**The Wheel Story: The Impact of Wheels and Tires on Manual Wheelchair Propulsion Efficiency**

**Notes Taking Outline**

1. **Wheel Story:** Imagine a meticulously configured ultralightweight manual wheelchair: anatomically correct, appropriate for skill level, aggressive set up, stripped of secondary components. . .
   1. It’s issued with mag wheels with airless inserts
   2. Can we articulate why this wheel/tire combo was selected? Was it maybe. . .
      * 1. Maintenance considerations- the user is unable or unwilling to maintain a pneumatic tire
        2. Environment of use
        3. User preference (client factors & perspectives: values, priorities, expectations)
        4. Previous experience
2. **Propulsion Efficiency**
   1. In a manual wheelchair, high efficiency is the goal, and work required to maneuver it can be a measure of efficiency. The most efficient wheelchair is the one that takes the least amount of work to maneuver.
   2. What can be done to affect the inherent efficiency of a manual wheelchair?
      1. Mass, or Weight Distribution
         1. The proportion of system mass over the rear wheels as compared to that over the front wheels
            1. Impacted by adjusting wheelbase; aka CG adjustment
            2. Impacted by changes in posture resulting from adjustments to seating
      2. Wheel and Tire Selection
      3. So, What’s Important?
         1. “When considering propulsion effort within ULW manual wheelchairs, ample scientific evidence suggests that wheels, tires and weight distribution are the most impactful. So, by focusing solely on mass [of the chair], one neglects the most important factors affecting propulsion effort.“ Quote from Dr. Stephen Sprigle, PhD, PT
3. **How do Wheels work?**
   1. Wheels reduce friction –
      1. When friction is reduced, the force needed to cover the same distance is less, so work goes down
   2. Wheels provide leverage
      1. Principle of force (or speed) multiplier
         1. Examples: small sport handrim which can increase speed, or grasping tire instead of handrim on an incline for more force (leverage)
4. **Rolling Efficiency**
   1. When a wheel rolls on a surface, energy is lost
      1. This is typically referred to as Rolling Resistance
      2. The lower the Rolling Resistance the more Efficient it is
   2. Energy Loss Parameters include:
      1. Rebound Loss
         1. The energy expended by deformation is greater than the energy recovered by returning to its original shape
         2. This energy loss is a significant contributor to a decrease in rolling efficiency
      2. Deformation
         1. Tire deformation –
            1. As a tire rotates under the weight of the load, it experiences repeated cycles of deformation and recovery, and it dissipates the rebound energy loss as heat
         2. Surface Deformation
            1. Some have some rebound – such as sport courts
            2. Some permanently deform – such as carpet, sand, soft dirt, gravel
      3. Slippage
         1. When a surface and tire interaction do not have enough traction, the tire can slip, which is lost energy
   3. Other factors contributing to Rolling Efficiency:
      * 1. Tire Design
           1. Material

Rubber or Polyurethane

Solid tires commonly made from Polyurethane, a synthetic ‘rubber-like’ material

* + - * 1. Profile

All the cross-sectional characteristics and shape of a tire, how tall, how wide, how round or ‘square’, etc.

* + - * 1. Construction – Tire Type

Pneumatic or Air Filled – inner tube, filled with air to maintain pressure

Solid

Airless insert – low density foam insert inside of a pneumatic tire, instead of a tube filled with air

Fully Solid- solid material of a particular density

Only the air-filled tire has the capability to be adjusted to influence rebound loss

Pneumatic tires exhibited lower rolling resistance than solid tires - *Sawatsky, et al, 2004*

As load increased, solid tires experienced larger increases in rolling resistance than pneumatic tires. *Kwarciak, et al, 2004*

* + - 1. Contact Patch
         1. Deformed area of a tire in contact with the support surface, the ‘footprint’ on the ground
         2. Surface area amount (surface area = length x width)
         3. Shape - how long compared to how wide?
         4. Function of Pressure and Load (system weight = weight of chair + occupant)

Tire Pressure in PSI = System Weight in Pounds / Area in Square Inches

If tire pressure is constant, and load is constant, then area must remain constant

* + - 1. Inflation pressure
         1. At the same inflation pressure, a wide tire and a narrow tire have the same amount of contact area (patch), but it’s not the same shape. A wide tire is flattened over its width, whereas a narrow tire has a slimmer but longer contact area. (remember, area = length x width. Can be short x wide or long x narrow)
         2. The longer contact patch has greater rolling resistance, or lower rolling efficiency
         3. A narrower tire/contact patch can be used at a higher inflation pressure, which will decrease the surface area of the contact patch, meaning less deformation, and improved rolling efficiency
      2. Wheel Diameter and Circumference
         1. Tires with a Larger Circumference (C=𝜋 𝑥 𝐷𝑖𝑎𝑚𝑒𝑡𝑒𝑟) have a higher rolling efficiency than those with a Smaller Circumference.

e.g. a 4” long contact patch is a smaller percentage of the roundness (circumference) of a 24” wheel than it is of a 20” wheel.

Same issue as the slimmer, but longer (front to back) contact patch above (3a). The relative length of the contact patch affects rolling efficiency.

* + - * 1. A larger wheel rolls over obstacles more easily than a smaller wheel

Larger wheel has a shallower contact angle

1. **Inertia**
   1. Rotational Inertia, or Moment of Inertia (I) I = mass x radius2
      1. Resistance to change in velocity of a rotating object
      2. Where the mass is located on the wheel matters
      3. A wheel with more mass will have a higher moment of inertia than one with less mass
      4. A higher moment of inertia is harder to accelerate or decelerate, and a lower moment of inertia is easier
      5. Manual Wheelchair Use: Bouts of Mobility in Everyday Life *Sonenblum, Sprigle and Lopez, 2012*
         1. Lots of starts, stops and turns – acceleration and deceleration happen a lot
   2. Rotational Inertia on another axis – Yaw (as seen from overhead)
      1. Relates to turning the wheelchair left or right, and where weight (mass) is located relative to the axis of rotation.
         1. Example of turning the shopping cart with a heavy load at the front end
   3. Clinical application: Don’t try to accelerate to ‘full speed’ within the first push stroke or two
2. **Wheel Construction**
   1. Mag Wheels
      1. ‘Spokes’ are support columns that support the load from underneath it
   2. Spoke wheels
      1. Hold their form by means of tension on the metal wire spokes. The load is being ‘suspended’ from above
      2. Hub Flange
         1. A larger diameter hub flange means a shorter spoke, which will make a wheel more stiff laterally
            1. Hub and spokes form a triangle – a triangle with shorter sides will be more stable
            2. Important during turning maneuvers High end spoke wheels vs entry level?
   3. Premium Wheel considerations
      1. Improved stiffness = higher rolling efficiency, better energy transfer from user to system
      2. Lighter weight rims and spokes = less rolling mass, or lower rotational inertia
3. **If there is no perfect wheel, then what do I need to consider?**
   1. Drive Wheels
      1. Pneumatic Tires have a higher Rolling Efficiency than Solid Tires
         1. Pneumatic tires do require maintenance
         2. Higher Pressure Tires have a higher Rolling Efficiency than Lower Pressure Tires
      2. Wheels with Less Mass have a higher Rolling Efficiency than Wheel with More Mass
         1. Where the mass is located on the wheel matters, but in general, Mag wheels have more mass than spoke wheels
      3. Wider Contact Patch (tire) vs Narrower Contact Patch (tire) –
         1. At the same pressure, the narrower contact patch has lower rolling efficiency than a wider one, but the advantage of narrow tires is they can tolerate higher pressures, and thus improve rolling efficiency
         2. A wider tire (contact patch) may provide better floatation on soft rolling surfaces
      4. Larger Diameter wheels have a higher Rolling Efficiency than Smaller Diameter wheels
         1. The Biomechanical fit / needs of the user is primary in this case, however
      5. A wheel with Less Tread has a higher Rolling Efficiency than one with More Tread
         * 1. More tread will provide improved traction
   2. Caster Wheels
      1. Pneumatic Tires have a higher Rolling Efficiency than Solid Tires
         1. Pneumatic tires do require maintenance
         2. On a small tire, a little bit of air loss can negate the benefits of the pneumatic tire
         3. Pneumatic casters tend to only be available in larger sizes, e.g. 6” or 8”
      2. Wheels with Less Mass have a higher Rolling Efficiency than Wheel with More Mass
         * 1. With caster wheels, the differences in mass from one to another are very minor in their effect on overall system mass or inertia
      3. Larger Diameter wheels have a higher Rolling Efficiency than Smaller Diameter wheels
         1. With casters especially, larger ones roll over obstacles better than smaller ones, e.g. a piece of gravel on the surface
      4. A wheel with Less Tread has a higher Rolling Efficiency than one with More Tread
         * 1. A caster wheel is passive and really doesn’t contribute to traction
           2. Caster wheel may be subject to more scrub torque due to the swiveling of the caster about the stem
      5. A Premium Caster Wheel is reported to have a higher Rolling Efficiency than a Standard Caster Wheel
         * 1. A higher quality, more dense polyurethane has a lower loss of energy due to Rebound Loss
      6. Wider Contact Patch (tire) vs Narrower Contact Patch (tire) –
         1. A wider tire (contact patch) may provide better floatation on soft rolling surfaces
         2. Like snowshoes will help to stay near the surface of snow
   3. All Things Considered. . . *Sprigle, Huang and Misch, 2019*
      * 1. There is no perfect drive wheel or caster wheel for all surfaces
        2. Shifting more load onto the drive wheels is the most effective means of reducing resistance