevation + Function / Activities

Measures of Activity and Participation

Participants N= 8 (7 males, 1 female).
Median years using the Elevation wheelchair = 3

Functioning Everyday with a Wheelchair (**FEW**) Questionnaire

MEAN score = 54
(Range 47 – 60)

Perceived usefulness related to 10 basic wheelchair uses
(e.g. reaching, transfers). Scored from 0 to 6 each (MAX score = 60)

Correlations between
times changing
Seat position and
Participation

$r_s = 0.77$ ($p < 0.05$) - **ASAP**
$r_s = 0.57$ ($p = 0.14$) - **WhOM**

Elevation + Freewheel

Future DWM?

- Power wheels?
- Sliding seat + seat height + back recline
- The floor!
  - Floor to seat transfers
  - Activities near the floor (kids, picnics, etc.)

Atlantic Rehab and Education Conference 2014

Atlantica Halifax Hotel, Halifax, Nova Scotia

Merci!

Dynamic Wheeled Mobility--The Next Chapter in the Ultralight Evolution

Coming Soon

31ST ISS

The Next Chapter

2015 International Seating Symposium

2015 International Seating Symposium

Hosted by the University of Pittsburgh

Nashville, TN