THE DEVELOPMENT OF AN ULTRALIGHT WHEELCHAIR WITH DYNAMIC SEATING

Jaimie F. Borisoff[1,2,3] and Lowell T. McPhail[2,3]
[1]*British Columbia Institute of Technology,* [2]*International Collaboration On Repair Discoveries,* [3]*Instinct Mobility Inc. Vancouver, BC, Canada*

INTRODUCTION

The Elevation™ wheelchair[1] was recently developed and introduced to the market as an alternative to conventional ultralight rigid wheelchairs normally used by paraplegics and others with disabilities necessitating the daily use of a manual wheelchair. The Elevation wheelchair provides independent user-adjustable seat positioning during normal usage. Elevation allows the user to quickly and easily adjust in real-time the seat height, as well as backrest recline angle, all in a manual ultralight rigid wheelchair form factor. This allows for dynamic seat positioning to suit the tasks and comfort of users throughout their daily activities. The rationale for and user-driven development of the Elevation wheelchair is summarized here.

Mobility devices such as manual wheelchairs can improve the activities of daily living and promote participation in the community[2]. However, long term wheelchair use (and static sitting) is associated with a myriad of issues including for example: pain and discomfort, pressure-induced tissue degradation, joint immobility and contractures, spasticity, and musculoskeletal issues associated with mobility via chronic arm propulsion. The use of dynamic seating, similar to that employed in conventional seating ergonomics (e.g. office chairs or automobiles) may mitigate some of these issues[3-6]. The concept of dynamic seating as defined here refers to the user's ability to easily and quickly (i.e. in real-time while sitting in the chair) adjust their seating position independently during normal wheelchair usage.

A RESNA position paper on the use of seat elevation mechanisms installed on power wheelchairs was recently published[6]. According to this publication, wheelchair seat elevation (i.e. increasing seat height) is often medically necessary for a variety of reasons. Some benefits of seat elevation identified by RESNA are: improving the ability to perform activities of daily living, facilitating transfers, providing psychological benefits by equalizing eye to eye contact with others (especially in pediatric applications), enhancing independence and productivity, and positively impacting pain and secondary complications associated with wheelchair use. It is not unreasonable to think that similar benefits from seat elevation and other dynamic seating capabilities would be conveyed to the manual wheelchair user as well.

The effects of decreasing seat height, that is to create a "dump" position or negative seat angle with a lower rear seat height compared to front, may also provide benefits to wheelchair users such as increased seating stability / balance and wheeling efficiency. This seating position is typically chosen by wheelchair rugby players and higher-level paraplegic wheelchair basketball players. It was a design goal during the development of the Elevation wheelchair to allow for significant seating dump positions as well as seat elevating features.

Power wheelchairs offer choices for dynamic seating including seat tilt, backrest recline, standing, and elevation (seat lift) features[7,8]. Manual wheelchairs that offer some of these features also exist in the form of conventional tilt-in-space wheelchairs, or reclining chairs, as well as manual standing wheelchairs that also incorporate aspects of dynamic seating. However, these chair styles are typically heavy and cumbersome when compared to ultralight rigid chairs. The Elevation wheelchair design offers dynamic seating of both seat elevation and backrest recline in an ultralight wheelchair configuration (i.e. the complete wheelchair weighs less than 25 lbs.).

DESIGN CONCEPT

Several specific experiences of the first author (JFB) as a long-time manual ultralight wheelchair user led to the concept behind the design of the Elevation Wheelchair. First, the use of a manual standing wheelchair (Levo LAE) during graduate school highlighted the benefits of seat elevation for performing many activities of daily living. The author found that his most predominant use of the seat elevating features of the standing wheelchair was to achieve approximately counter top / work bench sitting height rather than higher standing heights. At this more conservative height the wheelchair could still be propelled and sitting stability was comfortable for working for several hours while elevated. As well, reaching tasks felt safe and stable, unlike when the seat was more fully elevated. Second, the contrast experienced between wheeling in a typical daily-use wheelchair with conventional setup (i.e. front seat height = 19", rear seat height = 17") compared to wheeling in a basketball wheelchair setup for a high-level paraplegic (i.e. front seat height = 20", rear seat height = 14") demonstrated the benefits of greater seat dump on sitting stability and wheeling efficiency. Third, maneuverability, performance, simplicity, and transportability inherent to conventional ultralight rigid wheelchairs were recognized as requirements. Especially important was ease of use and simplicity of design. A performance consideration was centre-of-gravity (COG) by incorporating adjustable rear wheel positioning. And fourth, the use of third party accessories (e.g. a Jay back) led to a requirement of maintaining industry conventions for seat and back design (e.g. tubular seat rails capable of carrying conventional seat slings or attaching rigid seating hardware, and tubular backrest posts with a ¾" backrest rigidizer bar). These user experiences led to specific design requirements for the development of the Elevation wheelchair, as shown in Table 1.

Figure 1: The Elevation Wheelchair raised and lowered.

Table 1: Design Requirements

Weight of entire chair under 25 lbs.
Maintain a similar form factor to exemplary rigid wheelchairs on the market in North America (e.g. esthetics and size)
Performance characteristics of ultralight rigid wheelchairs
Conventional ergonomics and configurable with typical components
Conventional "fixed" adjustments; i.e. backrest height, footrest height, COG
Ability to dynamically lower the rear seat height to create more seating "dump"
Ability to dynamically raise the seat height above the horizontal for sitting at counter top heights
Provisions for stable seating when the seat height is raised above the horizontal
Ability to dynamically change the backrest angle or recline the backrest
Ease of use and ability to naturally actuate the dynamic seating features
Manufacturable in the variety of sizes typically used in North America
Competitively priced with higher end ultralight rigid wheelchairs

DESIGN

The commercial design of Elevation is shown in Figure 1. This design evolved through several 3D modeling studies and three usable prototypes that underwent extensive real-world testing. Finite element analysis was performed on the lower base frame in order to design a wheelchair frame that lacked a direct linkage of the rear seat to the frame near the rear wheels. This design was necessary due to the dynamic rear seat height capabilities, and is in contrast to conventional box frame or cantilevered frame wheelchairs which have direct attachment of the seat to the rear of the frame.

The basic wheelchair design is a lower triangular frame made of 7005-T6 Aluminum with a pivot at the front seat height upon which a seat in attached. The seat is stabilized by two laterally spaced gas springs that attach from the lower frame to the rear of the seat. The gas springs are infinitely adjustable and lockable in length through a simple hand lever actuator under the front of the seat. An added benefit of the gas springs are that they act as a firm suspension, providing about 0.5" of travel for the rear seat height. This suspension is enough to dampen the jarring effects of dropping off curbs for instance, while preserving sufficient rigidity for wheeling power and efficiency.

The front frame incorporates pivots through which the seat angles from dump to elevation. Approximately 10" of rear seat height adjustment range is possible. The effect of this seat height range depends on where along the length of the seat the gas springs attach. Thus the user can select if they want more dump or more seat elevation. In the typical chair setup with a 16" seat sling depth as shown in Figure 1, this adjustable seat height range translates to angles of –15 degrees below to +19 degrees above the horizontal, or rear seat to floor heights from 14.5" to 25".

The backrest is attached by a pivot to the rear of the seat and linked in a parallelogram configuration to the lower base frame (see schematic in Figure 2). The parallelogram linkage serves to maintain the angle of the backrest at substantially a constant angle throughout the range of seat elevating heights. The linkage is also arranged such that it can be lengthened or shortened to adjust the backrest angle relative to the seat (Figure 2). The current design utilizes a gas spring for this adjusting feature, which also enables the user to adjust the backrest angle while continually loading the backrest. The original design used a Mechlok (Crane Aerospace) which required the user to un-load (i.e. lean forward off the backrest) before adjusting. Approximately -10 to 30 degrees of dynamic adjustment to the backrest angle with the simple squeeze of a lever was the result of this design.

The ability to lower into a steep dump seating position necessitated an unconventional camber bar design. The lower parallelogram linkage may interfere with the camber bar at the lowest seat heights, thus the camber bar was designed with the transverse tube member under the axle receivers rather than collinear as is typically found. This created as much space in the center of the wheelchair as possible for allowing lower seat heights. The design maintained the ability to adjust COG and also led to a novel and simple camber adjustment mechanism. Unfastening a single bolt and adjusting the length of a set screw (used as a spacer) allows for infinite adjustability of camber from 0 to 10 degrees.

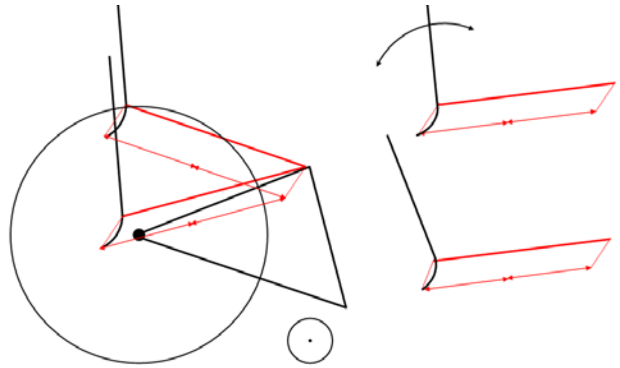

Figure 2: Wheelchair design schematic.

Another novel feature of Elevation is the movement of the clothing/side guards. When elevating above the horizontal, the front of the side guards lift the front of the seat cushion (Figure 3). In the absence of a user, this movement keeps the seat bottom at a constant angle to the backrest. In practice when a user is sitting in the chair, their body weight, and the flexibility in the side guards and cushion, result in less lifting and creates a pocket that serves to provide stability to the user that prevents them sliding forward at elevated seat heights (Figure 3).

Figure 3: Seat stability system.

RESULTS AND USERS PERSPECTIVE

The dynamic seating features of Elevation are actuated by levers attached underneath the front of the seat. By holding the front of the frame and squeezing one lever, a user can push with their opposite hand on the rear wheel to raise the seat height. A lever on the opposite side of the chair similarly activates the backrest adjustment. The design of the frame and moving mechanisms are such that there is no risk of pinching hands during adjustments.

Figure 4: Sitting at counter top height.

People with a variety of different disabilities are currently using Elevation as their primary every day wheelchair, including those with paraplegia, cerebral palsy, and spina bifida. They have found many benefits of dynamic seating, similar to those described by Arva et al[6]. Thus users can more fully interact with others in the community (Figure 4) and more easily perform activities of daily living. Other benefits are being revealed with greater usage. For instance it was found by a tetraplegic user that wheeling down hill was easier and safer when substantially reclining the backrest first.

The following quote is from a woman with T4 complete paraplegia who has used Elevation for three years.

"On a daily living basis it has improved the quality of my life tremendously. Having the instant ability to adjust both backrest and seat, the Elevation chair has made life less challenging by making everything easier to accomplish - domestic duties, high transfers, reaching high and low, pressure relief, wheeling on different terrain and slopes, travel, and comfort. It is encouraging to know that this chair will allow me to keep up with ever changing body concerns while aging with a spinal cord injury."

CONCLUSIONS

The design requirements for the Elevation ultralight wheelchair have been fulfilled. The development and commercialization of this wheelchair has established a new wheelchair category for previously unmet needs of many people with various disabilities. Dynamic seating lets people adjust their position in real-time to suit particular activities, such as talking to someone standing, sitting at counters, or wheeling uphill, thus promoting independence and community participation.

It is also hoped that this type of dynamic seating will provide substantial health benefits, although more research is needed. One study presently underway is investigating the influence of different wheelchair seating positions on cardiovascular control[9]. As well, we are instrumenting Elevation with data loggers to track usage of dynamic seating features during daily activities. Perhaps an optimal static wheelchair seating position is not possible. Not only may specific activities dictate varying seating positions, but musculoskeletal changes, for instance due to daily fluctuations in spasticity, may dictate that frequent real-time seat adjustments are preferred for the health of long-term wheelchair users.

ACKNOWLEDGEMENTS

We thank Ed Bell and William Gelbart for prototyping help during development. Both authors are principals in Instinct Mobility Inc. which manufactures and distributes Elevation.

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