Science, Technology, & Human Values

A socio-technical history of the ultra-lightweight wheelchair: A vehicle of social change.

Journal:	*Science, Technology, & Human Values*
Manuscript ID	ST&HV-2019-02-041.R2
Manuscript Type:	Original Article
Keyword:	Wheelchair, Assistive Technology, Disability history, Boundary Object
Abstract:	The emergence of the ultralightweight wheelchair has transformed the lives of millions of disabled people. It has radically changed the principles and practices of wheelchair design, manufacture and prescription and redefined wheelchair users and wheelchair use. Designed and built largely by wheelchair users themselves it was driven initially by a desire to improve sport performance and later by a wish for improved access to the community and built environment. In this paper we draw on oral histories and documentary sources to reconstruct its socio-technical history. We employ the analytical concept of 'boundary object' to illuminate how the wheelchair as a technological artefact is implicated in relations of social change and show the role of wheelchair users in the development and emergence of the ultra-lightweight wheelchair. We highlight the tensions and negotiations within this history and the push and pull between different social groups. The emergence of the ultra-lightweight wheelchair helped to reconfigure ideas about wheelchairs and their users and allowed wheelchairs to gain a foothold within broader social and technological infrastructures. What makes this account powerful is that this is a success story for a group who have historically been excluded from design process.

A history of the ultra-lightweight wheelchair

Abstract

The emergence of the ultralightweight wheelchair has transformed the lives of millions of disabled people. It has radically changed the principles and practices of wheelchair design, manufacture and prescription and redefined wheelchair users and wheelchair use. Designed and built largely by wheelchair users themselves it was driven initially by a desire to improve sport performance and later by a wish for improved access to the community and built environment. In this paper we draw on oral histories and documentary sources to reconstruct its socio-technical history. We employ the analytical concept of 'boundary object' to illuminate how the wheelchair as a technological artifact is implicated in relations of social change and show the role of wheelchair users in the development and emergence of the ultra-lightweight wheelchair. We highlight the tensions and negotiations within this history and the push and pull between different social groups. The emergence of the ultra-lightweight wheelchair helped to reconfigure ideas about wheelchairs and their users and allowed wheelchairs to gain a foothold within broader social and technological infrastructures. What makes this account powerful is that this is a success story for a group who have historically been excluded from design process.

Introduction

Emerging in the late 1970s, the ultra-lightweight wheelchair constituted a technological revolution that transformed the lives of millions of disabled people around the world. Although this was an innovation invisible to many, it marked a radical change transforming the principles and practices of wheelchair manufacture and prescription and contributed to the redefinition of wheelchair users and wheelchair use. Designed largely by wheelchair users themselves, this phase of wheelchair development was driven initially by their athletic endeavors and later by their wish for wider access to the community and built environment.

To many, the wheelchair may seem an uncomplicated and self-explanatory machine (Watson and Woods 2005). Literature reviews from areas of medicine and engineering portray wheelchair development in terms of linear scientific and technological progress serving to obscure the complex social interactions that underpin them (Goggin and Newell 2003,9; Watson and Woods 2005). The

history of the ultra-lightweight wheelchair is neither straightforward nor linear. Developments emerged as part of a "self-help" culture. As Williamson has argued, disabled people have long been involved in the self-modification of their homes, cars and other technologies as they have sought to make them useful and have shared these ideas through a range of routes (2019).

To reconstruct this history, we draw upon work from within science and technology studies (STS) and employ the analytical concept of "boundary object" to illuminate how the wheelchair as a technological artifact is implicated in relations of social change (Star 1989; Star and Griesemer 1989). What makes this account powerful is that this is a success story for a group who have historically been excluded from design processes and whose contributions have been ignored (Blume et al. 2014; Williamson 2019).

We have used both oral histories and documentary sources. We conducted a range of interviews with people who played a key role in the development of the ultra-lightweight wheelchair, or those who were particularly well-placed observers of this development. We interviewed wheelchair users, wheelchair athletes, wheelchair designers, representatives from wheelchair manufacturers, medical and health professionals and government officials and civil servants. Our life history methodology involved the research team conducting a type of in-depth interview where the interviewer's intentions guided, but did not dictate, the informant's stories and/or recollections (Blewett 1990). In addition to oral histories we also carried out a search of specialist publications, including those by disability groups such as; *Magic Carpet* (the journal of the Invalid Tricycle Association, ITA), *Paraplegia News* (the journal of the Paralysed Veteran's of America, PVA) *Sports'nSpokes* (a journal also published by the PVA focusing on wheelchair sports). We also reviewed technical-scientific publications, such as *Paraplegia*, *Archives of Physical Medicine and Rehabilitation* and the *British Journal of Biomedical Science.* Other sources accessed included the UK's Public Records Office and the National Register of Archives and the National Archives in the US.

This article begins with an outline of the concept of boundary object before proceeding to a socio-historical overview of the 20th century wheelchairs, which preceded the development of the ultra-lightweight wheelchair. We then move on to consider the emergence of the ultra-lightweight wheelchair as a result of the innovations from wheelchair users themselves, specifically wheelchair athletes. By utilizing the concept of boundary object we are able to highlight the tensions and negotiations within this phase of development and the push and pull between different social groups. The emergence of the ultra-lightweight wheelchair helped to reconfigure ideas about wheelchairs and

their users and allowed wheelchairs to gain a foothold within broader social and technological infrastructures.

Boundary Objects

The boundary object is a heuristic that enables an analysis of the dynamic socio-historical processes involved in the development of technological artifacts (Bowker and Star 1999; Griesemer 2016). It is an ecological approach, viewing scientific and technological knowledge as the outcomes of collective work from different communities of practice, each engaged in their own projects with their own interests and objectives (Bowker and Star 1999; Fujimura 1992). Boundary objects mean different things to different groups but share enough of a coherent identity across these communities that cooperation and knowledge production can take place without consensus. This allows communities to reach their goals independently of one another whilst at the same time maintaining a shared understanding of the artifact (Star and Griesemer 1989). Boundary objects:

> inhabit several intersecting worlds...and satisfy the informational requirements of each of them… [they are] plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become more strongly structured in individual use (Star and Griesemer 1989).

Boundary objects are characterized by *interpretive flexibility* to the communities involved. However, to make use of the boundary object in a way that does more than simply record different interpretations we must capture the dynamic between communities of practice by situating accounts within broader social infrastructures (Star 2010; Gal et al. 2005). As Bowker and Star (1999: 297) noted, "boundary objects arise directly from the problematics created when two or more differently naturalized classification systems collide." It is when the interpretations of different communities clash to create tensions and frictions that we can observe the socio-technical practices and relations of power which underpin these artifacts. As boundary objects represent an attempt to communicate and translate the ideas of groups they can act as sites of conflict as well as cooperation (Boland and Tenkasi 1995).

An ecological approach captures details that might otherwise slip through the cracks and does not presuppose the "epistemological primacy" of any perspective; "the viewpoint of the amateurs is not inherently better or worse than that of the professionals" (Star and Grisemer 1989: 389). It avoids the

pitfall of some constructionist approaches that uncritically apply a *principle of symmetry* in their analysis of communities of practice and may neglect the power asymmetries between groups (Feenberg 2017). Understandings of wheelchairs and wheelchair use have tended to reflect the concerns of medical, technical and managerial communities and have largely portrayed the wheelchair as "a necessary, but undesirable piece of clinical equipment" (Sapey et al. 2005: 493). We wanted to work with the accounts of those that are often made invisible, "systematically deleted" or excluded by processes of technological power because these accounts are the most analytically powerful (Timmermans 2016; 4). By showcasing the work of disabled designers and wheelchair users during this phase of wheelchair development, our analysis indicates a more political understanding of the wheelchair that recognizes the invisible work involved and the actors otherwise overlooked (Star 1990; Timmermans 2016; Williamson 2019).

It is an account that allows us to examine that which risks being omitted from social history and so protects against a one-sided history (Goggin and Newell 2003). This account also acknowledges the impact that this technology had for disabled people, recognizing that personal experiences, opportunities and social relations were shaped and recalibrated by wheelchair development (Timmermans 2016). This is to say that when we talk of social shaping of technology we must be sure to include the "valid aspect of technological determinism" or how technology shapes social relations, something which is generally left out of social constructivist accounts (Winner 1980; Mackenzie and Wajcman 1999: 41). Rather than viewing users and technologies as separate objects of study, our approach seeks to unpack connections between the two, revealing "the co-construction of users and technologies that go(es) beyond technological deterministic views of technology and essentialist views of users' identities" (Oudshoorn and Pinch 2003;3). Supplementing this approach with the concept of boundary object we have been able to reveal the constraints imposed on wheelchair users by the State, wheelchair manufacturers and health professionals.

In an effort to contextualize the emergence of the ultra-lightweight wheelchair as a boundary object within a broader period of wheelchair development it is helpful to locate the social infrastructure in which it was embedded (Gal et al. 2005). In the next section we present a brief overview of the socio-historical conditions that characterized understandings and constrained the development of the wheelchair during the 20th century. It is not intended to be a complete history.

Foundation Stones

The wheelchair as a technological artifact inhabited and was influenced by the multiple communities of which it was a part. Broadly speaking these communities of practice might be loosely grouped as medical professionals (including rehabilitation services), wheelchair designers, manufacturers and providers (including government/welfare and veteran agencies) and wheelchair users themselves. For much of the 20th century the wheelchair was predominantly considered a medical device that enabled the transport of passive patients rather than a tool to facilitate the independence of their users (Sapey et al. 2005; Roulstone 2016; Woods and Watson 2004, 2005; Tremblay 1995). Implicit within this medicalized understanding were naturalized ideas about disability (such as those of pathology, lameness and frailty) as well as the idea that the user would be housebound or institutionalized. Consequently wheelchairs were designed to reflect the minimal needs of indoor use and prioritized patient safety (Woods and Watson 2004, 2005; Guffey 2017; Roulstone 2016). There was little concern for the weight of these chairs, which weighed between 70 and 110lbs. Often constructed from fragile wicker and wood they were not suitable for outside use, serving to greatly inhibit the practice of those who used them (Woods and Watson 2004).

The key design change in the manual occupant-propelled wheelchair, which came in the 1930s, though did not ascend to dominate until the 1950s, was the relatively lightweight (30-40lbs) tubular-steel, folding general-purpose wheelchair. Perhaps the most iconic example of this design was the Everest & Jennings (E&J) single X brace, folding wheelchair, designed in 1933 by engineers Herbert Everest (who had been paralyzed in a mining accident some years previously) and his partner Harry Jennings (Woods and Watson 2005). Everest, in 1955, reflected on the motivation behind his design "When I tried to earn a living, I found my greatest difficulty was the lack of a usable, folding wheelchair" (Anon 1955;4) Convinced that he could design an alternative that granted better access at his workplace and usability with his car, the pair developed a folding wheelchair and together they launched the company that was to dominate the wheelchair industry until the 1970s (Guffey 2017; Shepard and Karen 1984). Although still heavy by today's standards, these chairs formed the basis of what came to be called "the lightweights" (Woods and Watson 2005). They were not only easier to handle and to get in and out of cars, they were easier to use in the built environment. In combination with increasing disability legislation this contributed to wheelchair users' greater access beyond the home or institution and raised their expectations of finding employment in the mainstream (Woods and Watson 2004).

This model of the wheelchair became the basic product of nearly every manufacturer and the most prescribed wheelchair in the world (Brubaker 1986). By the 1960s, wheelchair innovation had reached a standstill with little change in the general design of the chair since the 1930s (Brubaker 1986). Although wheelchair users were starting to demand better wheelchairs, development was inhibited by a conservative approach towards its design out of fear of product rejection as well as producers' desire to create a simple and standardized design that was economical to make (Brubaker 1986). While providers were aware of the desire for lighter chairs it was thought that changes made to decrease the weight might also reduce the lifespan of the chair, adding to an already expensive service (Woods and Watson 2005). Wheelchair provision was concerned more with price than performance (Brubaker 1986). The clash between the demands of users and that of wheelchair designers and suppliers is a familiar one and is repeated throughout the history of their development (Woods and Watson 2003).

As a result of the power of medical and rehabilitative professionals, wheelchair users' expertise and desires were overlooked (Sapey et al. 2005). The medicalized ideological content of the wheelchair as a boundary object had significant bearing on its acceptance and inhibited its development (Fox 2011).

In the US, wheelchair provision was completely in the private sector and E&J monopolized wheelchair production and controlled wheelchair design (Shepard and Karen 1984). They were accused of employing price fixing, intimidation and threats and preventing new companies from emerging.[1] Economic factors hindered wheelchair development and *financial* rather than technological rationality underpinned wheelchair progress, demonstrating the power of organizations in forcing the temporary closure or stabilization of technological objects, even when the product is unsatisfactory to other groups involved (Klein and Kleinman 2002:39; Humphreys 2005). As Bowker and Star (1999) noted, communities of practice are heterogeneous and some groups are cooperative whilst others are coercive, illustrating the difficult socio-technical terrain to be negotiated when working upon boundary objects.

Wheelchair development then was constrained by the socio-political arrangements of key players rather than by technical rationales. Although the field of medicine was not directly responsible for wheelchair development, it propagated hegemonic ideas about disability that influenced design and undermined the value of disabled people's expertise and contributions (Williamson 2019). The shaping of technology takes place in distinct socio-political environments that characterize and constrain how groups interact with each other and the artifacts they work upon (Harvey and Chrisman

[1] United States v. Everest & Jennings International, No. 77-1648-R (C.D. Cal. Feb. 5, 1979)

1998). In this respect the boundary object encapsulates a set of social relations, demonstrating how more powerful groups can coerce the temporary closure of objects. This inertia inhibited the practices of wheelchair users, contributing to the broader pattern of exclusion of disabled people and the preservation of medicalized perceptions of wheelchair users as dependent and unable—such is the *valid aspect* of technological determinism (Mackenzie and Wacjman 1999; Woods and Watson 2004). The wheelchair is umbilically tied to issues of access. The medicalized content of the wheelchair has depicted these issues of access as individual problems of pathology, which has inhibited the normalization of wheelchairs outside of healthcare settings. This has had significant consequences for disabled people through the failure to incorporate wheelchairs into wider architectural and design infrastructures, reifying the structural exclusion of disabled people in public spaces. But before we fall into the cyclical logic of strong technological determinism it is crucial that we indicate the active role disabled people played in the development of the wheelchair, demonstrating the socio-technical malleability of the wheelchair as a boundary object that was open to renegotiation.

This renegotiation of the wheelchair was an outcome of the intersection of social, medical and technical developments (Woods and Watson 2004, Williamson 2019). The mass production of antibiotics in 1945 led to the emergence of a new constituency of active wheelchair users, people surviving with spinal cord injury. This in turn led to the emergence of new practices in rehabilitation and state-organized resettlement, coupled with a political will to find solutions for the returning war-wounded from World War II. The polio epidemics of the 1940s and 50s, the victims of Thalidomide in the 1960s, and wounded veterans from the Vietnam war exerted similar effects. Expectations of disabled people to live in their community and find employment drove changes in assistive technologies (Williamson 2019). The increased availability of the motorcar in the US, state provision of invalid tricycles in the UK and improved public transportation made possible independent mobility and with that calls for greater access to such transportation (Johnson and Shaw 2001). With this came the realization of political empowerment (Woods and Watson 2004). This transformed ideas of what life could be like for disabled people and new movements emerged, such as the Independent Living Movement (deJong 1983) and these in turn filtered back into wheelchair design and use (Woods and Watson 2004, Trembley 1996, Williamson 2019).

From its development in the 1930s through to the 1960s there was limited user involvement. The drive for modifications, as we show below, initially came through wheelchair sports, in particular wheelchair basketball (Cooper 1996). In the next section we will discuss the collective work of wheelchair users upon lightweight chairs, which enabled the ultra-lightweights to emerge.

The Birth of the Ultra-lightweights – The Influence of Wheelchair Sports.

This section will explore how lightweight wheelchairs were conceptually reconceived and transformed by the collective technological practices of wheelchair users and in particular wheelchair athletes. This was a gradual process that entailed a great deal of innovation as well as the managing of tensions between multiple perspectives. The conservative ethos of manufacturers and medical professionals continued to exert influence in wheelchair use and design.

The role of wheelchair sports in the development of the ultra-lightweight wheelchair has been acknowledged by many (Brubaker 1986; Roulstone 2016; LaMere and Labanowich 1984). Athletes sought to modify their chairs as they tried to improve their performance and to gain advantage over their opponents. As wheelchair designer Vincent Ross told us:

> the real reason for doing this was not just because I wanted a lighter more movable chair… I started to make these more maneuverable and lighter chairs so I could compete with some of these more able players.[2]

Wheelchair sports first took shape in hospitals in both Britain and America in the immediate aftermath of the Second World War as part of the rehabilitation practices that were emerging at the time (Woods and Watson 2004b). In Britain, under the directorship of neurologist Dr. Ludwig Guttmann at Stoke Mandeville, medical staff tightly supervised and controlled the games, setting their rules and regulations. By the end of the 1940s, wheelchair sports in the UK had embraced a range of activities including archery, javelin, club throw, shot putt, netball and snooker (Scruton 1998; Goodman 1986). In addition to strictly controlling the conduct of wheelchair sport, Guttman also regulated the design and appearance of the wheelchairs used and was not in favor of changes to the wheelchair, with some indication from those we interviewed that he may have held back the development of the wheelchair with his conservative approach:

> He did a great thing for improving the lives of wheelchair users when he started the games, but towards the latter part of his life he did a lot, I think, to hinder the development.[3]

In the US wheelchair basketball was the dominant sport and until 1957 was the only wheelchair sport of note played in the country. It is also arguably the sport that has had the most impact on wheelchair design. For wheelchair racing an athlete needed a chair that could go fast on a flat, straight surface.

[2] Interview Vinnie Ross
[3] Interview Rory Cooper

Basketball demanded a lightweight chair with greater responsiveness and maneuverability, features that translated well into day-to-day handling.

In the US wheelchair basketball was not as strongly associated with or shaped by rehabilitation services. Although initially founded by Dr. Tim Nugent, a physical educator from the University of Illinois in charge of a rehabilitation-education program for disabled students, the National Wheelchair Basketball Association (NWBA) very quickly became controlled by the players themselves (LaMere and Labanowich 1984). In 1950 Nugent handed over control of the NWBA to an Executive Committee of four people elected by the member teams to oversee administration of the sport. Nugent was appointed Technical Advisor, although as he was neither a player nor disabled he had, under the organization's constitution, no voting privileges. Nugent set up an association that was run by the membership for the membership and his role was solely to provide assistance in administrative matters. In 1952 the NWBA stated that the official chair should be the E&J Standard Universal Model or similar (LaMere and Labanowich 1984). Phil Craven, who represented Great Britain in basketball from 1969 to 1993, for example observed:

> *When I started wheelchair basketball, there were regulations that everybody had to have the same chair. So, if you were 6'6" or 5'10" you had the same chair.* (in Chronic Girl 2008)

The dominant manufacturers of the time discouraged modifications to the chair and were more interested in promoting sales than meeting the needs of athletes (Shapiro 1993). It was the athletes themselves who led the change, as they learnt how to work their way around the rules and modified their chairs to gain advantage (Lamere and Labanowich 1984). At first these modifications did not significantly change the appearance or structure of the chair—for example, by incorporating pneumatic tires to reduce the rolling resistance of the chair (LaMere and Labanowich 1984). Pushrims were also moved away from the wheel to allow the athlete to get a better grip on them and were coated with a non-skid surface material. Other athletes chose to remove the rims altogether and pushed directly through the wheels. This not only helped in pushing the chair it also helped avoid damage as the chairs were less likely to become entangled with each other (LaMere and Labanowich 1984).

In addition to the tension between athletes and manufacturers was another boundary to be negotiated between the athletes themselves, demonstrating the push and pull that sometimes takes place *within* communities of practice. While there were those who considered the wheelchair to be a sporting device open to the adaptations of its users, others saw this as bestowing an unfair advantage (LaMere and Labanowich 1984). They believed that athletes should adapt their performance to the

parameters of a universal chair. By contrast, there were those who considered the wheelchair as an aid that should enhance rather than restrict the athlete and therefore encouraged modifications that made the chair more amenable to different body shapes and sizes (LaMere and Labanowich 1984). This tension illuminated how the athletes variously interpreted wheelchair use within sport and the changing relationship between athletes and their wheelchairs as their practice was gradually transformed. While the practice of wheelchair users had previously been restricted by *disabling* wheelchairs, athletes were gradually enabling greater freedom of movement through their redesigns, redrawing the boundaries of what wheelchairs could do.

Weight reduction

The next step in the evolution of the basketball wheelchair saw more radical alterations as the athletes took steps to reduce the weight of the chair and in so doing altered the form of the wheelchair itself (LaMere and Labanowich 1984). Although sport was the primary driver for these new developments, by the 1960s a new constituency of wheelchair users had emerged and, dissatisfied with the chairs on offer, they had started to complain about the weight of their chairs. They demanded lighter chairs to improve their opportunity for access, seeking to influence both the pace and the direction of innovation (Woods and Watson 2004). Articles in disability publications such as *Magic Carpet*, and *Paraplegia News,* criticized wheelchair designs:

> Ever since the weight of the Ministry Model 8F folding transit chair shot up to 56lb we have been receiving complaints from our members concerning excessive weight. (Denly 1964;43)

Wheelchair designer Ralf Hotchkiss told us that instead of listening to what wheelchair users wanted, manufacturers

> listened to the squeaky wheel of rehabilitation professionals and were more concentrated on very aggressive marketing than they were necessarily on marketing through product improvement.[4]

Manufacturers such as E&J were complacent to the demands of wheelchair users and rebuffed suggestions for lightweight wheelchairs with “Fine, make it yourself” (Cliff Crase in Shapiro 1993: 215-

[4] Ralf Hotchkiss interview

216). And so they did. Weight reduction was achieved through the removal of parts that had no function on the basketball court or which got in the way when they were going about their everyday activities (LaMere and Labanowich, 1984). At this time very few people had a chair dedicated solely to sport and therefore used their chair for both their normal day-to-day activities and to play sport.[5] This meant modifications had to translate into use outside of sport or had to be easily restored once the activity was completed. First to go were the armrests and the brakes. The brakes were normally only removed for the duration of the game, although some removed them on a permanent basis.[6] Removing the armrests became a statement. Armrests were considered essential in all chairs and the consensus was that chairs must be designed with detachable armrests. They acted not only to provide users with somewhere to place their arms but, more importantly from the point of view of therapists and health professionals, they were a *safety barrier*, preventing the user from falling out. They added significant weight and interfered with transfer in and out of the chair. An article on wheelchair design published by the Council of Industrial Design, for example stated, "He will need to get out of it sideways to get into bed or into a bath, or to use a lavatory, so the side pieces should be detachable" (Raynor 1962; 30).

Raynor's article was widely criticized by wheelchair users. In preparing this article Raynor talked to doctors, Ministry of Health officials, manufacturers, an industrial designer, and an expert in anthropometric design. However, she failed to consult with wheelchair users themselves, a major criticism leveled at the report by the Invalid Tricycle Association (ITA) (Denly 1963). The design considerations reflected able-bodied assumptions about wheelchair users as passive and vulnerable and predominantly concerned with mundane aspects of care (resting, bathing, toileting) rather than as active individuals. Accounts like these demonstrate wheelchair users' continued exclusion from participating in knowledge production and design processes. They show how knowledge from some communities of practice are translated at the expense of others and therefore fail to contend with the specific tensions which emerge in practice (Carlile 2002).

Perhaps most importantly, this response showcases the expert knowledge produced by the embodied experiences of wheelchair users and demonstrates the value of knowledge created by groups invested in its practice (Carlile 2002). Wheelchair sports, especially basketball, finally saw the end of the armrest, albeit with great resistance from therapists. Eventually, as John Hockenberry (1995: 136)

[5] John Smith, Interview
[6] John Smith, Interview

described, a culture emerged off-court in which armrests were deemed not just unnecessary but unfashionable:

> *Walter [a fellow wheelchair user] would grab my chair from behind and say "When are you going to lose the armrests pussy?...Armrests are for Tiny Tim, cup-in-hand, poster boy 'Jerry Lewis Telethon' crips."*

This is perhaps the first evidence of sports wheelchairs having an impact on design away from the sport arena. Athletes continued to make alterations to their chairs; changes that were more than modest adaptations, they were radical redesigns. Back height was reduced but, perhaps, most radically of all, the rear push handles were removed (LaMere and Labanowich 1984). This modification not only reduced weight and enabled better freedom of movement of the upper body (a very important consideration in wheelchair basketball), it also made a very strong statement. Wheelchair users who cut off the handles were clearly articulating the belief that they could live and move about the environment without the help of non-disabled people. It was more than a technical innovation, it was a claim to independence.

The Ultra-Lightweight Takes Shape

In the early 1960s even more radical modifications were introduced although they did not initially catch on. Bud Rumple and Joseph Jones experimented with wheelchair design by removing the folding mechanism and replacing it with an aluminium square box that reduced the weight by 10lbs (LaMere and Labanowich 1984). In addition to reducing weight it also reduced frame deformation and ensured that energy was not lost in propulsion. A solid, rigid frame has much more strength and more of the energy from the push is translated directly into forward motion. Whilst it made the chair lighter and dramatically improved its performance it was not widely copied because it required a lot of disassembling and reassembling in order to be transported and was not practical for day-to-day use.

People continued to make further experiments and alterations to the chairs throughout the 1960s, 1970s and 1980s. The athletes learned from each other, worked together and freely shared their innovations as they sought to improve their performance.[7] The wheelbase, (the contact points of the wheels with the ground), was altered and the chair was made much shorter. The axles were shifted

[7] Interview Vinnie Ross, Rory Cooper

forward and upwards, moving the center of gravity backwards and downwards. This idea was initially developed by Rod Williams and Gary Kerr who took an E&J chair and inserted a new post for the rear wheels.[8] This served to unweight the front castors and gave a better ergonomic position for propulsion (van der Woude et al, 2001). It also made the chair much more responsive. Dave Kiley recalled in interview:

> I was like one of the first basketball players to experience [repositioning of] the center of gravity when you leaned forward and I had such an advantage at that particular time before everybody got one themselves. From those simple little adjustments and being ahead of the athletic curve because you were there first with those little gadgets that meant a big difference.

In shortening the wheelbase, however, the front castors had to be reduced in size to ensure clearance of the front footplate. In the US wheels from skateboards were chosen to replace the usual front castors (LaMere and Labanowich 1984),[9] in the UK where skateboards had not yet entered the market, adapted wheels from conveyer belts were used.[10] Using small castors had the potential to increase fluttering and also the risk of sudden stops. However, because the center of gravity was shifted on to the rear wheels the weight through the front castors was greatly reduced from approximately 40% of the total to 15% and, in forward propulsion the castors in effect floated (Cooper 1998). A downside to these developments was that it increased the instability of the chair and placed greater demands on the rider, making the chairs unpopular with wheelchair providers and health professionals.

Although not yet fine-tuned, the wheelchair had changed profoundly from a cumbersome medical device into an avant-garde piece of technology. The field of wheelchair sport provided athletes with the space in which to challenge and "undo" the naturalized classifications and ideological content of wheelchair, instead applying knowledge gained through embodied practice (Bowker and Star 1999; Fox 2011; Carlile 2002). This was not without resistance from medical professionals who viewed these new chairs as dangerous and unstable. At first, the changes made by athletes may have represented small-scale local tailoring. However, as these modifications shifted from sport into the mainstream and quickly translated into everyday practice, these technological developments began to impress a wider community of users and soon supplanted existing conventions.

[8] Interview David Killey
[9] Interview Ralf Hotchkiss
[10] Interview Vinnie Ross

Movement off the court

By the late 1970s, the benefits of these adaptations for daily usage were apparent and new wheelchair manufacturers began to appear, applying the principles of these sports wheelchairs to their day-to-day chairs. These included: Quadra Wheelchairs, Production Research Company, Halls Wheels, Magic in Motion, Hand Crafted Metals, Baer Chairs, Baret Chairs, and E&G Wheelchairs (Cooper 1996). Although these wheelchair companies were small, they challenged the complacencies and orthodoxies of larger wheelchair manufacturers and demonstrated the potential of these lightweight chairs outside of sports as well as the commercial possibilities in wheelchair development (Cooper 1996; Shapiro 1993). Invacare and E&J, the two dominant wheelchair manufacturers at the time, viewed the entrance of these new chairs with skepticism (Cooper 1996). In 1978 E&J faced an antitrust suit that weakened its market position and allowed for other manufacturers to enter the market (Shepherd and Karen 1984). Failing to recognize the developments made by the newer wheelchair companies and neglecting the demands of wheelchair users themselves, dominant wheelchair producers began to relinquish total control of the market and of wheelchair design. As wheelchair athlete Dave Kiley told us, "They had no ear to what we were trying to say. They felt like they didn't have to change because they had the market and they learned the hard way."

Perhaps the most important new chair, and the one that was to have the most impact in the development of ultra-lightweights, was the Quadra produced by the wheelchair athlete Jeff Minnebraker in 1972. It was the first completely adjustable, rigid, aluminium-frame chair. He removed the handles, built the cushion into the seat, developed a system that allowed for a variety of axle placements and produced an innovative footrest. He developed a plate drilled with several holes to enable adjustable axle positions, which allowed the individual to alter the center of gravity and meant that the wheelchair could be easily adapted to meet specific requirements. Minnebraker is also credited with incorporating a quick-release axle mechanism, imported from aerospace technology.[11] These made rigid framed wheelchairs much more practical, allowing the wheelchair to be disassembled quickly and easily for transport and allowed the chairs to be used in conjunction with the car (Cooper 1996; LaMere and Labanowich 1984). Minnebraker first produced this chair for basketball, and whilst it caused some disquiet among other teams it was eventually accepted and was copied by many other athletes. Minnebraker has acknowledged that had he been playing in a more successful team, or had been a better player, then it is likely that his innovations would have been rejected by the NWBA for giving too much advantage (LeMere and Labanovitch 1984). It is difficult to

[11] Interview Ralf Hotchkiss

overstate the transformative power of these chairs. Those who used them remarked on the ease with which they moved and responded and how the chairs enhanced their abilities, leading one user to state, "When I got in it… I felt like my disability went away" (Boegel in Vogel 2012). These chairs were life-changing (Vogel 2012).

The appeal of the Quadra was clear and provided inspiration to wheelchair-users-cum-designers such as Vincent Ross and Russell Simms in the UK and Marilyn Hamilton and her colleagues in the States. Not only were they wheelchair users, they had engineering, technical and design skills: "The point is, you need people like Russ [Simms] and Vinnie [Ross] you know, who are engineers, who know the factors."[12]

The Quadra, whilst a big step forward, did have a number of faults. It was not well engineered and was poorly put together: "The problem with the Quadra was that they didn't have good quality control in their manufacturing and so on…… So that you would buy one Quadra and if a part broke it was hard to get parts."[13] And failures were hardly surprising given Minnebraker's approach to product testing: "Jeff used to test his chairs by putting one in his van, open up the side of the door, this was R n B in testing, and he would throw it out as you were moving at 50mph and see if it broke."[14]

The company was also inefficient, with a waiting time of between 6 and 12 months for delivery and there was poor aftercare; the focus was on the chair and sports not the market.[15] It was these factors that drove Marilyn Hamilton and her colleagues to develop the Quickie wheelchair, a chair that according to Shapiro (1993:213) changed wheelchairs forever: "She took a piece of medical equipment and made it fun and sporty. She took the universal symbol of sickness and turned it into a symbol of disability self-pride."

Hamilton broke her back while paragliding in 1979 and following her rehabilitation and discharge from hospital she was provided with what she described as a "stainless steel dinosaur", ordered for her by her physical therapist (Shapiro 1993: 211). The chair, she felt, had not kept pace with modern development : "There was more technology in a toy that I had, and more fun colours than what was now given to me as my legs being a wheelchair."[16]

[12] Interview John Smith
[13] Interview Rory Cooper
[14] Interview David Kiley
[15] Interview David Kiley
[16] Interview Marilyn Hamilton

Looking for a chair to both help her get around and to use for tennis Hamilton ordered a Quadra. After waiting 12 months for her Quadra to arrive, she was disappointed with both the service and the design:

> …I got my first Quadra wheelchair a year after I ordered it….and there was absolutely, it had disk brakes on it that I took off and threw away before I rode it the first time as they didn't function. It was like Rube Goldberg with the square anodised tubing, it had no colour, …it had vinyl for the seat that was attached to 2 bars on either side and so for a woman that had bigger hips you could sink down into this thing and your hips would be sitting on these 2 tubes and what is going on! And so when you go out and play sports you sweat, you sit in moisture and this doesn't work, great idea but something is missing here, like a lot![17]

She wanted a chair that was "fun and it looks good."[18] Working with two colleagues, Don Helman and Jim Okamoto, they employed technology from paragliding, particularly the use of high performance seamless aluminum tubing:

> We design and manufacture ability so we designed using the most high-performance materials … that no one else was using, added creature features to the chair and adjustability.

Incorporating ideas from the Quadra, and other wheelchairs, together the team developed what later became known as the Quickie wheelchair and founded Motion Design. The Quickie was sleek, lightweight and robust and improved upon the design of the Quadra by making a chair that was more user-friendly (Shapiro 1993). According to Ralf Hotchkiss, "Quickie left them in the dust for a very good reason, which was design, and it was designed by real hang-glider engineers."

Motion Design were not the first company to try and produce a commercial ultralightweight wheelchair, but were the most successful. They recognized that the wheelchair should be seen as a consumer item and that disabled people wanted stylish products (Williamson 2019). They also understood that they had to be customer focused; they aimed to have the chair delivered within two weeks of order and the chair was available in 12 colors. It was robust, they set up standards and took testing seriously. The chairs were fun and stylish and as wheelchair designer Vincent Ross put it:

[17] Interview Marilyn Hamilton
[18] Interview Marilyn Hamilton

> The fact that it doesn't look like a wheelchair with the modern materials and the lightweight design and the new wheels. They look less like pieces of medical equipment and more like personal items belonging to that particular person.[19]

This stylishness was instrumental in shaping attitudes towards wheelchairs and wheelchair users. They also recognized the importance of the market and in developing their strategy talked to dealers to make sure they could meet their needs as well as those of the users, although the consumers were always the primary focus:

> We put the package together and every aspect of it, really looking for that consumer perspective. If you put your stake in the ground, the most important person is the consumer. How you meet the therapist needs, the dealers' needs, the funding needs, it is all wrapped around what that consumer wants.[20]

Involving therapists in the process was key to the success of the Quickie, a fact Rory Cooper acknowledged when discussing the failure of his model, the *Equalizer,* to establish itself in the market*:* "And so it was hard at that time to convince therapists. They were used to just the Everest and Jennings or Invacare type models that they just weren't ready to convert to a chair that was that radical."[21]

The lack of appreciation as to just how much difference the new chairs made was also shared by many wheelchair users, so Gary Karp, author of *Life on Wheels* told us:

> I didn't realize how good lightweights were, what a big difference they made, until I got one. Up till then I just thought that an E&J was just as good…When I first got a lightweight chair people started to look at me in a different way. They would come up and ask me questions about it, like it was a high tech bike.[22]

No longer resembling a clunky medical monstrosity, Quickie wheelchairs put people at ease and in tandem with disability politics of the time, promoting the idea that there was no shame in being disabled (Shapiro, 1993). The emergence of the Quickie marked the arrival of the ultra-lightweights

[19] Interview Vinnie Ross
[20] Interview Marilyn Hamilton
[21] Interview Rory Cooper
[22] Interview Gary Karp

to the mainstream. Quickie soon completely dominated the market and mainstream manufacturers "because they couldn't compete now at all."[23]

This arrival was not without its tensions and many therapists and health service professionals viewed these ultra-lightweight machines with suspicion. The new chairs were unrecognizable to medical professionals and were perceived as unstable and unsafe, demanding more skill than traditional chairs. A number of therapists expressed concern about the new designs, feeling that they increased the risk of pressure sores and injury. This concern was tangible enough that it prompted Dr. Frederick Shepard, a spinal surgeon, to write to *Sports and Spokes* , the leading wheelchair sports magazine:

> …At a recent conference on the topic of pressure sores, one or two of the professionals expressed concern for the innovative designs for sport wheelchairs that are creeping into general use—i.e., the "topless" designs with no arms and minimal backs… Before the new designs get unjustified condemnation for contributing to spine and skin complications, I would like to hear from readers who are using "topless" chairs… Should anyone worry about the increased use of the new chairs among nonathletes? (Shephard 1985;6)

It was difficult to persuade professionals of the new chairs' merits.[24] Dave Kiley recalled that he tried to "open the minds" of therapists and insurance companies to consider these chairs for everyday use but who resisted prescribing or funding what they thought was a *sports chair*.

Despite resistance from professionals who struggled to reconcile this new wheelchair with their own interpretations, the Quickie grew into a $40 million industry within ten years, appealing to the increasingly self-sufficient disabled consumer (Shapiro 1993). Originally designed for sport, the ultra-lightweights quickly became available for everyday use with design emphasis and marketing strategies centered on the machine's capacity to deliver greater independence for the user (LaMere and Labanowich, 1984). Adverts for New Hall's Wheels, a company founded by the wheelchair athlete and designer Bob Hall, appeared in magazines such as *GQ* and *Glamour.* For Hall these adverts were about empowerment: "By running these ads in magazines with a circulation of a couple million people, we are making a statement, we are educating the public about the coolness of people with disabilities" (Bob Hall in Vogel 1998). The wheelchair left the realm of the hospital and became a successful

[23] Interview David Kiley
[24] Interview Rory Cooper

consumer item. These were not chairs you were *prescribed* by others, they were chairs you chose for yourself.

Conclusion

The ultra-lightweight wheelchair is a complex technological artifact with an important, and hitherto unexplored, socio-political history. Until the emergence of the ultra-lightweights, wheelchairs were relatively unwieldy pieces of *medical* technology. Strongly tied to loss, tragedy, passivity and dependency, wheelchairs were largely viewed as machines that disable, confine, restrict and remove independence (Watson and Woods 2005). Wheelchairs were not integrated into the mainstream, and the needs of wheelchair users were not routinely considered and their access requirements were often ignored. This inhibited the practices of their users and was key to their exclusion and marginalization. Wheelchairs shape the user, constructing what the person can do, shaping their worlds and defining who they are (Winnace 2006). Companies and agencies that manufactured, prescribed or supplied wheelchairs had failed to engage with how they were used. Unlike many other technologies, wheelchairs could not stabilize as "working technology" because they lacked an anchor into the wider socio-technical networks and systems within society.

The wheelchair as a boundary object therefore tells us much more than the various interpretations of an artifact. It reflects ideas held about wheelchair users and disability more generally and evinces the relations of power between diverse communities engaged in technological work. Overturning their historical exclusion from design processes, wheelchair users transformed these relations. The boundary object therefore allows us to foreground the political nature of the wheelchair within a complex and contested sociotechnical terrain and to conceptualize the active agency of disabled people invested in its development. The ultra-lightweight wheelchair and the disabled athletes who produced them challenged the hegemonic association between wheelchairs and injury, illness, passivity and dependency. They achieved this in spite of direct and indirect resistance from those who had previously controlled wheelchair design and use. We have traced this tension between groups across the trajectory of its modern development as it has shifted from medical device to sporting equipment to consumer good. The ultra-lightweight is both an outcome and an expression of disabled people's agency as active citizens, and, at the same time, it is the device that helped to facilitate this agency. They have both transformed and formed the lives of those who use them. By situating the approaches of the various communities that shaped wheelchair design, we have shown the structural and political factors that characterized and constrained its development and provide an enriched

understanding of the wheelchair as a vehicle for social change (Winner 1980; Humphreys 2005; Klein and Kleinman 2002).

Wheelchair design and wheelchair access are inextricably linked: changes in wheelchair design simultaneously developed from and were catalysts for the demand for greater access to the built environment. Previously Woods and Watson have argued that the emergence in the 1950s of relatively lightweight folding-wheelchairs (2004) and developments in powered wheelchairs (2003) extended the possibility of independent-mobility within the community. With these new technologies, physical access to the built environment, and with it the possibility of independent living, increasingly became political rather than medical issues. Although it would be hyperbolic to suggest that the ultra-lightweights precipitated a new democratic movement, they did coincide with radical changes in disability politics, helping to recalibrate the status quo through enabling better access to the environment and greater ease in performing activities independently (Cooper and De Luigi 2014). Changes in the design of both manual and powered chairs saw new groups of liberated wheelchair users emerge who demanded greater independence and this further politicized disability. As Shapiro (1993: 214) has argued, "the revolution of wheelchair design was tied to the revolution in disabled people's self-image."

In turn, the legislative response has, to a limited extent, reshaped our communities and buildings to incorporate wheelchair use, although this is by no means complete. This is what the disabled people's movement would describe as a "social model approach," where the focus is on changing the environment, not the individual (Oliver 1990). Traditional approaches to disability that pathologize wheelchair users and render them powerless has meant that their role in the development of technologies has mostly been ignored. What we have shown here is how those changes were driven by wheelchair users themselves and it is their involvement in the process that was key to their success.

Acknowledgements

The authors wish to thank Dr Brian Woods for his advice on earlier drafts of this paper and his contribution to the collection of data.

Declaration of Conflicting Interests

There are no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the authorship, and/or publication of this article.

Hilary Stewart is a research associate in the Medical School, University of Lancaster.

Nick Watson is Professor of Disability Research and Director of the Centre of Disability Research, located in the School of Social and Political Sciences, University of Glasgow.

References

Anon. 1955 Profiles: meet H.A. Everest. *Paraplegia News* Dec**:** 4

Blewett, Mary. 1990 *The Last Generation: Work and Life in the Textile Mills of Lowell Massachusetts, 1910-1960* (Massachusetts);

della Porta, Donatella 1992 "Life Histories in the Analysis of Social Movement Activists," in M. Diani & R. Eyerman (ed) *Studying Collective Action* (London), 168-193.

Blume, Stuart, Vasilis Galis, and Andrés Valderrama Pineda. 2014. "Introduction: STS and Disability." *Science, Technology, & Human Values* 39 (1): 98–104.

Boland, Richard J., and Ramkrishnan V. Tenkasi. 1995. "Perspective Making and Perspective Taking in Communities of Knowing." *Organization Science* 6 (4): 350–72.

Bowker, Geoffrey C., and Susan Leigh Star. 1999. *Sorting Things out: Classification and Its Consequences*. Inside Technology. Cambridge, Mass: MIT Press.

Brubaker, Clifford E., 1986 "Wheelchair prescription: an analysis of factors that affect mobility and performance." *Journal of Rehabilitation Research Devolopment* 23, no. 4 : 19-26.

Carlile, Paul R. 2002. "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development." *Organization Science* 13 (4): 442–55.

Chronic Girl 2008. More sexy wheelchairs https://chronicgirl.wordpress.com/ Accessed February 18th 2019

Cooper, Rory. 1996 "A perspective on the ultralight wheelchair revolution." *Technology and Disability* 5, no. 3-4 (1996): 383-392.

Cooper, Rory. 1998 *Wheelchair selection and configuration* Springer Publishing

Cooper, Rory A., and Arthur Jason De Luigi. 2014. "Adaptive Sports Technology and Biomechanics: Wheelchairs." *PM&R* 6 (8): S31–39.

Denly, O A 1963 Wheelchairs *Magic Carpet* Vol XV No 1 Spring

Feenberg, Andrew. 2017 "Critical theory of technology and STS." *Thesis Eleven* 138, no. 1: 3-12.

Fox, Nick J. 2011. "Boundary Objects, Social Meanings and the Success of New Technologies." *Sociology* 45 (1): 70–85.

Fujimura, Joan H. 1992 "Crafting science: Standardized packages, boundary objects, and "translation." *Science as practice and culture* 168: 168-169.

Gal, Uri, Young jin Yoo, and Richard Boland. 2005 "The Dynamics of Boundary Objects, Social Infastructures and Social Identities," http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.333.567&rep=rep1&type=pdf (Accessed October 3rd 2019)

Goggin, Gerard, and Christopher Newell. 2003. *Digital Disability: The Social Construction of Disability in New Media*. Rowman & Littlefield.

Griesemer, James 2016 "Sharing spaces, crossing boundaries." *Boundary Objects and Beyond: Working with Leigh Star* 602: 201.

Guffey, Elizabeth. 2017. *Designing Disability: Symbols, Space, and Society*. Bloomsbury Publishing.

Harvey, F, & Chrisman, N., 1998. "Boundary Objects and the Social Construction of GIS Technology." *Environment and Planning A* 30 (9): 1683–94.

Hockenberry, John, 1995 *Moving Violations: A memoir. War Zones, wheelchairs and decelerations of independence* New York Hyperion Page 136

Humphreys, Lee, 2005. "Reframing Social Groups, Closure, and Stabilization in the Social Construction of Technology." *Social Epistemology* 19 (2–3): 231–53.

Johnson, M., & Shaw, B. 2001 *To Ride the Public's Buses: The Fight that Built a Movement*. Louisville, Advocado Press.

Karp, Gary, 1999. *Life on wheels. For the Active Wheelchair User.* Sebastpol, Calif: O'Reilley & Associates.

Klein, Hans K., and Daniel Lee Kleinman. 2002. "The Social Construction of Technology: Structural Considerations." *Science, Technology, & Human Values* 27 (1): 28–52.

LaMere TJ, Labanowich S. 1984 The history of sport wheelchairs: part 1 – development of the basketball wheelchair. *Sports 'n Spokes* 9: 6–11

MacKenzie, Donald A., and Judy Wajcman, eds. 1999. *The Social Shaping of Technology*. 2nd ed. Buckingham [Eng.] ; Philadelphia: Open University Press.

Raynor, Claire. 1962 Wheelchairs *Design*, 164; 30

Oudshoorn, Nelly, and Pinch, Trevor, 2003. Introduction: How users and non-users matter. In Oudshoorn, Nelly and Pinch, Trevor (eds) *How users matter. The co-construction of users and technology*, Cambridge, MIT Press 1-25.

Roulstone, Alan. 2016. *Disability and Technology: An Interdisciplinary and International Approach*. London: Palgrave Macmillan.

Sapey, Bob, John Stewart, and Glenis Donaldson. 2005. "Increases in Wheelchair Use and Perceptions of Disablement." *Disability & Society* 20 (5): 489–505.

Scruton, Joan,1998 "*Stoke Mandeville, Road to Paralympics."* The Peterhouse Press, 1998;

Goodman, Susan, 1986. *Spirit of Stoke Mandeville: The story of Sir Ludwig Guttmann* Collins.

Shepard, Donald S., and Karen, Sarita L. 1984 The Market for Wheelchairs: Innovations and Federal Policy (Health Technology Case Study 30), OTA-HCS-30, Washington, DC: U.S. Congress, Office of Technology Assessment, November

Shepard, Frederick, 1986, Letters to the editor *Sports'N'Spokes* Page 6 May/June 11 (1): 6

Shapiro, Joseph P. 1994. *No Pity*. 1st Pbk. Ed edition. New York: Times Books.

Star, Susan Leigh. 1989. "The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving." In *Distributed Artificial Intelligence*, 37–54. Elsevier.

Star, Susan Leigh. 2010. "This Is Not a Boundary Object: Reflections on the Origin of a Concept." *Science, Technology, & Human Values* 35 (5): 601–17.

Star, Susan Leigh, and James R. Griesemer Reviewed work(s): 1989. "Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39." *Social Studies of Science* 19 (3): 387–420.

Timmermans, Stefan. 2016. "Introduction: Working with Leigh Star." In *Boundary Objects and Beyond: Working with Leigh Star*, 9. MIT Press.

Tremblay, Mary. 1995. "The Canadian Revolution in the Management of Spinal Cord Injury." *Canadian Bulletin of Medical History* 12 (1): 125–55.

Tremblay, Mary 1996. Going back to Civvy Street: A historical account of the impact of the Everest and Jennings wheelchair for Canadian World War II veterans with spinal cord injury. *Disability & Society*, *11*(2), 149-170.

Vogel, Bob. "Quadra and the Lightweight Wheelchair Revolution." New Mobility. http://www.newmobility.com/2012/11/quadra-and-the-lightweight-wheelchair-revolution/ (accessed 01/02/2019)

Watson, Nick, and Brian Woods. 2005. "No Wheelchairs Beyond This Point: A Historical Examination of Wheelchair Access in the Twentieth Century in Britain and America." *Social Policy and Society* 4 (1): 97–105.

Williamson, Bess. 2019 *Accessible America: A history of disability and design*. NYU Press, 2019.

Winance, Myriam. "Trying out the wheelchair: the mutual shaping of people and devices through adjustment." *Science, Technology, & Human Values* 31, no. 1 (2006): 52-72.

Winner, Langdon. "Do artifacts have politics?." *Daedalus*(1980): 121-136.

Woods, Brian, and Nick Watson. 2003. "A short history of powered wheelchairs." *Assistive Technology*, *15*(2), 164-180.

Woods, Brian, and Nick Watson. 2004. “The Social and Technological History of Wheelchairs.” *International Journal of Therapy and Rehabilitation* 11 (9): 407–10.

Woods, Brian, and Nick Watson. 2005. “When Wheelchair Innovation in Britain Was under State Control,” *Technology and Culture 17*(4), 237-250.

van der Woude LH, Veeger HE, Dallmeijer AJ, Janssen TW, Rozendaal LA. Biomechanics and physiology in active manual wheelchair propulsion. *Medical Engineering & Physics* 2001 23:713-33.