EFFECTS OF DRIVE WHEEL POSITION AND SUSPENSION PROPERTIES ON A SINGLE POWER WHEELCHAIR

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BACKGROUND

Power wheelchairs (PWCs) are either rear, mid or front wheel drive. Each drive wheel position has its advantages and disadvantages, especially as a function of the terrain and environment. Mid-wheel drive PWCs are highly maneuverable indoors. Focus groups of power wheelchair users confirmed their awareness of the limitations of single position drive wheel systems. There are currently no power wheelchairs available that can provide the advantages and avoid the disadvantages of a single position drive system.

As a Phase I SBIR project, funded through NIDRR, Criterion Health designed and fabricated a proof-of-concept model (PofCModel) variable position mid-wheel drive system power wheelchair to establish the feasibility, i.e., benefits, of the design. The PofCModel provided a 38.1 cm range for the position of the drive wheels. The design was consistent with available popular mid-wheel drive power wheelchairs. The gearboxes, motors, and control system from an Invacare Torque SP power wheelchair base were used.

For the PofCModel, changing the drive wheel position required mechanically cranking a linear motion system to move the drive wheels forward or backward. In the forward drive position, the front casters were raised off the ground and in the rear drive position, the rear casters were raised off the ground. The PofCModel is shown in Figure 1 in Rear Wheel, Mid Wheel, and Front Wheel drive positions.

Figure 1. PofCModel 100m outdoor course.

The PofCModel was tested extensively, drawing on the Wheelchair Skills Test, clinical experience, and end-user input. The tests included a 100m outdoor open field course, indoor maneuverability, crossing thresholds, ascending and descending ramps and curbs, and traction in mud. Most tests were conducted at 50% and 100% power settings.

On any task that possibly resulted in seating system accelerations, the 3-dimensional acceleration, D(ti)xyz, was calculated as follows (Z includes the acceleration of gravity and is normally 1, Z-1 is used to normalize D to the origin and keep X, Y, and Z on the same scale):

$$D(t_i)xyz= (X_i^2+Y_i^2+(Z_i-1)^2)^{1/2}$$

The primary dependent measure was the Maximum value of the 3-dimensional acceleration that occurred during the event, MaxDxyz. Two MSR 145 data loggers were used, one attached behind the seat near the sacral/coccyx area and the other 7.62cm below the top of the backrest. Sampling was at 10 Hertz. In Table 1 the Maximum 3-dimensional accelerations (MaxDxyz) experienced at the backrest and seat data loggers on the 100m outdoor course are provided. (The Seat data logger failed after the MWD and FWD trials.) The main result is that accelerations decreased significantly from RWD to MWD to FWD at the backrest.

Table 1. MaxDxyz on the 100m outdoor course.

Accelerometer position/Power	RWD	MWD	FWD
Backrest Low	3.16	2.52	1.49
Backrest High	4.79	3.83	2.78
Seat Low	N/A	0.80	0.79
Seat High	N/A	1.39	1.16

The basic conclusions from the feasibility study were:

In the testing conducted for Phase I of the project, the rear wheel drive contributes little benefit to power wheelchair handling. It does demonstrate superior traction over a firm slippery surface (such as frost on a wheelchair ramp)

The mid wheel drive is superior for indoor maneuverability both in terms of the reduced time to complete many tasks, as well as the reduced number of maneuvers, which is especially important for many users. The mid wheel drive also tracks best on a side slope.

The front wheel drive demonstrated its superiority for use in open ground outdoor environments/terrains, climbing curbs, descending curbs, crossing thresholds, ascending and descending 10 degree inclines, etc. The reduced magnitude of the 3-dimensional acceleration at the backrest in the front wheel drive configuration is especially important for those with minimal upper body strength, poor trunk control, poor head control, etc. The reduced 3-dimensional acceleration at the seat in the front wheel drive position is a benefit since it may help to maintain proper positioning of the client back in the seat, may reduce skin shear, and may improve overall seating stability and functionality for some clients. End users expressed their concerns about getting stuck. The front wheel drive had significantly greater traction than either the mid or rear wheel drives over soft muddy terrain. The rear wheel drive position had significantly greater traction than either the front or mid wheel drives over a firm slippery surface.

The current study

Based on driving experiences with the PofCModel, we decided that it was important to better understand the role of the suspension system in the design of the fully functioning prototype, which is to be built as a consequence of receiving NIDRR Phase II SBIR funding.

Suspension system primer

A single compression spring model (total of 4) was used for both the front and rear suspension systems of the PofCModel. A compression spring can be described by its Spring Rate, the amount of force required to compress it 1 inch. The four springs for the PofCModel had Spring Rates of 320 lbs/in. However, the direct effect of the suspension springs on a power wheelchair is described as Wheel Rate and is measured as the amount of force required to lift the wheel (caster) 1 inch off the ground. If the spring is, for example, vertical and rigidly inserted directly above the axle of a caster, the wheel rate will be close to the spring rate (assuming no mechanical binding and minimal friction). However, if the spring is inserted at an angle and/or offset forward or rearward from the axle of a caster then mechanical advantage is altered and the wheel rate may be substantially less than the spring rate. A compression spring has a set free length (the length when not compressed). When mounted in the suspension system, the spring can be pre-compressed, which can increase the wheel rate. In RWD there is only a functional front suspension and in FWD only a functional rear suspension.

The PofCModel is a **unique** test bed that allows direct comparisons of different drive wheel positions with a single power wheelchair base. In the present study we examine the effects of different spring rates and, in turn, wheel rates on rear, mid, and front wheel drive performance crossing a 2cm threshold and lurching to a stop (sudden deceleration).

Method

A variety of front and rear suspension spring setups were evaluated, including different spring pre-compressions. For example, the same spring might be pre-compressed 3/8 inch and then 5/8 inch. Table 2 shows the various combinations and the drive wheel conditions under which they were tested. The basic paradigm was to conduct 3 trials within each condition.

Table 2. The different suspension set-ups tested in FWD, MWD, and RWD.

RWD only Front casters and suspension MWD both Front and Rear casters and suspensions FWD only Rear casters and suspension			Rear caster spring rate/Wheel rates (lbs/in)	
			320/95	351/118
			FWD	FWD
Front caster spring rate/Wheel rate (lbs/in)	107a/116	RWD	MWD	Not tested
	107b/102	RWD	MWD	Not tested
	194/170	RWD	MWD	MWD
	320/143	RWD	MWD	Not tested

Note: For the front casters, 107a and 107b reflect two different pre-compression settings of the spring.

Tasks

Threshold crossing. The PofCModel was set at 75% power, allowed to reach top speed and then driven across a 2cm x 10cm wooden strip that was securely fastened to a level asphalt surface. The dependent measure was MaxDxyz, the maximum 3-dimensional acceleration ($D(t_i)xyz$) for the event. The data loggers were two Sensr GP1s located at the seat and backrest, recording at 100 Hertz.

Lurch (sudden deceleration). The control system for the PofCModel was set to 100% power and 20% braking (a standard braking setting for the controller), allowed to reach top speed on a level asphalt surface, and then the joy stick released to create a lurch condition (sudden deceleration to a stop).

Results

Threshold crossing

The MaxDxyz values, maximum value for 3-dimensional acceleration (g), are shown for the three drive wheel positions for the Backrest and Seat accelerometers in Figure 2. The values of MaxDxyz decreased significantly from RWD to MWD to FWD, with the acceleration force being dramatically less in FWD. The relatively large increase in acceleration at the Backrest compared to that at the Seat demonstrates the importance of measuring forces where they may have a major impact on the user, for example, if there is difficulty maintaining upper body position.

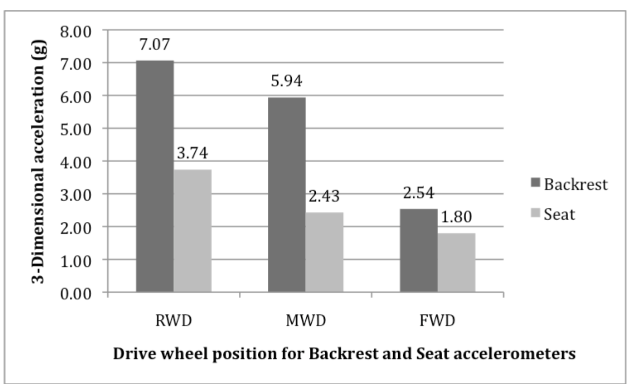

Figure 3. Acceleration at the Backrest and Seat as a function of drive wheel position, pooled over suspension conditions.

Comparable data for each suspension combination tested are shown in Figure 4. The measured Wheel rate for the front and rear wheel casters in each suspension setup is provided. The major results were: 1) no single suspension setup is optimal for all drive wheel positions, 2) the maximum percentage increase in 3-dimensional acceleration at the Backrest and Seat for the different suspension setups were, respectively: RWD 39%/41%; MWD 24%/30%; FWD 5%/16% and, 3) most noticeably at the Backrest the MWD accelerations were all substantially greater than the FWD accelerations even though the Seat accelerations for MWD and FWD were similar.

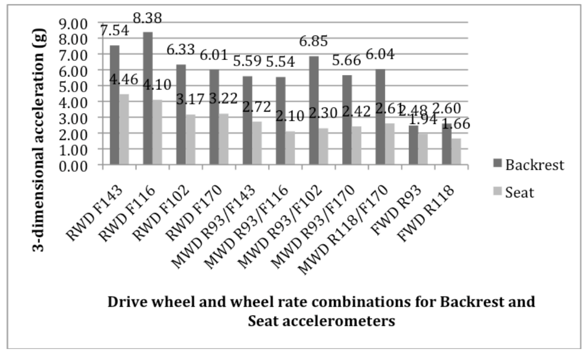

Figure 4. Acceleration at the Backrest and Seat as a function of drive wheel position and each of the Wheel Rate conditions.

Lurch conditions

The MaxDxyz values, maximum value for 3-dimensional acceleration (g), pooled across suspension conditions are shown in Figure 5 for the Lurch testing.

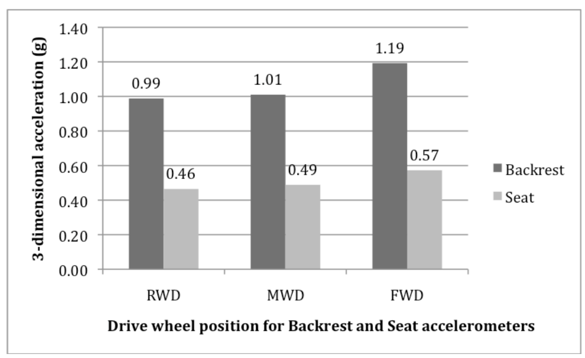

Figure 5. Pooled Lurch results as a function of drive wheel position at the Backrest and Seat accelerometers.

There were no significant differences among the drive wheel positions pooled across Wheel Rates although the acceleration at the Backrest is approximately 100% greater than at the Seat. In Figure 6, the results for the individual Wheel Rate conditions are shown.

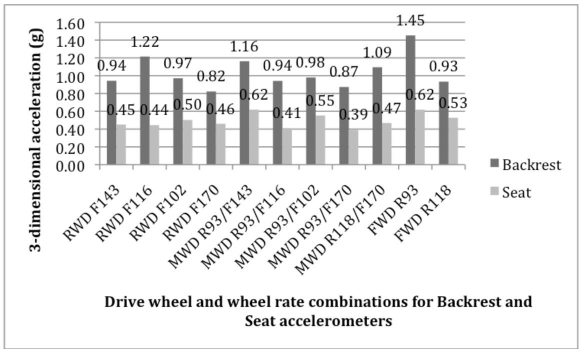

Figure 6. Lurch accelerometer results at the Backrest and Seat as a function of drive wheel position and Wheel Rate conditions.

Fisher LSD paired comparisons within the Analysis of Variance (a most sensitive of several techniques) for the Seat accelerometer showed that for the Mid wheel drive the Lurch was significantly less with the 170lbs/in front wheel rate than the 143lbs/in front wheel rate. For the Backrest accelerometer: for the Rear Wheel drive conditions the Lurch for the 170lbs/in front wheel rate was significantly less than for the 116lbs/in wheel rate; for the Front Wheel drive (rear casters), the Lurch for 118lbs/in wheel rate was significantly less than for the 93lbs/in wheel rate.

Although the absolute values of the measured accelerations during Lurch are relatively small compared to those for Threshold crossing, they are experienced differently by the user. Acceleration rates during a Lurch are slower than during a threshold crossing but the durations are longer (more accelerometer travel distance at the seat and, especially, backrest locations). Threshold crossing is similar to a “jarring” event where the accelerations are much shorter in duration but more abrupt (faster acceleration rates) and can cause whole body vibration.

Conclusions

The results are a first step toward understanding more fully the role of the suspension system in the performance of power wheelchairs as a function of the terrain/environment and its impact on users. The results confirm that the user is subjected to significantly smaller accelerative forces with a front wheel drive system in rough terrain (which the Threshold Crossing represents). The results are not so obvious if measured only at the Seat; however, they are obvious when measured at the Backrest, a location that reflects what is happening to the user’s upper body (arms, trunk, neck, head), which is involved in driving.

The analysis of the different Wheel Rate conditions for different tasks are important to refine and optimize the design of suspension systems for power wheelchairs.

The results for the testing of Lurch show that Lurch itself is an important performance variable that affects the user but which can be controlled to a limited extent through the suspension system.

The springs that constitute a suspension system have a Spring Rate that nominally defines the amount and nature of the suspension; however, the Wheel Rate defines the functional suspension. The present study is a beginning toward better understanding the role of suspension properties for power wheelchair performance.

Acknowledgements

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