Dynamic Wheeled Mobility

The Future of Ultralight Wheelchairs for Active Users

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Jaimie Borisoff, PhD
Canada Research Chair in Rehabilitation Engineering Design
Dynamic Wheeled Mobility
Gateway to the Future of the Ultralight Wheelchair

Jaimie F. Borisoff, PhD
British Columbia Institute of Technology

Steven J. Mitchell, OTR/L, ATP
Cleveland VAMC SCI/D Service

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

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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?

**Tilt & Recline**
(conventional dynamic seating)
e.g. from PDG Mobility

**Power**
(conventional dynamic seating)
e.g. from Permobil

**PAPAWs**
e.g. from Alber

**Standing**
e.g. from LEVO AG

Dynamic Wheeled Mobility
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

BORISOFF & MITCHELL
An Introduction To Dynamic Wheeled Mobility
1st Edition

A Reference for the Rest of Us!
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


\[ \theta_2 = 100-120^\circ \]
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


- 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.
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)
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-offs need to be made to the user's base configuration.
These concessions & trade-off's frequently result in a base configuration to be less than optimal for any single context of use…

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

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

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

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

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**

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Bouts</th>
<th>Occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 km</td>
<td>58 min</td>
<td>96</td>
<td>11 hrs</td>
</tr>
</tbody>
</table>

*~ 10%*

“**Bouts of Mobility**”

Sonenblum and Sprigle, Georgia Tech
Daily Activities

An average day: Eat, sleep, media

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 $= 41 \text{ lbs.}$ [1]

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”


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

*Sagawa Y Jr*, *Watelain E*, *Lepoutre FX*, *Thevenon A.*
Where is weight important?

- Lifting the chair into a car
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
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
2.5" of Fore/Aft Seat Adjustability

2.5" of Dynamic Wheelbase Adjustability
2.5" of Dynamic Fore / Aft Seat Adjustability
Modified Icon A1

2.5” of Fore/Aft Seat Adjustability
Modified Icon A1

2.5" of Dynamic Wheelbase Adjustability
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: easy to use
“On the fly” adjustability
Elevated seating stability

“lifting” side guards
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
Dynamic Wheeled Mobility

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

$\Delta \text{angles}^{\text{USER}}$

90°
Conservation of Contextual Angles

\[ \Delta \text{angles} \]
Conservation of Contextual Angles

$\Delta \text{angles}$

USER

90°
Conservation of Contextual Angles

\[ \Delta \text{angles} \]

100°
DWM Applications: Reach

"Avoid positioning the hand above the shoulder"
"Avoid positioning the hand above the shoulder"
"Avoid positioning the hand above the shoulder"
"Avoid positioning the hand above the shoulder"

That’s How!
A NEW WAY THAT THE ULTRALIGHT CAN EFFECTIVELY IMPLEMENT A CPG!!
FUNCTIONAL REACH

What about the Ground? Reaching Down?

- Reaching to grab objects
- Tasks “on your lap”
"Minimize the Forces Needed to Complete Upper Limb Tasks“

"Minimize Extreme or Potentially Injurious Positions“

…SLOPES!
SLOPES

ADA Standard 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
An Optimal Configuration for Smooth Level Surfaces
17x16+0 85 Degree TiLite ZRc
An Optimal Configuration for Smooth Level Surfaces

Back Angle = 95°

Seat Slope = 14°

Occupied Frame Length = 23"

COM
17x16+0 85 Degree TiLite ZRc
The Same Configuration on a 10° Slope

Grade = 10°
17x16+0 85 Degree TiLite ZRc
Configuration on a 10° Slope

Effective Back Angle = 105°

COM

Effective Seat Slope = 24°

Grade = 10°
Conservation of Contextual Angles

Analysis

\[ \Delta \text{angles}_{\text{DEVICE}} = D \]

\[ \Delta \text{angles}_{\text{USER}} = U \]

\[ \Delta \text{angles}_{\text{HILL}} = H \]

\[ \sum \Delta \text{angles}_{\text{COMBINED}} = \sum \Delta \text{DUH!} \]
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 Wheeled Mobility
Dynamic Repositioning For Function: PROPULSION – UP HILL (10 degrees)

Effective Back Angle = 105°

Effective Seat Slope = 24°

14° SEAT slope
95° BACK decline

Dynamic Wheeled Mobility
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 Seat Slope = 4°

Effective Back Angle = 85°
Dynamic Repositioning For Function: PROPULSION – DOWN HILL (10 degrees)

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

Effective Seat Slope = 8°
Effective Back Angle = 100°
Dynamic Repositioning For Function: PROPULSION – COG changes (relative in mm)

<table>
<thead>
<tr>
<th></th>
<th>Seat</th>
<th>Back</th>
<th>CoG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up hill</td>
<td>0</td>
<td>80</td>
<td>-25</td>
</tr>
<tr>
<td>Level ground</td>
<td>10</td>
<td>95</td>
<td>0</td>
</tr>
<tr>
<td>Down hill</td>
<td>18</td>
<td>110</td>
<td>21</td>
</tr>
</tbody>
</table>
Shoulder vs Elbow Angle

**Seat 12 - Back 96**

**Seat 12 - Back 86**

**Seat 18 - Back 91**

**Seat 2 - Back 87**
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
"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.

Dynamic Wheeled Mobility
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 stroke volume changes between dumped, level, and elevated sitting)
DWM Applications: ADL’s

- Other Activities
- Participation
How do people use Elevation?
Dynamic Repositioning For Function ~ socialization
Dynamic Repositioning For Function ~ socialization
Children (Pediatrics)
Recreation
High reaching
Self care
Different Users, Different Uses
“Low” setup

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

Dynamic Wheeled Mobility
“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

<48 cm>

<41 cm>

Dynamic Wheeled Mobility

AREC 2014
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

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

**MEAN score = 54**  
(Range 47 – 60)

Correlations between

- # times changing Seat position and Participation  
  
  \[ r_s = 0.77 \quad (p < 0.05) \quad - \text{ASAP} \]
  
  \[ r_s = 0.57 \quad (p = 0.14) \quad - \text{WhOM} \]
Future DWM?

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

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Atlantica Halifax Hotel, Halifax, Nova Scotia
Dynamic Wheeled Mobility--The Next Chapter in the Ultralight Evolution

2015 International Seating Symposium
Hosted by the University of Pittsburgh
Nashville, TN

Coming Soon