IMPACT OF MOBILITY AIDS ON PEOPLE WITH MULTIPLE SCLEROSIS

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The use of mobility assistive (MAT) devices has been pointed out as important factors to improve impaired mobility. The overall purpose of the study was to investigate the benefits of a new MAT device among people with multiple sclerosis (MS). This dissertation was based on three studies that investigated characteristics of MAT devices mostly used by adults with MS and the compliance of scooters, popular MAT devices among this population within three studies.

The first study was a systematic literature review of research related to the use of mobility assistive technology (MAT) devices among persons with multiple sclerosis (MS). Results of this systematic review showed that there are limited numbers of articles with higher levels of evidence were found in regards to use of MAT benefits specifically for adults with MS. The second study investigated the impact of MAT devices on quality of life, community participation and satisfaction with MAT devices of this population. We collected information of participants who came to two specialized seating and mobility clinics in Western Pennsylvania and MS support groups. Overall, participants' reported an increase in physical independence among participants who received new MAT devices. Satisfaction with MAT device at follow up increased particularly among participants who transitioned from non-wheeled to wheeled MAT devices. The third study investigated compliance of 4 scooter models with ANSI/RESNA standards. Our results suggest that scooters currently available may not meet ANSI/RESNA standards. These results have serious implications to the users who rely on these devices to

conduct their daily activities. Furthermore, these results indicate that the regulatory framework to ensure these devices are safe may need to be revised.

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PREFACE

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1.0 MULTIPLE SCLEROSIS AND MOBILITY-RELATED ASSISTIVE TECHNOLOGY: A SYSTEMATIC REVIEW OF THE LITERATURE

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1.1 ABSTRACT

Multiple Sclerosis (MS) causes a wide variety of neurological deficits; with ambulatory impairment as the most obvious cause of disability. Within 10 to 15 years of disease onset, 80% of persons with MS experience gait problems due to muscle weakness or spasticity, fatigue, loss of balance. To facilitate mobility, persons with MS frequently employ mobility assistive technology (MAT), such as canes, crutches, walkers, wheelchairs, and scooters. The purpose of this study was to conduct a systematic review of the published literature concerning MAT use among persons with MS. We searched the literature using electronic reference lists such as OVID Medline® and PubMed. We located 50 articles that met these initial criteria of providing good evidence of types of MAT devices and their benefits among individuals with MS. Limited numbers of articles with higher levels of evidence were found in regards to use of MAT benefits specifically for persons with MS. Evidence-based literature provides the basis for the strongest method of measurable clinical performance; therefore, having a strong research study design is vital to justify prescription and reimbursement decisions when prescribing MAT . However, paucity in studies with higher level of evidence (LOE) based practice does exist.

Keywords: Assistive Technology, Cane, Mobility, Multiple Sclerosis, Scooter, Walker, Wheelchair.

Abbreviations: AT-Assistive Technology; CNS – Central Nervous System; MS-Multiple Sclerosis; QoL-Quality of Life, MAT- Mobility Assistive Technology.

1.2 INTRODUCTION

Multiple sclerosis (MS), a neurodegenerative disorder of the central nervous system, currently affects approximately 400,000 U.S. residents, with 200 newly diagnosed individuals each week [1,2]. MS causes a wide variety of neurological deficits, with ambulatory impairment as the most obvious cause of disability [3, 4]. Within 10 to 15 years of disease onset, 80% of persons with MS experience gait problems due to muscle weakness or spasticity, fatigue, and balance impairments [5, 6, 7]. To facilitate mobility, persons with MS frequently employ mobility assistive technology (MAT), such as canes, crutches, walkers, wheelchairs, and scooters.

Matching the most appropriate MAT to the needs of a person with MS is vital to his or her daily mobility. Mobility impairments frequently restrict participation in work, family, social, vocational and leisure activities [8]. Furthermore, persons with MS often experience difficulties adapting to the changing and progressive nature of mobility loss, frequently marked by exacerbations and remissions [9]. These difficulties can compound relatively high levels of emotional distress, which can exacerbate efforts to accommodate mobility with MAT [10]. A 2008 survey of persons with MS found that 37% were too embarrassed to use MAT, while 36% reported that they do not use their MAT as much as they should [11].

In addition to standard MAT, new and emerging technologies are undergoing development that could accommodate mobility needs for persons with MS. More studies are exploring the consequences and patterns of MAT use among persons with MS. However, no recent review has examined the growing scientific evidence-based literature about MAT use in MS. We aimed to conduct a systematic review of the published literature concerning MAT use among persons with MS.

1.3 METHODS

We searched the literature using electronic reference lists: OVID Medline® (1950 to 2008); Cumulative Index to Nursing & Allied Health Literature – CINAHL (1982 to 2008); PubMed (1966 to 2006); and SCOPUS database (1985 to 2008). The searches used the following keywords: falls, mobility, multiple sclerosis, cane, walker, wheelchair, assistive technology, and psychological problems. We considered only publications concerning persons with MS with impaired mobility and published in a peer-reviewed journal. After reviewing potential articles, we located 50 articles that met these initial criteria of providing good evidence of types of MAT devices and their benefits among persons with MS (Table 1).

The articles reviewed in our literature review were evaluated and included according to their levels of evidence (LOE) and significance proposed by Sackett and colleagues[12]. Their approach is based on evidence based medicine defined by the authors as: "a practice of integrating individual clinical expertise with the best available external clinical evidence from systematic research"[12]. To make the process of evaluating published research more efficient, Sackett and colleagues outlined categories of evidence and stratified them in order from strongest to weakest:

I. Evidence is obtained from meta-analysis of multiple, well designed, controlled studies.

II. Evidence is obtained from at least one well-designed experimental study.

III. Evidence is obtained from well-designed, quasi-experimental studies such as non-randomized, controlled single-group, pre-post, cohort, time or matched case control series.

IV. Evidence is from well-designed, nonexperimental studies such as comparative and correlational descriptive and case studies.

V. Evidence from case reports and clinical examples.

1.4 PATTERNS OF MOBILITY IMPAIRMENTS

1.4.1 MS and the Risk of Falling

Persons with MS are particularly predisposed to various impairments including fatigue and falls due to brain and spinal cord involvement [13, 14]. In an observational survey study of 1089 persons with MS aged 45 to 90 years, Finlayson reported that 52.2% of participants had experienced a fall in the past six months. Factors associated with an increased risk of falling included being male, having a fear of falling, a deteriorating MS status, balance problems or mobility limitations, and poor concentration [13]. In addition, another survey study found that the absence of weight bearing activities, unsteady gait, and use of a cane contributed to the multifactorial nature of falls among persons with MS [14]. Common sequela of falls include fractures, abrasions, lacerations, compromised mobility, loss of confidence in performing tasks and fear of falling [13]. Therefore, assessment of different aspects of MS-related motor impairments and the accurate determination of factors contributing to falls are necessary for disease management and therapy, and for the development of fall prevention programs [14].

1.4.2 MS and Mobility through Ambulation

Understanding the experiences of mobility loss from the perspective of persons with MS may provide insight into the development of programs, services and advocacy efforts that support people with MS as they age [15, 16]. These development efforts must take into consideration several symptoms of MS that influence the ambulation of persons with MS: loss of balance, weakness, fatigue, cognitive impairment, fear of falling, spasticity, tremor and visual impairment [17, 18]. In addition, resistance to using appropriate MAT must also be addressed.

A 2000 literature review conducted by Noseworthy et al. found that even though MS causes a wide variety of neurological deficits, ambulatory impairment is the most common form of resulting disability [5]. Within 15 years of onset, 50% of persons with MS will require assistance with walking. Therefore, most persons with MS will require some type of mobility assistance within the course of their disease progression [5]. A survey study conducted in 2001 with 220 participants with MS found similar results to the Noseworthy et al. study, finding that the probability of walking 10 to 20 meters without assistance 15 years after diagnosis was 60.3%, while the probability of managing to walk a few steps without using a manual wheelchair as a back up was as high as 75% [19]. The researchers also found that the existence of motor symptoms and advanced age at disorder onset indicated more unfavorable outcomes, but these factors were associated with the progressive course of MS. Baum and Rothschild in 1983 conducted an observational study with 1145 persons with MS and found that approximately 51% of participants reported they needed help with personal mobility both indoors and outdoors [6]. Among study participants, 4% reported using crutches, 12% walkers and 40% used wheelchairs at 13 years after diagnosis [6]. A recent survey based study conducted with 906 persons with MS also concluded that factors such as being seen by an occupational therapist, and the type of MS were the strongest predictors of acquiring an assistive device (AT) [20].

1.5 CURRENT ASSISTIVE TECHNOLOGY AND SERVICE DELIVERY

1.5.1 Mobility-related Assistive Technology

When gait difficulties do not respond to therapeutic interventions, MAT devices may be useful tools to enhance mobility [17]. Most persons with MS have mobility restrictions that require MAT devices [9, 20, 21]. A study with 101 persons with MS indicated their expectancy of becoming MAT users were as follows: 22.5% reported that they expected to be wheelchair-dependent in the short-term (2 years); 38.7% expected to be wheelchair-dependent in the mid-term (10 years), and 54% expected to be wheelchair-dependent in the long-term (over 10 years) [22]. Provision of MAT for persons with MS has the potential to diminish activity limitations and participation restrictions, prevent or reduce fatigue by energy conservation, and ultimately improve Quality of Life (QoL). MAT includes any device used to maintain or improve mobility[15, 23, 24]. They are also designed to improve functioning, enable a person to successfully live at home and in the community, and enhance independence [25].

Therefore, a variety of assistive devices have been used by persons with MS including:

1) Ankle-foot orthoses (AFO) have been an effective solution on compensating weakness, restoring energy and helping to control unstable knee and ankle musculature. AFOs' are also used for drop foot, a condition in which the individual cannot clear his or her toes in the

swing-through phase of mobility, that affects normal gait [26]. Orthoses can be made from composite materials or plastics with two different mechanisms: rigid or articulated. Recently, carbon-fiber AFOs have become popular among persons with MS. They generally come in two styles: - an anterior shell with a medial or lateral upright component that creates knee stabilization preventing knee extension and reduces foot drop; the second style is a posterior shell that compensates for ankle dorsiflexor weakness while it returns energy by providing a spring effect during toes push off, consequently helping with toe clearance during the swing part of gait. Few negative factors associated with AFO’s are: limited ankle and knee mobility while kneeling, running, or stooping.

2) Functional Electrical Stimulation (FES) has been used for treatment of muscles deprived of nervous control that provides muscle contraction and functional movement [26]. For persons with MS, FES has been a useful tool used for foot drop, balance and walking training during rehabilitation treatment; advanced technology enabled a new system unit with wireless communication. However, the decision between using an AFO and/or different models of FES is ultimately a clinical decision that needs to be made by the potential user, physical therapist and physician together.

3) Hip flexion assist orthoses (HFAO) is another option for persons with MS who do not effectively ambulate despite the use of an AFO or FES. The HFAO is indicated for persons with a unilateral lower extremity weakness in the hip and knee flexors along with the ankle and dorsiflexors muscles [26].

4) Canes assist ambulation in maintaining an even distribution of weight on the hips that is characteristic of a normal gait. Canes are also beneficial when walking is only mildly unstable, reducing walking effort and risk of falls when compared to AFO and HFAO [26]. Several types of

canes are available, including single-legged canes and ‘quad’ canes, which have a broad base of support and can remain upright independently, so they do not become a tripping hazard.

5) Crutches are also used to aid with ambulation by helping with balance, widening the base of support, and decreasing weight bearing on a single lower extremity. Crutches provide more balance than canes while walking and are indicated for people who need bilateral support and have good upper extremity control [26].

6) Walkers and/or wheeled walkers (rollators) are indicated for persons with moderate deficits and also provide increased stability due to the walker’s larger footprint compared to a cane or crutches. In addition, they can be purchased with wheels, brakes and modified handgrips to aid in function and safe use [26]. Further, to assist with fatigue, some walkers are equipped with seats for short rest periods during ambulation.

7) Manual wheelchairs provide a more stable wheeled option, while still providing some level of physical activity [26]. In addition, manual wheelchairs can be used part-time or as a primary exclusive mobility option for persons who are experiencing difficulty in balance and frequent falls.

8) Power-assist pushrim-activated wheelchairs (PAPAW) are manual wheelchairs with a force/moment-sensing pushrim, which provide assistance with wheelchair propulsion while requiring less physical strain. For people with MS, PAPAWs may prove to be a good compromise between the fatigue caused by propelling a manual wheelchair and lack of exercise among power wheelchair users [26].

9) Scooters are a popular mode of powered mobility among persons with MS. Some users prefer a scooter to a manual wheelchair since upper extremity fatigue is not an issue. However, scooters are often less desirable than power wheelchairs due to their lack of stability during turns

and limited seating system options to accommodate users with specific seating needs as seen in progressive disorders such as MS [26, 27]; Scooter are available in two types: three and four wheeled. The four-wheeled scooters typically offer more device stability compared to the three-wheeled scooters, but as a result, they are difficult to maneuver, are heavier and thus more difficult to transport.

10) Power wheelchairs should be considered a mobility option not only for advanced stages, but should be recommended as a MAT option to address fatigue, a hallmark symptom of MS[14, 25, 28, 29]. In contrast to scooters, power wheelchairs permit power seating system upgrades that may be indicated as the client progresses and are configured in different types of driving base designs. Three main power wheelchair base options are available: rear-wheel, mid-wheel and front-wheel drives [25].

Among the various mobility device options, manual wheelchairs (60%) have been reported as the most common MAT used by persons with MS, followed by canes and crutches (44%), walkers (39%), and power wheelchairs (8%) [20]. In an observational study, Baum and Rothschild have also shown that a greater number of persons use wheelchairs (40%) when compared with walkers/canes (12%), leg braces (6%) and crutches (4%) [6]. In a recent retrospective study, manual wheelchairs (33%) were again the most prescribed devices, followed by power wheelchairs (13%), walkers (6%), braces (6%), and canes (2%) [30]. The use of wheelchairs has been positively correlated to the duration of the disease, age, and awareness of the diagnosis [6, 30].

Characteristics of ambulatory persons with MS who transitioned to a wheeled mobility device were compared to persons with spinal cord injury (SCI) and investigated by Ambrosio in a retrospective study [31]. Participants with MS were not able to ambulate at functional speeds and had sedentary activity levels. Further, quality of wheeled mobility devices recommended to persons with MS was inferior compared to those issued to persons with SCI. In another survey based study by Perks et al., 59% of wheelchair users stated that they did not feel their wheelchairs met their mobility needs and therefore they had difficulty navigating within different environments [32]. In addition, a 2002 literature review study by Fay and Boninger investigated the efficacy of manual wheelchair propulsion in full-time manual wheelchair users with MS [33]. Results showed that persons with MS were unable to maintain a functional speed of wheelchair propulsion when compared to a control group composed by persons with SCI and a group of persons with no disability. Kinetic analyses revealed that with propulsive stroke of the manual wheelchairs, persons with MS applied a force in the opposite direction of forward propulsion, essentially working against themselves every time they pushed their chairs, leading to increased energy expenditure during wheelchair propulsion. This higher energy expenditure is a significant problem for this population, for whom fatigue is a major limiting factor [33]. Thus, powered mobility, such as a scooter or power wheelchair, would be more appropriate than prescribing a manual wheelchair, depending on many factors such as client diagnosis, co-morbid conditions, living environment and use of transportation. Users of MAT devices frequently view mobility devices as a symbol of loss of function or greater disability. Despite this fact, transition from manual to power wheelchair has been reported to provide an occupational performance enhancement, with increased feeling of competence, adaptability and self-esteem [34].

Given the scarce of research on AT for persons with MS and its importance on their activities of daily living (ADL), healthcare professionals and researchers had to refer to work done on other populations with disabilities such as SCI or cerebral palsy (CP) [33]. Persons who are not able to walk and relied primarily on a combination of manual and power wheelchairs are more likely to be active in the community, compared to those with these disabilities but who are able to walk and therefore, use an ambulation aid and manual wheelchair combined [35]. Power wheelchairs allowed persons with MS to minimize the effort needed to ambulate or propel a manual wheelchair, resulting in energy conservation for use with other activities [35, 36]. Having an appropriate mobility device can significantly influence how a person with a disability perceives life [34].

Power wheelchairs with different seating systems such as tilt-in-space and recline have been assisting persons with MS to rest comfortably in their chairs during the day without needing to return to bed or transfer to a static chair [36]. In a descriptive study, Dewey et al. concluded that people with severe MS symptoms preferred to be out of bed as much as possible, and, thus, prescribing tilt-in-space options should be highly considered when looking for power wheelchairs despite their cost [36]. A prospective study conducted by Dan et al. examined the use of tilt-in-space and recline among able-bodied persons and their results showed that most favorable angles with maximum pressure reduction were with 45^{o} of tilt and 120^{o} of recline [37]. In addition, the authors also reported that a combination of tilt and backrest recline have shown to achieve greater pressure reduction than a seat with tilt alone. Therefore, power seat functions provide a positive impact on users' QoL as they allow users to remain in their chairs longer, decrease the risk of pressure sores, conserve energy, access a variety of environments and participate in more activities during the day [38]. In addition, tilt-in-space decreases the user risk of pressure sores especially in advanced cases of MS where the person has decreased pressure relief ability [35, 36]. The use of power seat functions proves to be essential in helping power wheelchair users to be more comfortable with less need for transfers throughout the day especially among persons with progressive diagnoses [29].

Caution should be taken in prescribing MAT devices especially for persons with MS; if the prescription does not meet the user's needs, the MAT prescribed might not be used, and instead abandoned. A retrospective study conducted by Verza, Carvalho, Battaglia and Uccelli (2006) found that AT devices were abandoned due to worsening in physical status (36.4%) followed by non-acceptance of the device by the user (30.3%), inappropriateness (24.2%) and insufficient/lack of information and training (9%)[30]. A reason for this device abandonment could be due to a change in medical condition; in addition, functional ability is a strong factor influencing abandonment of AT [25]. Unlike other diagnoses, MAT for people with MS may not be long-term solutions because of the progressive nature of the disorder. MAT abandonment is costly both in financial terms and outcomes achievement, regardless of whether the abandoned equipment is of high or low technology [25]. Device abandonment could be reduced if consumers were actively involved from the start of the MAT service delivery process. A better understanding of how and why persons decide to accept or reject different types of MAT is critical to improving persons' quality of life [25].

1.5.2 MAT use and service delivery

In advanced stages of MS, several interventions can provide assistance with independence to the individual such as: 1) provision, education, and instruction in use of assistive devices (walking aids, power/manual wheelchairs and car adaptations); 2) education and instruction about compensatory strategies to accomplish an activity (safe transfers); 3) environmental modifications - ramps, lifts, widening doors, level access showers, bath aids and environmental control systems [9, 20].

MAT must serve as an interface between the person with disability and the activity the person chooses to perform, and promote reintegration into community life [39]. To provide a comprehensive conceptual model representing factors to be considered when designing an AT device or when developing a service delivery program which meets not only user needs but also is in accordance to policy regulations, services models are used as guidelines [39]. Therefore, researchers have been working to develop a comprehensive model of service delivery that includes those factors and improve not only service delivery but also policy regulations.

A new service delivery model was recently developed by researchers from the University of Pittsburgh called the PHAATE model. This model incorporates policy, human, activity, assistance, technology and environment on service delivery of AT [39]. The PHAATE model was developed as an attempt to create a comprehensive model representing factors to be considered when designing AT devices or when actually developing a service delivery program. When prescribing AT, each individual's medical benefit should be prioritized and reimbursement policy should be considered to avoid denial of reimbursement due to lack of well documented letters of medical necessity. However, the policy should not influence or dictate the final clinical recommendation for the most appropriate MAT device. The environment and context should be considered during the service delivery process as people perform activities in a variety of environments [39]. One problem of AT provision lies in the paucity of AT outcome studies, partially due to the inadequate funding support for research studies or lack of understanding the need for specialized clinical expertise, especially among insurers and non-rehabilitation medical professionals [39].

Studies investigating service delivery models in countries such as Ireland and Canada showed that the development of an AT service delivery with a client-focused social and participatory service delivery model in AT can achieve the best results for people with disabilities and their caregivers [40]. Another observational study was conducted in 2005 by Ripat & Booth to identify key characteristics of an AT service delivery model preferred by the various Canadian stakeholders [41]. When prescribing AT, clinicians should focus on persons' medical necessity and their specific needs during the decision making process as well as when choosing appropriate AT devices. Based on these study results, recommendations for service delivery were proposed for future use in other AT clinics. These study results may help in the development of funding guidelines, supporting the importance of AT in enabling meaningful activities, and examining current delivery of services in different contexts. Participation of the end-user needs to be considered throughout the entire AT process. The evaluation process should address the user's skill, goals, abilities, supports, resources and context [40, 41].

Assistive Technology is, therefore, best delivered using a team approach, including assistive technology professionals (ATP), and rehabilitation engineering technologist (RET) working in cooperation with a qualified physician, with all focused on the needs of the end-users. For this reason, the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) provide the ATP and RET credentials to identify knowledgeable clinicians, suppliers and engineers [42]. With these efforts and research studies on how to improve AT service delivery, it may decrease AT abandonment and consequently increase users' satisfaction, community participation and lastly quality of life.

1.6 NEW AND EMERGING MOBILITY ASSISTIVE TECHNOLOGIES

In a prospective research study, Sawatsky et al. (2007) investigated the use of another powered mobility device, the Segway Personal Transporter device for persons with limited ambulatory ability, such as people with MS and those with lower extremity amputations [43]. Segway devices are described as "the first self-balancing, electric-powered transportation devices." The rider stands on a small platform supported 20cm off the ground by two parallel wheels, and holds onto the handlebars. A twist grip on the left bar is used to steer the device. When the rider moves forward, the Segway moves forward; when the rider leans back it moves back or stops. The Segway is marketed as a revolutionary device that requires no special skills and that "virtually anyone can use." In this particular study, the authors found that the Segway was a useful device for a wide range of disabilities (e.g. MS, spinal cord injury, amputation) and it may also increase personal mobility for some people with functional limitations. Therefore, it would enable people with functional limitations to become more involved in meaningful activities, and hence increasing one's quality of life [43].

For persons with difficulty in operating a mobility device due to decreased physical strength or due to environmental accessibility barriers, a new concept has been developed to accommodate those issues, the Independence IBOT 3000 mobility system [44]. The IBOT was recently developed with the purpose of overcoming many of the limitations of current mobility devices available [44]. The IBOT design has a computer system design to provide a dynamic balance reaction in the fore-aft direction, and has five different operating functions: 1) standard function (similar to a traditional power wheelchair); 2) four-wheel function: four- wheel drive for outdoor mobility including curb climbing; 3) balance function: 2 wheel drive, dynamically balanced in two wheels for mobility at the elevated height of a standing person; 4) stair climbing function: rotation of the wheel clusters to allow "stepping-up" 1 star at the time; 5) remote function: nonoccupied mobility device [44] . Even though the IBOT offers a good mobility option for persons with ambulatory impairment, it is an expensive device with unavailable funding by Medicare, and hence it is no longer available on the market.

Another option of power wheelchairs design to be used indoor and outdoors as well as climbing stairs is called TopChair [45]. This power wheelchair is composed by combined wheels and a caterpillar track. The TopChair was tested in France among 25 persons with Spinal Cord Injury and results showed that all participants were able to operate the power wheelchair indoor and outdoors successfully. Due to its electromechanic property and caterpillar tracks the TopChair is a little bulkier and heavier than other power wheelchairs with similar functions. However, no studies have evaluated the benefits of the TopChair among persons with MS.

Even though new technologies have been developed recently to enhance mobility and community participation, many factors must be considered when trying to match a person with an assistive device [30]. Using an assistive device for mobility could vary in two ways: person uses it full- or part-time, depending on their level of disability and functional characteristics [30]. Evaluating and understanding the pros and cons of each device either with a new design and features or a device already on the market is vital when prescribing MAT. The success of using each MAT will be based on the interaction of the knowledge of the disorder stage by rehabilitation professional and a person with MS willingness to accept and use what was suggested.

1.7 PSYCHOSOCIAL FACTORS AND MAT USE

1.7.1 Psychological Aspects of MS

Emotional distress is higher among persons with MS compared with other chronic illnesses, and is three times more common in persons with MS than in the general population [10]. Contributing factors to high emotional distress rates in persons with MS include the uncertainty and unpredictability of symptoms and disability over the course of time. Results from a secondary analyses of a survey based study by Gulick suggested that the presence of emotional and financial support together with coping strategies explain how persons with MS can enhance their performance in everyday activities including personal care, mobility, recreation, socializing and intimacy, despite the presence of emotional distress arising from this disabling chronic disorder [10]. Support groups are options for persons with MS who are either recently diagnosed or having problems dealing with or adjusting to their diagnosis of MS. These groups are designed to take people from the initial emotional response of acknowledging their diagnoses, into a different view of how to cope and practically manage their symptoms [46]. Participation of care partners become particularly important at these times, mainly due to the fact that they will then learn from other families how to best support their loved ones with MS [52]. The psychological aspects of MS have not only been reported among adults, but also among children. Interestingly, psychosocial difficulties seen among children and adolescents with MS have the same manifestations as adults [47]. These manifestations affect the persons' self-image, role functioning, mood, and cognition not only in school but also at work, in their interpersonal relationships and during treatment compliance. Among older adults, the fear of the future is the major concern which enhances the fear of experiencing future losses of mobility and independence, becoming a burden on caregivers leading to moving into a nursing home [48].

Another important factor on persons with MS psychological aspects is the use of an AT device, especially for mobility, which has a great influence on the activities of daily living and independence of persons with MS. The inability or difficulty to go out in the community increases the frustration level and increases dependence on others, consequently, increasing the probability of depression. Another survey based study by Bunning, Angelo, and Schmeler (2001) was conducted to investigate the impact of transition from manual to powered wheelchairs as well as its influence on persons' occupational performance and psychosocial coping in regards to this transition [34]. The authors found that changing from a manual to a power wheelchair increased not only participants' occupational performance in daily life before and after using a power wheelchair, but also their satisfaction using a power wheelchair increased their competence, adaptability and self-esteem [34]. Even though the study population was small (n=8) these results suggest that the use of power wheelchairs may positively influence not only people with chronic disabilities (e.g. Spinal cord injury, traumatic brain injury), but also persons with progressive conditions such as MS and muscular dystrophy. Despite how persons with MS think of their disability while using MAT devices such as power wheelchairs, these devices can contribute to their resilience during mobility related activities of daily living by restoring the ability to perform actions, tasks and projects by which occupational and role performances are supported [34].

Apart from the decision to find the best option when a rehabilitation professional prescribes an AT device, it is equally important to emphasize the influence of a good interaction between the person with MS and their family [25, 49]. Furthermore, having a family member with

MS may affect the overall family dynamics whether the person is a child or an adult [47]. Poor communication between the person with MS and his/her family may jeopardize the decision to acquire an appropriate AT device. In cases in which only family members are available to make a decision on an AT device, their decision could have detrimental effects on the psychosocial well-being of their family member with MS if they feel that they don't have control or input into what kind of equipment they obtain [49]. The person with MS and family should discuss and agree on the risks and benefits of the AT to be used to maintain a supportive environment with good adaptation to the new device [50]. An open relationship between the person with MS, their family members, and the rehabilitation professional involved in prescribing an AT device will result in better outcomes [34, 49].

Pain is an important factor influencing psychosocial functioning. In a study conducted among veterans with MS, increased fatigue, poor general health and greater depression symptom severity were significantly associated with higher levels of pain. Therefore, pain should be treated aggressively to minimize functional impairment [50]. Also, preventing pain from extended seating in wheeled mobility devices should be addressed.

1.8 MOBILITY IMPAIRMENT AND QUALITY OF LIFE

A survey based study conducted with 412 persons with MS showed that over 50% of persons with longstanding MS require assistance both in and out of their home [14]. In addition, factors' increasing the percentage of people who needed assistance included longer MS duration, being diagnosed at an older age, and individual's acknowledgment of their diagnosis [6, 9]. Reduced mobility has been associated with built environmental barriers, difficulty in completing daily activities, restrictions with participation in life tasks [15, 16], and perceived reduced quality of life and community participation (QoL) [23, 51]. In 2002 a literature review study conducted by Fay and Boninger found that quality of life was closely correlated with mobility [33]. Recently a retrospective study conducted in 2007 among 196 persons with MS showed that persons with decreased physical activity also had a reduced quality of life. The same study concluded that barriers in the built environment have also influenced physical activity level as well as influence persons' with MS community participation [52]. An accessible environment not only promotes high levels of physical activity for ambulatory and wheelchair users, but this accessibility also results in increased community participation particularly among persons with MS.

Significantly decreased mobility and self-reported QoL in the MS population has been highlighted as an important need for intervention [6, 24, 52]. Over time, persons with MS experience reductions in health status and physical function [53]. In addition, persons with chronic progressive MS experience more activity limitations than relapsing-remitting and benign types of MS. Fatigue, weakness, balance impairments, spasticity, tremors, speech and swallowing problems are the most troublesome MS symptoms that impact activity performance of persons with MS [53, 54]. Hence, the resulting impaired ambulation is an important contributor to disability and decreased quality of life in persons with MS [23, 55].

1.9 CONCLUSION

Besides the physical, psychological and economic impact of MS on patients and family members, this disorder causes a wide variety of neurological deficits of which ambulatory impairment is the first symptom and the most common form of disability [4]. Common symptoms of MS include fatigue, weakness, spasticity, ataxia, in addition to somatosensory symptoms such as visual impairment, and other impairments of cranial nerves and brain stem structures [19].

The type, severity and frequency of symptoms are a determinant of the MS progression and potential need for MAT devices. The unpredictable nature of MS is a constant challenge not only for persons with MS, but also their family and friends. The possibility of losing the ability to walk increases the stress and psychological aspects of being diagnosed with MS. Therefore, relying on an assistive device for mobility becomes very important to all persons with MS.

One of the biggest challenges for rehabilitation professionals and persons with MS is to find a mobility device that will meet the user's needs in addition to maintaining or increasing community participation [51]. Being able to remain active in the community and also keep their jobs is one of the biggest challenges among persons with MS. Independence is just one of the important factors that must be taken into consideration when prescribing a mobility assistive device (MAT). Other factors that require consideration are degree of fatigue, activities that the person with MS wants to do, the context in which the device will be used, how the device will be funded, and acceptance of the device by the user. There are many options of MAT available on the market. The options vary from AFOs, canes and walker to power wheelchairs with many different functions. It is important to note that pursuing MAT devices is a process that involves the person with MS, their rehabilitation professional team, and family members. To be a successful process, the MAT device must improve the overall quality of life of the person with MS.

Throughout our literature review we observed that limited numbers of articles with higher levels of evidence were found regarding the use of MAT benefits specifically for persons with MS. There is a paucity in studies with higher levels of evidence (LOE) based practice and most of the articles found were from levels IV and V (n= 32 and 15, respectively, followed by 2 with LOE III and 1 with LOE II). Evidence based practice is the strongest method of measurable clinical performance; therefore, having a strong research study design is the best way to justify prescription and reimbursement decisions. Future quantitative studies should be conducted with the purpose of providing a better understanding of the benefits of an appropriate MAT for persons with MS. In additions, assessing the quality of life (QoL) of potential users prior and after MAT acquisition might also be another way to understand and enhance the benefits of MAT devices on persons with MS.

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Table 1. Summary of articles reviewed

Reference	Purpose	Population	Intervention	Relevant Findings	Study Design & Level of Evidence
Ambrosio, Bonninger, Fitzgerald, Liu, Mapa & Collins, (2003)	To examine the relationship between type of mobility device used and social participation in persons with multiple sclerosis	19 individuals with MS between age 18-65 years	Questionnaire	- Results showed that individuals who are non ambulatory and have a manual and power wheelchair available to them have the highest activity level. - The ultimate prescription of an AT should be to re-engage the user in activities they value.	Observational Study LOE= IV
Ambrosio, Boninger, Fitzgerald, et al., 2007	To investigate the demographic differences between veterans with MS and veterans with SCI who were issued a wheelchair by the Veterans Health Administration and describe differences in mobility device prescription	2 Veterans Health Administration databases	Not Applicable	-Veterans with MS were significantly less likely to receive higher quality wheelchairs (manual or power) compared to veterans with SCI.	Observational Study LOE = IV
Aronson, 1997	To describe satisfaction with QOL and determining relationships between QOL as a whole and several other factors, such as demographic characteristics	697 individuals with MS	Questionnaire	-Health received the lowest satisfaction rating -Poorer QOL was associated with unemployment, MS symptoms of moderate or worse, fatigue, mobility limitations on stairs, a disease course other than stable, and social	Observational Study LOE = IV

	and measures of physical disability			activities	
Baum & Rothschild, 1983	To examine mobility restriction among individuals with MS and its relationship to selected disease and demographic characteristics	Individuals in the National Multiple Sclerosis Survey database	Not Applicable	-Over half of the individuals reported needing assistance indoors and outdoors -Longer duration, older at the time of first diagnosis, admitted awareness of the diagnosis, currently unmarried, nonwhite, and a "probable" MS diagnostic code were significant factors increasing the percentage needing assistance -Most individuals relied on a wheelchair or person's assistance -Few individuals relied on crutches or leg braces	Observational Study LOE = IV
Blake & Bodine, 2002	To: 1) review the impairments and associated activity limitations and participation restrictions of persons with MS; 2) provide an overview of high- and low-tech AT appropriate for persons with MS; 3) discuss funding opportunities for AT; 4) review current studies of AT used for person with MS and discuss future research directions, and 5) consider AT as an intervention for disability prevention	Not applicable for a systematic review	Not applicable	- Constellations of impairments are seen during a lifetime with MS - A paucity of research exists in MS AT use - MS Soc. Of Canada survey: (427 respondents) indicate 61% had a manual wheelchair, 44% used other mobility aids, 39% used walkers, 15% used scooters, 8% electric wheelchairs, and 7% orthotics. - Proper seating and positioning is needed. - Need to incorporate the "service" component of the AT process - Limited info available about AT cost benefit analysis, outcome measures, & adequate and standardized assessment processes - Funding for AT is biggest obstacles for those with MS, due to progressive nature of the disease - Identified need for AT outcomes research	Systematic Review; LOE = V
Boss and Finlayson, 2006	To develop an understanding of family members' reactions to the acquisition of power mobility by persons with multiple sclerosis (MS) from the perspectives of the end users and their family members	Participants with MS who use power mobility devices.	Semi structured interviews	- It is important to family members and patients to understand and agree on the acquisition of a power mobility device. The success in this process will determine the positive use of the device chosen.	Descriptive study LOE= IV
Buning, Angelo, & Schmeler, 2001	To describe the transition from manual to powered mobility and its influence on occupational performance and feelings of competence,	Convenient sample of 8 individuals with both static and progressive conditions	Occupational Performance History Interview and Psychosocial Impact of Assistive Device Scale was used to measure participants' perceptions of the impact of the PMD on	-A significant improvement in occupational performance was shown after the introduction of the powered mobility device. -The Psychosocial Impact	Repeated Measures Intervention study LOE= V

	adaptability, and self-esteem		their competence, adaptability, and self-esteem	of Assistive Device Scale showed a positive impact of 2 or greater for 75% of the participants on 19 of 26 items.	
Cattaneo, De Nuzzo, Fascia, Macalli, Pisoni & Cardini, 2002	To quantify fall risk among patients with multiple sclerosis (MS) and to report the importance of variables associate with falls.	Fifty people with MS divided in two groups according to their reports of falls.	Not applicable	- variables pertaining to balance skills, gait impairment, and use of a cane differed between fallers and non-fallers group and the incidence of those variables can be used as predictive model to quantify falls risk in patients suffering with MS. - These findings emphasize the multifactorial nature of falls in this patient population.	Retrospective case-control study with a 2-group sample of convenience LOE=V
Craddock and McCormack, 2002	Outlines the development of an AT service delivery model and suggests a client center approach.	NA	NA	- The success of a service delivery program is based on a client centered focus.	Systematic review LOE=V
Dan, Cooper R.A., Cooper R. & Kelleher, 2007	To examine how individuals use their power wheelchair seating functions such as tilt, backrest recline, and seat elevation, during typical daily activities using a seat feature datalogger (SFDL)	11 power wheelchair users with tilt, recline and or seat elevator. 6 males and 5 females were recruited.	- first visit to collect demographic information of subject and their wheelchairs and pressure mapping in different positions; - 10-14 data collection - mid visit to check sensor placement, download data and replace battery - final visit to return SFDL and complete a brief questionnaire	Results showed that subjects did not use large angles of tilt and recline as many as clinicians recommend, they used those features frequently and as result they had lower peak pressures.	LOE =III
Devitt, Chau & Jutai (2003)	Purpose was to investigate the impact of wheelchair use on the QoL of persons with MS	16 wheelchair users with MS	Not applicable	Participants (n=13) rated the wheelchair as being extremely important to their life with a high level of satisfaction. Participants who were independent with propulsion have an average satisfaction higher when compared to those who required someone to push the wheelchair form them. Tilt and power mobility impact positively on QoL. These options allow participants to stay longer in their chairs, conserve energy, access a variety of environments and participate in more occupations during the day.	Descriptive study LOE= IV
Dewey, Rice-Oxley & Dean, 2004	The purpose was to compare the experiences of tilt-in-space wheelchair use and conventional wheelchair use in individuals with multiple sclerosis	7 individuals with MS using a tilt-in-space wheelchair and 16 conventional wheelchair users with MS.	Not applicable	Fatigue was a symptom reported. 5 out 7 participants that use tilt-in-space wheelchair said that they could rest comfortable in the chair during the day without having to return to bed or to transfer to a static chair. Half of the conventional WC group described their chair as uncomfortable. Four out of 7 tilt in space group reported difficulty with the	Descriptive/Qualitative study LOE= IV

				size of their chair and its maneuverability in the home compared with 4 out 16 of the conventional group.	
Doerksen, Motl & McAuley, 2007	To examine the association between features in built environment with self report and objectively measured physical activity behavior.	196 participants returned questionnaires	Questionnaire	- Result s showed that aspects of a built in environment influence health status and behavior among people with MS.	Observational study LOE=IV
Fay & Boninger, 2002	To review the literature on mobility devices in MS and examine how it can be used to degenerative disorders such as MS	Not Applicable	Not Applicable	-Within 15 years of onset, 50% of individuals with MS will require assistance with walking. -Clinicians should be mindful of the past clinical history of clients with MS. -Canes may provide a simple, but effective solution for people with MS with ataxia and weakness.	Observational Study LOE = IV
Finlayson, Impey, Nicolle & Edwards, 1998	To gather information on demographics, heal, social and financial of persons with MS nationwide in Canada	Around 400 people with MS responded	Survey based study	- Performance limitation was found to be variable according to each person occupation but not in regards to fatigue level;	Observational study LOE=IV
Finlayson, Guglielmello, & Liefer, 2001	To describe the types of assistive devices in the possession of persons with MS and identify factors that best predicted the probability of possessing these devices	906 individuals with MS from an anonymous mail survey of members of the Multiple Sclerosis Society of Canada (Atlantic Division)	Secondary analysis using frequency distributions and logistic regression of existing cross-sectional data	-Mobility aids and grab bars were the most commonly reported assistive devices -Seeing an occupational therapist, now working, having a progressive type of MS, having more activity limitations and more symptoms, and having MS for a longer period were found to increase the probability of possessing assistive devices.	Secondary Analysis LOE = V
Finlayson & van Denend, 2003	To develop an understanding of the experience and meaning of mobility among older adults with MS.	Twenty seven participant with MS (mean age= 62 years)	Questionnaire based	- overall participants showed concern about their mobility loss, becoming a burden to their caregivers and the fear of possible move to nursing homes in the future.	Retrospective design with secondary analysis LOE= IV
Finlayson, 2004	To describe the health-related concerns and service need of adults with MS.	27 individuals with MS aged 55-81 years	Questionnaire based.	- Fear of the future was found to be a predominant concern among the participants. Within this fear participants expressed particular concerns about experiencing further losses of mobility and independence, becoming a burden on caregivers, and having to move to a nursing home.	Phenomenological approach LOE= IV
Finlayson, Peterson, & Cho, 2006	To identify factors associated with increased likelihood of reporting fear of falling among people with MS	1064 individuals with MS, aged 45-90 living in the Midwestern US	Phone interview	-63.5% of participants reported fear of falling -Increased likelihood of reporting fear of falling was associated with being female, experiencing greater MS symptom interference during everyday activities,	Observational study LOE = IV

				history of a fall in the past 6 months, and using a walking aid	
Freeman, 2001	To determine the factors that may contribute to restrictions in mobility and everyday functional activities in individuals with MS	Not Applicable	Not Applicable	-In MS, problems with balance, mobility and function may constantly evolve throughout the course of the disease. -When symptoms may be mild maintenance of mobility and function may be achieved by straightforward interventions. -When the problems are complex, a more comprehensive and intensive multi-disciplinary approach is necessary.	Observational study LOE = IV
Gulick, Yam, et al., 1989	To determine what conditions made performing work or tasks difficult and easier in individuals with MS	508 people with MS	Questionnaire	- Conditions reported to impede the performance of work and tasks were: physical restrictions, person-environment interaction, and MS-related symptoms. -Conditions reported to enhance the performance of work and tasks were: assistive devices, human support, personal attributes, health promotion behaviors, and person-environment adjustment	Observational Study LOE: IV
Gulick, 2001	To determine if personal attributes and social support function as mediating and/or moderating variables between emotional distress and ADL functioning in individuals with MS	686 individuals with MS	Not Applicable	-Personal attributes and social support functioned as mediator variables between emotional distress and ADL functioning	Observational Study LOE = IV
Harris Interactive, 2008	To examine symptoms experienced, difficulty walking, quality of life, mobility devices, finances, exercise, and partner experiences in individuals with MS	Survey 1: 1,011 U.S. adults with multiple sclerosis Survey 2: 317 U.S. adults who are currently involved with caring for a family member /friend with MS	Questionnaire	-2/5 people with MS reported difficulty walking -When first diagnosed, more people with MS were concerned about their quality of life than pain or potential costs -Most people with MS view mobility devices as a way to maintain independence -Difficulty walking resulted in an increase in daily expenses for people with MS -Exercise plays a positive role in people with MS -Most MS care partners are optimistic about their role	Observational Study LOE = IV
Janssens, Boer, van Door et al., 2003	Quantify expectations among wheelchair dependent patients recently	101 participants with MS and 78 partners.	Survey based study	- Most participants did not know what to expect in 10 years or in a lifetime after their diagnosis. - Participants with higher functional limitation had	Observational study LOE=IV

	diagnosed with MS and their partners.			higher perception of risk, but lower perception of seriousness.	
Klewer, Pohlau, et al., 2001	To analyze problems in elderly individuals with MS	53 individuals with MS from the Berlin Section of the German Multiple Sclerosis Association	Standardized Questionnaire, which considered social situation, daily problems, disease course, and disabilities, and by using the EDSS	-Elderly individuals reported impaired mobility and inability to use public transportation -About 96% presented EDSS scores above 6.0 -Nearly 50% complained about spasticity and pain due to spasticity -More than 70% suffered from bladder dysfunction	Observational Study: LOE = IV
Kraskowsky & Finlayson, 2001	To identify the major findings of published research on the factors influencing older adults' use of adaptive equipment	14 studies involving an older adult sample were selected from major electronic bibliographic databases	Not Applicable	-Between 47% and 82% of prescribed equipment continues to be used by older adults, with use decreasing over time -Equipment suitability, adequate training, and pre-prescription home visits contribute to rates of use of adaptive equipment. -Lack of fit among the person, his or her environment, and the equipment was the primary reason identified for nonuse of adaptive equipment.	Observational Study: LOE = IV
Reference	**Purpose**	**Population**	**Intervention**	**Relevant Findings**	**Study Design & Level of Evidence**
Lacoste, Weiss-Lambrou, Allard, Dansereau, 2003	To characterize the use of powered tilt and recline systems,	40 subjects, 32 men and 8 women power wheelchair users with multiple diagnosis: neuromuscular disease, SCI, and others were recruited from two rehabilitation centers in Montreal	Subjects were interviewed from a list of 25 objectives, reasons for what they used their repositioning system and to rank these reasons in order of importance.	Results showed that 97.5% of the subjects were using their powered tilt and recline system everyday, and their satisfaction was high. They also reported that their main objective was to increase comfort and to promote rest.	LOE = IV
Laffont, Guillon, Fermanina et al., 2008	Compare the performance of a power wheelchair with stair-climbing capacity and a conventional power wheelchair (Storm 3)	Twenty five participants with various diagnosis who used power wheelchair as their primary means of mobility.	Participants performed indoors and outdoors driving trials with both devices. In addition they performed curb-clearing and stair climbing with the TopChair	- Satisfaction with Storm 3 chairs was higher compared to TopChair; Going over curbs was easier with the TopChair, as expected. - Most participants found the TopChair easy to use, and only few of them felt insecure while driving the TopChair.	Open label study Experimental design LOE= II
Lankhorst, Jelles, Smits, et al., 1996	To determine characteristics of individuals with MS	73 Dutch and Flemish individuals with MS, 25 individuals with rheumatoid arthritis, 25 individuals with a spinal cord lesion	Individuals with MS were assessed by means of the Disability and Impact Profile (DIP). Results were compared with available data from the individuals with rheumatoid arthritis and with the individuals with a spinal cord lesion	****	Comparative Analysis LOE = IV
MacAllister, Boyd, Holland et al., 2007	To evaluate the impact of psychological distress and cognitive dysfunction among children with MS	Not applicable	Not applicable	- The impact of having a family member with MS affect everyone in a family; - Assessment and intervention of children with MS should be done in an interdisciplinary nature including the	Systematic review LOE= IV

				children school teachers.	
Mansson and Lexell, 2004	To assess the performance of ADL among individuals with moderate to sever MS	Not applicable	Survey were used to gather qualitative information	- Personal and instrumental ADLs were impacted by people with moderate to severe MS; however they were independent for personal ADLs but needed assistance to perform instrumental ADLs.	Descriptive study LOE= IV
Miller & Coyle, 2004	The purpose was to describe clinical symptoms and signs of MS	Not applicable	Not applicable	-The diagnosis of MS, while often straight forward, may be difficult in the absence of unequivocal and recurrent clinical signs. This chapter will review in detail the recently recommended McDonald criteria for the diagnosis of MS, which delineate the specific use of magnetic resonance imaging findings. Variants of MS, or closely related conditions, including Balos concentric sclerosis, Marburg variant, Devic's neuromyelitis optic, and acute disseminated encephalomyelitis will also be discussed.	Descriptive study LOE=IV
Myhr, Riise, Vedeler, Nortvedt, Gronning, Midgard & Nyland, 2001.	To evaluate disability and prognosis in an untreated population based incidence cohort	220 patients with MS	Patients were interviewed and examined during 1995 using EDSS questionnaire	- A relapse remitting (RR) course and long inter-episode intervals in the early phase course of disease were associated with a better outcome.	Analysis of disease progression through life table analysis with different endpoints and multivariate Cox regression analysis was performed for evaluation of prognostic factors
	of multiple sclerosis patients			Other onset characteristics indicating a favorable outcome were associated with RR course while characteristics indicating an unfavorable outcome were associated with the progressive progression (PP)	LOE= V
National Multiple Sclerosis Society, 2008	To answer frequently asked questions about Multiple Sclerosis.	Not applicable for a systematic review	None	-Multiple sclerosis is a chronic, unpredictable disease of the central nervous system. -Anyone can develop MS. -Approximately 400,000 people have MS. -Symptoms of MS vary from person to person. -MS symptoms occur when an immune-system attack affects myelin.	Non-Systematic Review; LOE = V
Noseworthy, Lucchinetti, Rodriguez, & Weinshenker, 2000	To research the causes and treatments of MS so more knowledge and improved care for MS patients can be obtained.	Not applicable	None	-MS is an autoimmune disease directed against CNS myelin or oligodendrocytes -Genetic and environmental factors are important in the development of MS -Treatment is directed at acute attacks and reduction of attack frequency	Observational Study LOE = IV
Osborne, Turner, Williams et al., 2006	To describe pain interference and explore its associations with several indexes	451 veterans with MS who had received service by the VA health	Participants filled out several questionnaires related to pain	- Participants reported moderate level of pain. - Poor general health and pain were significantly correlated, influencing	Cohort retrospective design LOE=IV

	of health and psychological functioning among people with MS.	administration between 1995 and 2000		their daily function.	
Perks, Mackintosh, Stewart, & Bardsley, 1994	To identify and describe the marginal user population and their propulsion difficulties.	A survey of wheelchair users in Tayside, Scotland	Home interviews about wheelchair-propelling experiences	-Marginal users represent approximately 15% of the occupant-propelled wheelchair propulsions -The model diagnosis was MS -59% of the marginal users felt that their wheelchairs were not adequate for their requirement	Measures Intervention Study LOE = V
Peterson, Cho, & Finlayson, 2007	To identify factors associated with increased likelihood of reporting fear of falling among people with multiple sclerosis and factors associated with activity curtailment among the subset of individuals reporting fear of falling	1064 individuals with MS, aged 45-90 living in the Midwestern US	Phone interviews	-63.5% reported a fear of falling -Increased likelihood of reporting fear of falling was associated with being female, experiencing greater MS symptom interference during everyday activities, history of a fall in the past 6 months, and use of a walking aid -82.6% of individuals reporting a fear of falling reported curtailing activity -Increased likelihood of activity curtailment was associated with using a walking aid, needing moderate or maximum assistance with instrumental activities of daily living, and having less than excellent self-reported mental health	Observational Study LOE = IV
Pittock, Mayr, McClelland, et al., 2004	To study the change in disability over 10 years in individuals with MS	161 individuals with MS in the 1991 Olmsted County, MN, multiple sclerosis prevalence cohort	Assessment at baseline and at year ten **Outcome Measures:** Expanded Disability Status Scale (EDSS); quantitative clinical measures; and self-reported by subjects	-Survival was reduced -30% of patients progressed to needing a cane or wheelchair over the 10-year follow-up period -Individuals within the EDSS of 3.0 through 5.0 range are at moderate risk of developing important gait limitations over the 10-year period	Repeated Measures Intervention study LOE = V
Ramsaransing & De Keyser, 2006	To review the literature on the benign course in MS to increase the understanding of the different aspects of the benign course in MS.	Previous studies' subjects with MS	Observation of previous publications that addressed different courses of MS and other relevant articles	The benign course in MS may involve: -different steps in pathophysiology -similar inflammatory response -a better regulating/inhibiting mechanism to counteract damage by inflammation -a superior repair mechanism for the neural damage done	Observational study LOE=IV
Ripat and Booth, 2005	To identify the key characteristics of an assistive device service delivery model preferred by various stakeholders in Canada	18 participants were interviewed in three focus group.	NA	- Facts emerged in the three focus group were: user of AT are unique, decision making process exists and is important, providing an AT is a complex process. - Future funding guidelines should be developed to improve	Descriptive Study LOE=IV

				service delivery in general.	
Sawatzky, Denison, Langrish, et al., 2007	To: 1) determine the functional measures that best correlate with the skill levels of people with disabilities who operate a Segway Personal Transporter, and 2) explore subject's personal experiences with the Segway through qualitative analysis	23 subjects aged 19-65 years with a variety of disabilities including MS, who could ambulate at least 6 m with or without assistance	Provision of a Segway **Outcome Measures**: Segway Task Assessment, Berg Balance Scale, and Timed Up & Go Test	- No correlation found between participants' functional scores & performances on the Segway; the Segway appropriate mobility device for a broader range of disability groups and functional levels than first realized **Benefits**: 100% felt device a highly useful mobility aid; could promote independence in self-care, productivity, & leisure; might enable them to be more involved in meaningful occupations; Disability was less visible when on device; At eye level with device **Barriers**: Cost & lack of funding by insurers; Difficult to get on/off or carry items; Weight and size of device; Access to public places and sidewalks a possible barrier. Performance: Segway features make it more desirable than current mobility options. More maneuverable, faster.	Prospective cohort study with 3 training sessions with the Segway LOE = IV
Scherer M., 1996	Results from many research efforts on the use of assistive devices are reviewed and summarized.	N/A	None	- To ensure that AT enhance user's quality of life, future emphasis should focus on consumer involvement in the selection and evaluation of appropriate assistive technology, and ways to make technologies more widely available and affordable.	Literature review LOE= V
Scherer and Glueckauf, 2005	This article defines the environment factors of the ICF and describes how ATs can improve function among individuals with disability.	Not applicable for a systematic review	None	- The effective use of an AT device can be maximized by matching the device with the user goals, need and environmental resources. - Abandonment can be decreased if those issues are taken into consideration.	Non-Systematic Review; LOE = V
Simsarian, Saunders, 2008	This article reviews a comprehensive care model for people with MS.	Not applicable	None	- In addition to inform individuals with MS of their diagnosis course, it is important for doctors and nurses to inform patients to seek councilor support to help not only themselves but their family members.	Non-systematic review LOE=V
Solari, Ferrari, & Radice, 2006	To prospectively assess changes in a self-perceived health status over 5 years	205 individuals with MS who participated in a 1999 postal survey and their significant others	Assessment at baseline and at year 5 **Outcome Measures:** Individuals were sent to the MSQOL-54, the Chicago Multiscale Depression Inventory (CMDI), and completed a demographic/clinical questionnaire. Health-related quality of life and CMDI were asses	-The proportion requiring constant bilateral walking assistance increased from 16% to 33%. -The proportion using housing adaptations increased from 17% to 27%. -The use of daily home care increased from 19% to 28%. -The proportion of those severely impaired	Repeated Measures Intervention study LOE = V

			in participants' significant others	doubled over the study period. -In 23% of participants, the disease remained mild over a median duration of 11 years.	
Sutliff M, 2008	Provide a review of importance of physical therapy care and mobility devices for individuals with MS with	NA	None	- The goal of physical therapy, while working in a team, is to provide improve in people with MS quality of life providing them with a good treatment and the adequate mobility device.	LOE= V
Uustal and Minkel, 2004	To test the safe and effective use of a new mobility device, the IBOT 3000 Mobility system by people with disabilities	Twenty subjects who used manual or power wheelchairs	Participants would use the IBOT for 2 weeks in their home or in the community	- No difference was found between using the IBOT compared to participants own wheelchair. - Ten out of twenty participants were able to climb stairs independently; the other 10 participants were able to climb stairs with assistance of one person. - Independent mobility can be enhanced with a feature such as climbing flights of stairs.	Prospective design with participants acting as their own controls LOE= III
Reference	**Purpose**	**Population**	**Intervention**	**Relevant Findings**	**Study Design & Level of Evidence**
Verza, Lopes-Carvalho, Battaglia & Uccelli, 2006	To evaluate whether an interdisciplinary approach to evaluating & prescribing AT reduces abandonment in MS; Also, to assess the types of AT devices abandoned by people with MS and why they no longer used the devices.	54 subjects (35 females and 19 males) obtained 151 AT devices over the 6-year period of the review	Establishment of an interdisciplinary evaluation team and involvement of patient and family in device selection. (Pre-intervention: the PT would make recommendations to the MD without patient or family involvement)	- 25(37.3%) devices abandoned during the pre-intervention period and 8 (9.5%) during the intervention - Reasons for abandoning the device during pre-intervention phase: a. 36.4% worsening of physical status b. 30.3% Non-acceptance by the user c. 24.2% Inappropriateness d. 9% insufficient/lack of training - During intervention phase, no abandonment due to inappropriateness or insufficient / lack of training	Retrospective medical records review – case series LOE - V
Whetten-Goldstein, Sloan, Goldstein, & Kulas, 1998	To obtain data on cost of personal health services, other services, equipment, and earnings of individuals with MS	606 subjects with MS who were members of the National Multiple Sclerosis Society	Not Applicable	-Most people with MS have health insurance -Health insurance covered 51 per cent of costs for services, excluding informal care -Compensation for earnings loss was an average of 27% -57 per cent of the cost is in the form of burdens other than personal health care for individuals with MS	Observational study LOE = IV

Sackett model definition of levels:

I. Evidence is obtained from meta-analysis of multiple, well designed, controlled studies.
II. Evidence is obtained from at least one well-designed experimental study.
III. Evidence is obtained from well-designed, quasi-experimental studies such as non-randomized, controlled single-group, pre-post, cohort, time or matched case control series.
IV.Evidence is from well-designed, nonexperimental studies such as comparative and correlational descriptive and case studies.
V. Evidence from case reports and clinical examples.

2.0 PRELIMINARY OBSERVATION OF MOBILITY ASSISTIVE TECHNOLOGY DEVICES, USER SATISFACTION AND INFLUENCE ON DAILY ACTIVITTIES AMONGST ADULTS WITH MULTIPLE SCLEROSIS

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Abbreviations: MS- multiple sclerosis; MAT- mobility assistive technology; CNS – central nervous system; PNS- peripheral nervous system; QoL- quality of life.

2.1 ABSTRACT

Purpose: Investigate quality of life, community participation and satisfaction with mobility assistive technology (MAT) device use among adults with multiple sclerosis (MS).

Methods: Participants were recruited from two specialized seating and mobility centers and MS support groups in Western Pennsylvania. The study was conducted in two phases: (1) *Baseline* through an in-person interview and (2) *Follow up*, conducted six months after baseline, for participants who received new MAT devices.

Outcome measures: quality of life (SF-36), community participation (CHART) and satisfaction with MAT device (QUEST).

Results: Eighty-seven participants were enrolled in the study and 24 participants completed the follow up. At baseline, participants using non-wheeled MAT (e.g. cane, crutches and walkers) devices reported higher quality of life (QoL) and community participation scores compared to wheeled MAT device (e.g. manual and power wheelchairs, and scooters) users. At follow up, physical independence results significantly increased among participants who received new MAT devices (n=12) (p=0.025). An increase in satisfaction with MAT devices was observed among participants who transitioned from non-wheeled to wheeled MAT devices from baseline to follow up. (QUEST= 4.00 to 5.00, respectively).

Conclusion: The evaluation of community participation and satisfaction with MAT devices among adults with MS yielded various responses among study participants. An increase in physical independence was noted for those who received new MAT devices. Participants reported to be quite satisfied with their new MAT devices compared to their previous devices.

Based on this study results, further investigation is needed to objectively investigate the benefits of new MAT devices among adults with MS.

2.2 INTRODUCTION

Impaired mobility has been reported as the most frequent cause of disability by adults with multiple sclerosis (MS). [1] Research has shown that ambulatory impairment is a contributor of further disability and it leads to a decrease in community participation, work activities and ultimately a decrease in quality of life (QoL). [1- 6] To enhance impaired ambulation and increase performance on daily activities, mobility assistive technology (MAT) devices are used.[4-7] However, few research studies have objectively looked into the influence of MAT devices on the QoL of adults with MS. [8, 9]

Manual wheelchairs (60%) are the most commonly used form of MAT devices by persons with MS, followed by canes and crutches (44%), walkers (39%), and power wheelchairs (8%). [10, 11, 12] Due to variability in the course of MS, matching appropriate MAT device to users creates challenges for rehabilitation professionals to find a MAT device that will meet the user's mobility needs and expectations while increasing their community participation and QoL [11]

Studies have shown that satisfaction with MAT device used is positively correlated with the active use of MAT devices. [13, 14] In addition, research has found that individuals, who are not satisfied with their MAT device, tend to abandon the device and do not use them to conduct their daily activities [13]. When the users are satisfied with the mobility device received, an increase in community participation has been reported. [14] Research has found that a successful prescription process may influence the user's satisfaction with their devices as well as the use of MAT devices while participating in daily activities. [15] Although studies have been conducted to identify what factors influenced the use of MAT devices among adults with MS, there is still a need for quantitative research studies evaluating the benefits of MAT devices prescribed for adults with MS.

Therefore the objectives of the study were: first, to describe quality of life, community participation and satisfaction with MAT device's used among persons with MS (baseline phase); second, to investigate if the type of MAT device used was a predictor of results of quality of life, community participation and satisfaction with MAT device of participants at baseline; third, to investigate, at follow up, if there was an improvement in community participation and satisfaction with MAT device amongst participants who received a new MAT device compared to baseline.

2.3 METHODS

2.3.1 Participants

Participants were recruited at two major specialized multidisciplinary centers: Hiram G. Andrews Center (HGA) in Johnstown - Pennsylvania, and the Center for Assistive Technology (CAT) at the University of Pittsburgh. In addition, participants were recruited from two MS support groups located in Western Pennsylvania. Participants were recruited via distributed flyers at the recruitment sites or approached by rehabilitation clinicians during their scheduled visit to one of the specialized multidisciplinary centers. The inclusion criteria for the study were: age 18 or older, diagnosis of MS, and use any type of MAT device as a primary mean of mobility. Participants in the study were categorized in two groups according to the type of MAT device used: 1) non-wheeled devices - cane, crutches, and walkers; and, 2) wheeled devices - manual and power wheelchairs, and scooters. Participants were excluded if they lived outside the Western Pennsylvania area, or were unable to provide informed consent.

2.3.2 Protocol

Informed consent was obtained from all participants enrolled in this study. The study was conducted in two phases: baseline and six months follow-up. At baseline, demographic information of participants was collected in-person by a study investigator including: type of MS, data regarding MAT characteristics and mobility-related expectations, preferences, employment status and transportation. It is important to note that participants enrolled at HGA and MS support groups were enrolled in the study only at baseline since they were not being evaluated for a new MAT device and did not require improvements to their current MAT devices. The participants' enrolled in sites other than the CAT answered their questionnaires on site. Participants enrolled at the CAT were recruited during their regular visit where they were looking for a new MAT device or repairs/upgrades on their current MAT devices. At baseline, participants who received services at the CAT and were enrolled in the study received the study questionnaires along with a postage paid envelope to return the completed questionnaires to the researchers.

The follow up phase occurred six months after participants recruited at the CAT were evaluated at baseline. At follow up, participants were contacted by a study investigator through a phone interview. Participants were asked to answer questions with regards to their current MAT device, their impairment level, community participation, and the satisfaction with their new MAT devices.

2.3.3 Outcome measurements

The outcome measurements used at baseline are described below:

2.3.3.1 CAT intake

The CAT evaluation process was used to supplement data and included the following items: chief concern related to mobility limitation(s), primary diagnosis resulting in mobility limitation(s), co-morbidities description of the specific mobility limitation(s), environmental accessibility, social support system, transportation availability, activity restrictions encountered without a mobility device (functional evaluation), and clinical trials and simulations of mobility-related AT options. Client preferences and expectations were also obtained as part of the CAT evaluation. At the end of each assessment, mobility-related AT recommendations were recorded as part of the CAT evaluation.

2.3.3.2 SF-36

The SF-36 is a valid and reliable tool used to evaluate quality of life (QoL) [16] The SF-36 consists of 8 subscales namely: physical functioning scale (PF), role physical scale (RP), social functioning scale (SF), bodily pain scale (BP), general health scale (GH), vitality scale (VT), role emotional scale (RE), and mental health scale (MH). In addition, a physical components summary score (PCS) and a mental component summary score (MCS) can be calculated. The raw scores range from 0-100 with higher scores indicating better health.

2.3.3.3 Expanded Disability Status Scale (EDSS)

A self-administered version of the Expanded Disability Status Scale (EDSS) was used to assess functional systems, mobility and impairment level for people with MS in a shorter version. [17] This version of the EDSS was developed based on the original Kurtzke Expanded Disability Status Scale (EDSS).[18] EDSS scores range from 0- normal neurological exam to 10- death due to MS.

2.3.3.4 Craig Handicap Assessment and Reporting Technique-Short Form (CHART)

The CHART- Short form is a 27-question outcome tool used for measuring QoL in terms of participation in everyday activities. [19] The CHART–Short form is composed of six domains: physical independence, cognitive independence, mobility, occupation, social integration and economic self-sufficiency. Each domain has a maximum score of 100 points, a level of performance typically achieved by individuals without disabilities.

2.3.3.5 Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST2.0)

The QUEST 2.0 determines users’ satisfaction with an assistive technology (AT) device and its service delivery program from which the device was provided. The QUEST is a valid and reliable tool that uses a five-point Likert scale (ranging from 1 to 5), where a score of 1 indicates "Not satisfied at all" and a score of 5 indicate being "Very satisfied." [14, 20, 21]

Due to possible increased fatigue during phone call interview some outcome measurements were not included at follow up. The outcome measurements used at follow up were: CHART, QUEST and EDSS.

2.3.4 Statistical analysis

2.3.4.1 Baseline analysis

Descriptive statistics were used at baseline to report participants demographic information including: gender, age, type of MS, type of MAT device used, time using current MAT device, race/ethnicity, work, impairment level, quality of life, community participation, and satisfaction with MAT device used. All data were examined initially for normality. At baseline, data were analyzed to examine if type of MAT device used was a predictor of the dependent variables results. Type of MAT device used was the independent variable in the model. Our reference categories for type of device were: 1=non-wheeled devices and 2= wheeled devices. The dependent variables were SF-36, CHART, QUEST questionnaires and the confounder variables entered into the model were: type of MS, gender, work status, age, years of education, years with MS, and EDSS. Work status was categorized into 0=working and 1=not working. Correlation coefficients were computed to examine the relationship between confounders and the dependent variables, and also within dependent variables. The variables included in the model were the ones correlated with the independent variable and possible confounder variables. The next step was to run a series of hierarchical linear regression models.

In each model, type of device was added as the first predictor accounting for results variation in each dependent variable. Confounders were gradually added to the model and EDSS was added as the last potential confounder. The reason for this strategy was that type of MAT device was considered as the independent variable of interest, and EDSS was considered as the major confounding variable.

2.3.4.2 Follow up analysis

Paired sample t-tests statistics were used to compare community participation and satisfaction with MAT device among participants who received a new MAT device (n=12) from baseline to follow up, and also to compare participants who transitioned from non-wheeled to wheeled MAT devices community participation and satisfaction with MAT device from baseline to follow up (n=5). A two-way mixed-model ANOVA with one between-subjects factor (type of transition) and one within-subjects factor (time) was used to investigate whether changes in community participation and satisfaction with MAT device used from baseline to follow up were greater for participants who transitioned from non-wheeled to wheeled devices (n=5) than for those who transitioned from wheeled to wheeled MAT devices (n=7). Effect size analysis was conducted for CHART and QUEST subscales using G Power 3.2.1 software (Kiel University – Germany Copyright, 2009) to evaluate clinical relevance of findings that were not significant. [22] All statistical analyses were computed using PASW v18.0[b] software (SPSS, Inc.), with the significance level set *a priori* at p= 0.05.

2.4 RESULTS

2.4.1 PARTICIPANTS DEMOGRAPHICS

Eighty-seven people with MS participated in the study at baseline. The majority of participants was Caucasian (85.2%), and the mean age was 51.16 ± 9.35 years old. Of the participants, 60.9% were female. Five types of MS were represented in the sample: benign, relapse remitting, secondary progressive, primary progressive and progressive relapsing. Thirty five percent of participants reported having a secondary progressive type of MS. Years since diagnosis ranged from 1 to 54 years with a mean of 18.13 ± 11.3 years. Thirty-three participants reported using non-wheeled mobility devices and 54 participants reported to be using wheeled mobility devices.

Of the total of 87 participants recruited at baseline, 31 participants were from HGA and MS support groups, 56 were recruited at the CAT. Twenty-four participants from the CAT completed the study follow up. Thirty-two participants from the CAT were lost to follow up either because fatigue prevented them from answering questions by phone at follow up, or because they could not be reached due to changes in phone number and/or address. Of the 24 participants from the CAT available at follow up, 12 received new MAT devices and 12 had modifications or replacement to their MAT device used at baseline.

For the 12 participants who received a new device at follow-up, Table 2 lists their baseline devices along with the devices they received at follow-up. Walkers were used by four of the five participants using non-wheeled devices at baseline. Only two of the seven participants using wheeled devices at baseline used manual wheelchairs; the other five used power wheelchairs. All but one participant received a power chair at follow up, this participant received a scooter.

Table 2. Devices distribution of participants who received new MAT

	Baseline	Follow up	
	Old Device	**New device**	**New MAT device**
Non wheeled to wheeled			
1	Walker	PWC	A200 Otto bock
2	Walker	PWC	Pride Quantum 600
3	Walker	Scooter	Gogo elite
4	Walker	PWC	Pride Quantum 600 with power seat elevator
5	Cane	PWC	Pride Quantum 600
Wheeled to Wheeled			
1	Pride Quantum 1122 - PWC	PWC	Invacare TDX with power tilt
2	Quickie P-220 - PWC	PWC	Invacare TDX with power seat functions
3	Depot MWC	PWC	Pride Quantum 6000Z swing away legrests
4	Invacare 9000 XT Lightweight-MWC	PWC	Permobil C300 with all power seat functions
5	Merits - PWC	PWC	Permobil C350 with all power seat functions
6	Invacare Pronto - PWC	PWC	Pride Quantum 6000Z with power seat functions
7	Pride Quantum 1122 - PWC	PWC	Pride Quantum 600

2.4.2 BASELINE RESULTS

Descriptive statistics at baseline were computed for participants using non-wheeled (n=33) and wheeled (n=54) MAT devices. QoL and community participation scores were higher (p=0.234) among non-wheeled MAT device users compared to wheeled MAT device users (Table 3). Non-wheeled MAT device users reported a lower impairment level (EDSS) than wheeled MAT device users (p<0.001). No significant difference in satisfaction with MAT device used was found between users of non-wheeled and wheeled MAT devices (p=0.229). On average, participants in both groups reported being “quite satisfied” (median =4) with their devices at baseline.

Table 3. Description of outcome measurement results of participants at baseline

Outcome measurements	Type of MAT device	
	Non-wheeled (n=33)	Wheeled (n= 54)
Quality of life (SF 36)		
Physical component	27.79 ± 7.6	25.55 ± 8.4
Mental component	48.30 ± 10.9	47.88 ± 12.5
Impairment level (EDSS)	5.83 ± 1.0	7.61 ± 0.91*
Fatigue level (MFIS)	13.30 ± 4.6	12.13 ± 4.8
Community participation (CHART)		
Physical independence	74.82 ± 36.3	59.24 ± 35.3*
Cognitive independence	74.18 ± 23.8	59.17 ± 30.4*
Mobility	77.82 ± 20.6	67.11 ± 23.4*
Occupation	59.09 ± 40.9	34.48 ± 38.3*
Social integration	85.88 ± 24.9	84.19 ± 24.4
Economic Self Sufficiency	85.70 ± 24.7	73.98 ± 32.1
Satisfaction with MAT device (QUEST)		
Device Subscale	4.0 ± 0.89*	4.0 ± 0.88

*p<0.05

Table 4 indicates which confounder variables other than EDSS were included in the models as predictors for each dependent variable. As shown in Table III, when entered alone in the first model, type of device was a significant predictor for all of the dependent variables with the exception of the Physical Component scale of the SF-36. When the selected confounders (other than EDSS) were entered in the second model, type of device remained a significant predictor for all of the dependent variables except the Physical Component scale of the SF-36. This indicates that type of device explains a portion of variation in the dependent variables that the other predictors do not explain. However, when EDSS was entered in the last/third model, the unique contribution of type of device was no longer significant (p>0.05) for any of the dependent variables. The regression coefficients indicate that having a high impairment level may influence participants' ability to participate in the community (p<0.035) and their quality of life (p=0.017). This shift occurred because of the variance shared by EDSS and type of device. It was seen in Table 3 that participants using non-wheeled devices at baseline had a significantly lower level of impairment as measured by EDSS than participants using wheeled devices.

Table 4. Results of the regression analysis at baseline

Dependent Variables/Model	Variables	Parameter estimator	Standard of Error	P value**
CHART Physical Independence				
Model 1(R^2=0.098)	Type of device+	22.02	7.43	0.004*
Model 2 (R^2=0.201)	Type of device	23.10	7.14	0.002*
	Years of education	3.59	1.76	0.045*
	Work status++	16.71	9.18	0.073
Model 3(R^2=0.257)	Type of device	6.62	9.67	0.496
	Years of education	3.56	1.71	0.040*
	Work status	4.59	10.19	0.654
	EDSS	-9.84	4.03	0.017*
CHART Cognitive Independence				
Model 1(R^2=0.064)	Type of device	15.01	6.20	0.018*
Model 2(R^2=0.145)	Type of device	14.05	5.97	0.021*
	Work status	21.07	7.48	0.006*
Model 3((R^2=0.190)	Type of device	1.21	8.38	0.885
	Work status	11.07	8.53	0.174
	EDSS	-7.46	3.48	0.035*
CHART Mobility				
Model 1(R^2=0.052)	Type of device	10.70	4.94	0.033*
Model 2(R^2=0.129)	Type of device	9.96	4.77	0.040*
	Work status	16.23	5.98	0.008*
Model 3(R^2=0.150)	Type of device	3.016	6.79	0.658
	Work status	11.16	6.92	0.111
	EDSS	-4.041	2.82	0.156
CHART Occupation				
Model 1(R^2=0.103)	Type of device	26.81	8.81	0.003*
Model 2(R^2=0.387)	Type of device	22.05	7.53	0.004*
	Age	-0.52	0.40	0.198
	Work status	52.40	9.10	0.000*
Model 3(R^2=0.470)	Type of device	-2.70	9.99	0.787
	Age	-0.33	0.38	0.381
	Work status	35.05	9.86	0.001*
	EDSS	-14.41	4.12	0.001*
SF-36 Physical component summary score				
Model 1(R^2=0.015)	Type of device	2.07	1.81	0.256

Model 2(R^2=0.081)	Type of device	-1.89	2.4	0.432
	EDSS	-2.19	0.90	0.017*

*p value for model at each step **p value for each variable at each step
+ Type of device (reference: 1=wheeled; 2=non wheeled)
++ Work status (reference: 0= working; 1=not working)

2.4.3 FOLLOW UP RESULTS

2.4.3.1 Participant demographics

Twenty-four participants were contacted at follow up. Among the 24 participants contacted, 12 received new MAT devices and 12 had repairs/upgrade done to their current MAT devices. The majority of participants were Caucasian (n=20), mean age was 51.16 $\pm$ 6.84 years old. Of the participants, 16 were female. Eleven participants reported having a secondary progressive type of MS. Twenty two participants received wheeled MAT devices and 2 were waiting for their new devices by the time they were contacted for follow up. These two participants did not receive their new MAT device on time due to health problem causing a delay on the prescription process.

2.4.3.2 Community Participation (CHART Short form)

Results of the physical independence subscale of the CHART were significantly higher at follow up than at baseline for participants who received a new MAT device (n=12) (p=0.025) (Table 5). Although the physical independence subscale was the only subscale with significant results (p=0.025), means on all CHART subscales were higher at follow up than at baseline. Large effect sizes were seen for physical independence (*d*=1.18) and cognitive independence (*d*=0.83).

Table 5. CHART subscales of participants who received new MAT devices

Subscales	Baseline(n=12)	Follow up (n=12)	P value	Cohen *d*
Physical independence	55.00 ± 39.04	86.33 ± 20.21	0.025*	1.18
Cognitive independence	68.17 ± 26.09	88.33 ± 18.93	0.092	0.83
Mobility	73.25 ± 24.61	76.67 ± 16.75	0.534	0.16
Occupation	28.58 ± 37.09	35.50 ± 34.76	0.753	0.21
Social integration	80.92 ± 24.62	82.33 ± 22.74	0.959	0.06
Economic Self Sufficiency	76.25 ± 34.17	82.08 ± 27.99	0.767	0.16

Note: CHART scores are shown in mean ± SD. * denotes statistical significance at $p<0.05$

A paired sample t-test analysis of community participation of participants who transitioned from non-wheeled to wheeled MAT devices did not show significant changes from baseline to follow up (n=5) ($p>0.05$) (Table 6). Hence, CHART results increased from baseline to follow up. Effect size analysis showed Cohen's *d* coefficients showed medium to large effect on the following CHART subscales: physical independence (*d*=0.50), cognitive independence (*d*=0.74), and economic self-sufficiency (*d*=0.88).

Two way ANOVA analysis was performed to investigate changes in community participation between the group of participants who transitioned from non-wheeled to wheeled MAT devices (n=5) and the group of participants who transitioned from wheeled to wheeled MAT devices (n=7). Results did not show a greater change in community participation between the groups of participants who transitioned from non-wheeled to wheeled MAT devices and the group of participants who transitioned from wheeled to wheeled MAT devices at follow up ($p>0.05$). (Table 6) Participants who transitioned from wheeled to wheeled MAT devices showed an increase in physical and cognitive independence scores. Results of effect size analysis showed medium effect size on physical independence (*d*= 0.507) and small effect sizes (*d*<0.5) in other CHART subscales.

Table 6. Differences in CHART scores between participants who transitioned from non-wheeled to wheeled and those who transitioned from wheeled to wheeled MAT devices

Subscales	Non-wheeled to wheeled(n=5) Baseline	Non-wheeled to wheeled(n=5) Follow up	Wheeled to wheeled(n=7) Baseline	Wheeled to wheeled(n=7) Follow up	P value	Cohen *d*
Physical Independence	70.40± 42.29	86.40 ± 26.16	44.00± 35.53	86.29 ± 17.10	0.248	0.507
Cognitive Independence	68.80 ± 21.75	90.40 ± 21.46	67.71± 30.53	86.86 ± 18.54	0.909	0.048
Mobility	80.00 ± 22.04	82.20 ± 18.17	76 ± 34.70	69.29 ± 31.28	0.911	0.047
Occupation	14.40 ± 25.16	34.40 ± 38.17	38.71± 42.58	36.29 ± 35.24	0.446	0.328
Social Integration	78.20 ± 29.87	89.40 ± 12.15	82.86± 22.49	77.29 ± 27.9	0.405	0.360
Economic Self sufficiency	76.60 ± 37.48	100 ± 0	76 ± 34.70	69.29 ± 31.28	0.331	0.422

2.4.3.3 Satisfaction with MAT device used (QUEST 2.0)

The QUEST device subscale was used to evaluate the satisfaction with MAT device use at baseline and follow-up. The service delivery subscale was not evaluated because most participants reported that they did not receive their baseline devices through a specialized seating clinic.

Satisfaction with new MAT device received was collected on 11 participants. One participant who received new MAT device asked to withdraw from the study during his phone interview. Median scores of 4 were observed both at baseline (range 3-5) and follow up of 4 (range 1-5). There was no significant difference in satisfaction between baseline and follow up (p=0.852).

At follow up, 4 participants transitioned from non-wheeled to wheeled MAT devices. Participants who transitioned from non-wheeled to wheeled MAT devices showed an increase in satisfaction with MAT devices median scores from baseline to follow up of 4 to 5, respectively (p=0.317).

Investigation of changes in satisfaction with device used between the group of participants who transitioned from non-wheeled to wheeled MAT devices and those who transitioned from wheeled to wheeled MAT devices did not show greater change in satisfaction between baseline to follow up (p=0.404). Two way ANOVA analysis showed that the group of participants who transitioned from non-wheeled to wheeled MAT devices showed an increase in satisfaction with the new MAT devices of 4 to 5 at follow up. Similarly, the group of participants who transitioned from wheeled to wheeled MAT devices also showed an increase in their median scores from baseline to follow up from 4 to 5, respectively. Results of effect size analysis suggested that satisfaction with device results had small effect on between the two groups of participants (*d*=0.388).

2.5 DISCUSSION

The first aim of the study was to describe quality of life, community participation and satisfaction with MAT devices used among participants with MS at one time point (baseline). Our baseline results revealed that participants using non-wheeled MAT devices reported higher scores in quality of life (measured by the SF- 36 questionnaire) and community participation scores (CHART) compared to those using wheeled MAT devices. At baseline, all study participants reported to be "quite satisfied" (QUEST results=4) with the type of MAT device they were using. Forty seven participants at baseline used wheeled MAT devices and reported high impairment level, as measured by the EDSS, compared to participants using non-wheeled MAT devices, similar to results found in a previous study [11]. Results from regression analyses obtained at baseline did not support the hypothesis that type of MAT device used was a predictor of participants' quality of life and the ability to participate in the community. Instead, it showed that EDSS scores (measure of impairment level) were predictors of community participation and quality of life. Therefore, this study shows that impairment level influences community participation and quality of life to a great extent compared to the type of MAT device used.

The second aim of the study was to investigate community participation and satisfaction with MAT device used among participants who received new MAT devices at follow up. Our study did not find significant results for community participation between participants who received new MAT devices, however, an increase in community participation results was observed. This may indicate that participants became more involved in daily activities because they were not limited by their physical disability.

Community participation results increased among participants who transitioned from non-wheeled to wheeled MAT devices at follow up, suggesting that the transition to power mobility devices may positively impact participants' ability to conduct activities in the community. This result supports previous studies which found an improvement in physical function and an increase in participation in daily activities among adults who transitioned to power wheelchairs. [23, 24] Participants who transitioned from wheeled to wheeled MAT devices at follow up showed an increase in CHART physical independence and cognitive independence subscales. A decrease in other CHART subscales (mobility, occupation, social integration and economic self-sufficiency) was observed. These results are in line with previous studies that demonstrated that individuals with disabilities exhibit a temporary reduction in their performance when introduced to a new technology. [25] A difference on device dimensions and driving bases may have initially interfered with participant ability to efficiently travel in the community.

Participants who received new MAT devices maintained their satisfaction results with new MAT device used at follow-up regardless to type of device transition from baseline to follow up. One participant, with a rare progressive-relapsing type of MS rated lower satisfaction with new MAT device received when transitioning from a walker to a power wheelchair, possibly due to a quick decline in his physical condition from baseline to follow up. A decrease in satisfaction among 3 participants who transitioned from wheeled to wheeled MAT devices at follow up (n=7) was observed. Based on those participants' type of MS (secondary progressive) and differences between their devices characteristics from baseline to follow up (e.g. transition from manual wheelchair to power wheelchair), the decrease in satisfaction with the new MAT device could be due to a rapid decline in physical condition and an increase in MAT device dimensions due to the power seat functions. Another possible reason for a decrease in satisfaction with new MAT devices was possibly due to participant's reimbursement policy. Depending on the reimbursement policy, those participants were not eligible to receive better quality power wheelchairs'; however this aspect was not explored in this study. Previous research has shown that power wheelchairs with power seat functions may increase difficulty in maneuvering the devices due to power wheelchairs' larger dimensions. [26]

Future studies should focus on recruiting larger sample sizes, and conducting case control study to compare a group of participants who received new MAT devices with a group of participants who did not receive new MAT devices. Studies may also compare people from different service delivery centers to improve result generalization. Suggestions to use observational tools may enhance the possibility of obtaining more sensitive results on the benefits of new MAT devices prescribed.

2.5.1 Limitations

There are limitations to be addressed such as a small sample size. Power analysis revealed that to develop a study (similar to ours) with 80% power and obtain significant results, as many as 200 participants would be required depending on the specific analysis. The study follow-up was conducted at one time point after participants received their new MAT devices and in some cases that may have resulted in a lapse in time where familiarization with the device was occurring.

The outcome measures used in the study may have not been sensitive enough to measure significant changes in community participation and satisfaction with new MAT device received. In addition, they are subjective tools and are based on participants own perception of their clinical condition, which might increase risk of reporting bias. Furthermore, the SF-36 and the MFIS questionnaires were not used at follow-up, therefore information on quality of life and fatigue level could not be compared between baseline and follow up.

2.6 CONCLUSION

To date, limited studies have objectively evaluated the benefits of MAT devices among adults with MS. MS is such a variable condition that it becomes difficult to gather a large number of participants with similar mobility characteristics and needs. Our study was the first research (to our knowledge) evaluating and comparing results of the prescription of new MAT devices and their impact on community participation and the satisfaction with the device received among participants with MS. For this reason, there is still need for future studies evaluating the impact of MAT devices prescribed with this population to not only guide clinicians with scientific evidence of the benefits of MAT devices but also to assist users on the benefit of being properly assed for an appropriate MAT device that meets the user needs.

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3.0 EVALUATION OF SCOOTERS USING ANSI/RESNA STANDARDS

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3.1 ABSTRACT

Objective: To test a selection of scooters according to the American National Standards Institute (ANSI)/Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) wheelchair standards.

Design: Objective comparison of the performance of four models of three wheeled scooters from two manufactures on standardized tests.

Devices: A total of 12 scooters were tested from two manufacturers: Pride and Golden Technologies. The scooter models were: Pride: Victory (n=3) and Gogo (n=3), Golden Companion I (n=3) and Golden Companion II (n=3).

Setting: Research Laboratory.

Intervention: not applicable

Main Outcome Measures: static tipping angle, dynamic stability, effectiveness of brakes, energy consumption, maximum speed, acceleration and retardation, climate testing, power and control systems integrity; static, impact and fatigue life (equivalent cycles) and tiller failure.

Results: Stability was significantly different between scooter models. The Golden Companion II and Victory were the most stable scooters. The Gogo was the least dynamically stable, while the Victory scooters were the most dynamically stable. No significant differences were observed between scooters responses on stability measure on different surface angles (Kruskal-Wallis). Energy consumption results showed that the scooters can travel 17.67 Km (range, 17.67 – 30.33 Km) prior to battery depletion. Five scooters failed the climatic testing: three Gogo and one Golden Companion I scooters failed the rain condition test and one Golden Companion II failed hot storage test (>65^{o}C). The Victory and Gogo scooters passed the powered and control systems tests; however, the Golden Companion I and II scooters failed parts of the power and control system tests. All scooters passed static and impact tests; all Gogo and one Golden Companion II scooters experienced motor failure, and two Golden Companion II had structural failure during durability tests (e.g. double drum and curb drop tests). The equivalent cycles between scooter models ranged from 62512 – 1178230 cycles. Average tiller load-to-failure results varied from 1394 – 1578 N, and most failures occurred when the tiller structure (typically round tubing) collapsed.

Conclusions: Results of each tests varied across scooter models. Our results indicate that those commercially available devices may not meet ANSI/RESNA standards. These results have serious implications to the users who rely on these devices for their daily mobility. Furthermore, these results suggest that the regulatory framework to ensure these devices are safe may need to be revised.

Keywords: ANSI/RESNA, scooters, durability, fatigue tests, stability tests, durability, failure, standards

Abbreviations: ANSI/RESNA- American National Standards Institute/ Rehabilitation Engineering and Assistive Technology Society of America; FDA- U.S Food and Drug Administration; ISO- International Organization for Standards; VHA- Veterans Health Administration.

3.2 INTRODUCTION

Recent statistics on older population growth from the Department of Health and Human Services - administration of aging, shows that people aged 65 years or older will increase from 35 million in 2000 to 40 million in 2010. This population represents 12.9% of the US population, which means 1 person older than 65 in every eight Americans [1]. It is expected that by 2030, there will be about 72.1 million older persons in the US, which is more than twice their number in 2000. This anticipated increase in life expectancy may also represent a proportional growth in disability, and ultimately a change in need of technical support to perform daily activities [2]. There is an estimate that 75 to 90% of disabled older adults use some form of assistive technology for mobility [3]. Related to this increase in the number of people 65 years or older, there is also a noted increase in the demand for power mobility devices including power wheelchairs and scooters [4, 5]. The use of wheeled mobility devices has increased in the past years in the United States with a total number of nearly 2.8 million users, amongst whom 291,000 use a powered device being 17% of them power wheelchair or scooters [6].

There are a variety of wheeled mobility device options found on the market including manual and power wheelchairs and scooters. As the market for mobility devices expands, a wide range of models are on the market. With so many models to choose from, it is important to choose the device that will not only meet the user mobility needs, but is also safe and durable [7]. Among mobility devices found on the market, scooters are commonly selected because users feel they are more socially acceptable than power wheelchairs. When clients come to a clinical setting looking for scooters, they are initially looking for similar devices that they have seen on TV or in a store, and they may not have knowledge of other technology options [8].

The prescription process should be client centered where the clinician work together with the user to find the most appropriate mobility device. With so many options on the market, it can be a challenging process to choose an appropriate mobility device. A final decision should only be made once information is gathered on the client's diagnosis, the goals and purpose of the device prescribed, and the device has been trialed within the home environment where it will be used. It is important to note that depending on the reimbursement criteria of each client's insurance provider, clinicians may be predisposed to select a mobility device that will not only be the most appropriate for the client's needs, but also fall within their insurance policy requirements. Currently, there are a number of different scooter models available and for this reason it is important for clinicians, rehabilitation professionals, and their clients to know the features, performance, durability and reliability of each device [9]. Research on the use of motorized scooters has shown that scooters might increase activity levels among people who have difficulty with ambulation and therefore increase their community participation [10]. Ensuring these devices are safe and durable is overseen by various organizations, and most rely on standardized testing methods. The American National Standards Institute (ANSI)/ Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) developed wheelchair standard tests to assist clinicians and clients to evaluate and compare different mobility device options and to decide the most appropriate device for the client's needs [11, 12]. The ANSI/RESA standards allow an objective comparison of mobility devices within different test procedures [11, 12].

Medicare requires many of the standard tests to be conducted in all power operated vehicles (POV) (e.g. scooters) to ensure the devices are safe, the performance meets target goals, and the performance and dimensions are disclosed to the end user and clinicians in a standardized format. Most tests can be conducted by the POV device manufacturer as long as they are conducted in a testing facility with equipment and personnel capable of testing in according to ANNSI-RESNA standards. Medicare requires some but not all of the tests to be performed by an independent test laboratory before the device is available for sale to the public, and rarely are the test reports available publically. The absence of objective test reports, as well as evidence of a high rate of wheelchair users' break-downs in the community (within a period of 6 months, approximately 45% of users have complete repair done to their wheelchair) has led to speculation that not all commercially available devices meet the standards [13]. Numerous researchers studied evaluating manual and power wheelchair compliance with the ANSI/RESNA standards [14-25] have substantiated these concerns. To date, one study has compared power wheelchairs and scooters compliance with ANSI/RESNA standards specifically on static and dynamic stability (Sections 1 and 2, respectively) [26]. Therefore, objective evaluation of Scooters on all of the relevant ANSI/RENSA standards is needed to evaluate the performance, durability and safety of these devices.

Medicare covers mobility devices under its durable medical equipment (DME) benefit program. An increase of expenditure on power wheelchairs has lately accounted for several issues since Medicare typically will not provide mobility devices that cannot be used in the home. Since scooters are devices that typically will not maneuver in the home easily, this may cause manufactures to try to make scooters with smaller bases and smaller turning radii, which may compromise user safety and stability when driving the scooter in their home environment.

In addition, the smaller the scooter base, the higher the probability that a scooter may tip during turns. Moreover, an additional concern is that providing scooters that will meet Medicare "in the home use" regulations may be putting the user under a risk of injuring themselves. Table 8 shows basic information of some scooter models found on the market.

Table 7. Brief description of popular scooters found on the market. Included are the scooters manufacturer, model, weight capacity and number of driving wheels

Manufacturer	Model	Weight capacity	Base
Pride	Gogo Ultra X	260 Lbs	3/4 wheels
	Gogo Elite	275 Lbs	3/4 wheels
	Gogo Elite Plus	300 Lbs	3/4 wheels
	Travel Pro	275 Lbs	3 wheels
	Revo	300 Lbs	3/4 wheels
	Legend	350 Lbs	3/4 wheels
	Victory 9	300 Lbs	3/4 wheels
	Victory 9PS	300 Lbs	3 wheels
	Victory 10	400 Lbs	3/4 wheels
	Celebrity X	350 Lbs	3/4 wheels
	Pursuit	400 Lbs	4 wheels
	Pursuit XL	400 Lbs	4 wheels
	Wrangler	400 Lbs	4 wheels
	Maxima	400/500 Lbs	3/4 wheels
Golden Technologies	Buzzaround Lite	250 Lbs	3 wheels
	Buzzaround XL	300 Lbs	3 wheels
	LiteRider	300 Lbs	3 wheels
	Golden Companion I	300 Lbs	3 wheels
	Golden Companion II	350 Lbs	3 wheels
	Golden Companion GC440	350 Lbs	4 wheels
	Avenger	500 Lbs	4 wheels
Invacare	Leo	350 Lbs	4 wheels
	Lynx L-4	300 Lbs	4 wheels
	Lynx L-3	300 Lbs	3 wheels
	Lynx L-3X	300 Lbs	3 wheels
Hoveround Electric Mobility	Transporter	300 Lbs	4 wheels
	Transporter GL	300 Lbs	3 wheels
	Bolero	350 Lbs	4 wheels

Since one research study evaluated scooters compliance on two specific ANSI/RESNA tests, the primary purpose of our study was to evaluate scooter model compliance with all ANSI/RESNA standards tests. We conducted this comparison study to compare and contrast the performance of scooters on standardized tests. Furthermore, we were interested in comparing the fatigue life of each scooter with the number of equivalent cycles. The equivalent cycles are the total number of durability cycles (double-drum cycles + 30*curb drop cycles) which the device endures prior to a class III failure (class III failure is defined as permanent damage, deformation or failure that significantly affects the ability to operate the wheelchair). Finally, we also were interested in the resistance of the tiller system to collapsing after a forward impact, which is a draft ANSI/RESNA test method.

3.3 METHODS

3.3.1 Scooters

We conducted the ANSI/RESNA tests on 12 scooters of four different models from two scooter manufacturers. The scooters tested in our study were: Victory (n=3) (Pride), Gogo (n=3) (Pride), Companion I (n=3) (Golden Technologies), and Companion II (n=3) (Golden Technologies) (Figure 1). The scooters tested are models most frequently prescribed at the Department of Veterans Affairs (VA) and also at the Center for Assistive Technology (CAT) at the University of Pittsburgh Medical Center.

The scooters were purchased through a third-party purchaser to ensure a random sample. Due to the cost and time invested in testing the scooters, we chose to test three of each scooter model from the two manufactures.

Figure 1. Scooters: A-Victory; B-Gogo; C-Golden Companion I; D-Golden Companion II

The scooter names were written on separate pieces of paper and after which our study researcher randomly chose the scooter order of testing one by one until the twelve scooters were selected.

The ANSI/RESNA standard manual is arranged in a way that each test is numbered and named into sections. All standard tests were conducted with each scooter in our study with an exception of sections 16 and 21 (ignition of upholstery and electromagnetic compatibility, respectively), as our laboratory is not fully equipped to conduct these tests.

The tests conducted were: static and dynamic stability (Sections 1 and 2 respectively), effectiveness of brakes (Section 3), energy consumption (Section 4), maximum speed, acceleration and retardation (Section 6), climatic testing (Section 9), impact and fatigue tests (Section 8) and power and control systems (Section 14). In addition to the standard tests, we conducted an additional test on the scooters tiller to determine the forward-directed load on the tiller that would cause it to deform and then fail.

3.3.2 Data collected

The tests conducted were: static and dynamic stability (Sections 1 and 2 respectively), effectiveness of brakes (Section 3), energy consumption (Section 4), maximum speed, acceleration and retardation (Section 6), climate testing (Section 9), impact and fatigue tests (Section 8), power and control systems (Section 14). In addition to the standard tests, we conducted an additional test on the scooters tiller to determine the forward-directed load on the tiller that would cause it to move and then fail.

3.3.3 Tests

3.3.3.1 Static Stability (Section 1)

The Static Stability test was performed by placing the scooter with a 100-kg test dummy on a test ramp, and changing the inclination of the test ramp until the angle is found where the scooter will tip (Figure 2). The angles were recorded with the scooter set up with the most and least stable configurations in the following directions: forward (wheels unlocked and locked), rearward (wheels unlocked and locked), sideways (left and right sides down slope), and on the anti tippers (either front or back). For the static stability test, the scooters were tested with and without their mechanical brakes on [9]. A total of 14 measurements were recorded.

Figure 2. Forward stability test with scooter in least stable configurations and without mechanical breaks on. All reward stability tests were conducted with the least stable configuration. (a) Scooter was placed facing uphill and secured with straps from preventing the scooter from tipping backward completely; and (b) angle recorded when the from wheels started to los contact with the testing plane

3.3.3.2 **Dynamic Stability (Section 2)**

Dynamic Stability is performed by evaluating the response of the scooter to dynamic tasks while traveling on flat surfaces at 0°, 3°, 6°, and 10° slopes. Responses were coded with a score from 0 to 4, where 4 indicates that “at least 1 uphill wheel remains on the test plane”; 3 indicates that the scooter “lifted all uphill wheels temporarily and anti-tippers did not contact the test plane”; 2 indicates the scooter performed a “transient tip when going uphill and the anti tippers touched the test plane”; 1indicates that the “uphill wheels lift off and the scooter remained on the anti-tipper devices”; 0 indicates that “the scooter tipped over completely”. These codes were recorded for 31 tasks, including starting and stopping, traveling upward and downward, while turning, and when traveling up and down a step transition of 12, 25, and 50mm. For all cases, a human operator maneuvered the scooter. All trials were performed at maximum speed.

3.3.3.3 Effectiveness of Brakes (Section 3)

Effectiveness of Brakes testing was performed with a person with weight equivalent to 100 Kg sitting in the scooter driving at its maximum speed. The person weight was determined by the standards according to the equivalent weight to the 95th percentile American men. Since the testing technician weighed less than the required 100Kg for testing, weight was added under the operator on the seat. The braking distance was recorded by measuring the distance from the point when the braking system was activated to the point when the scooter came to a complete stop. This test was also performed on 3°, 6°, and 10° test planes in both the forward and rearward direction. The person applied the brakes to the scooter three ways: throttle release, throttle reverse, and turning the key off. While testing the effectiveness of brakes on a 10^0 slope, scooters tended to tip completely, therefore, for safety reasons, some scooters were not tested on a 10° slope due to the high risks of tipping over completely and causing injuries to the person operating the scooter.

***3.3.3.4* Energy Consumption (Section 4)**

The theoretical range that each scooter can travel before it runs out of battery is calculated by the energy consumption that occurs over a measured distance. More specifically, by measuring the depletion of a fully charged battery (E ampere hours), with a known capacity (C ampere-hours) while traveling a known distance (D meters), the theoretical range can be calculated (R kilometers) by the following equation:

$$R = \frac{C \times D}{E \times 1000}$$

***3.3.3.5* Maximum speed, acceleration and retardation (Section 6)**

Speed, acceleration and retardation were measured with a person of weight of 100 Kg controlling the scooter. The testing technician on the scooter was asked to speed the scooter to its maximum speed on a flat surface. Overall acceleration was determined from a stop to the maximum speed, and maximum acceleration was identified and reported from these trials. Overall and maximum retardation were recorded from the point of braking to the point where the scooter came to a complete stop under three conditions: throttle release, throttle reverse, and key-off. As determined by the standards and for the drivers' safety these tests were conducted only at 0°, 3°, and 6° slopes in a forward direction.

***3.3.3.6* Climatic Testing (Section 9)**

Climatic Testing was performed by exposing the scooters to adverse environmental conditions including rain conditions, cold operating conditions, hot operating conditions, cold storage condition, and hot storage conditions. The rain condition test is composed of spraying the scooter with a steam of water for 10 minutes. The cold operating test was performed by placing a scooter in an environmental chamber at a temperature of $-25^0 + 2^0/-5^0C$ for 3 hours. The hot operating test was performed by placing the scooter on an environmental chamber for 3 hours in a temperature of $50^0 + 5^0/- 2^0C$. The last two tests (hot and cold storages tests) were conducted by placing the scooters in an environmental chamber with temperatures of $65^0 \pm 5^0C$ and $-40^0 \pm 5^0C$, respectively for 5 hours. Functional tests were performed 1 hour after removing the scooters from the environmental chamber. For the functional testing, each scooter was driven through a test track and any adverse responses would be reported as failure per the standards. The adverse behaviors and other causes of scooter failing the functional test could be (1) any dangerous behaviors while the tester is driving, (2) the time taken to drive around the test track is greater than 60 seconds, (3) the scooter fails to stop, or (4) the scooter fails to remain stationary when the control device is released.

3.3.3.7 Static, impact and fatigue tests (Section 8)

Static, Impact, and Fatigue tests were performed by applying static and impact loading conditions to parts of the scooters (armrests, footrests, wheels, shrouding) and by testing the fatigue life of the whole scooter. Static tests were performed with the scooter on the horizontal test plane as specific loads are applied to various parts of the scooter. The loads/forces applied are specified in the standard according to the part tested; the forces ranged from 15 N to 2000N. Impact tests were performed with a pendulum used to strike parts of the scooter which may occur during a user’s daily routine on the backrest, the foot rest structures, and anti tippers and shrouds. All forces and angles applied to the scooters were specified by the standards to mimic possible impacts and static stresses that a scooter is exposed to on a regular basis. Fatigue life (or durability) is tested using double-drum and curb-drop testing machines. Results on these tests were based on whether the scooters passed or failed each test; for the fatigue testing, the scooter passes if it endures 200,000 cycles on the double-drum and 6666 curb-drop cycles (which is equivalent to 3 - 5years of use). There are a total of three classifications of failures. Class I is defined as failures where minor adjustments or repairs that may be accomplished by the wheelchair/scooter user or an untrained assistant such as tightening a loose screw or bolt. Class II is a failure that encompass minor repairs that can be accomplished by a repair technician and include repairing or replacing flat tires or making complex adjustments (e.g. adjust a wheel). Class III failure is when there is a permanent damage, deformation, or failure that significantly impairs operability or safety of the wheelchair/scooter. We repeated the fatigue test on scooters that passed the initial 200,000 double drum cycles and /or 6666 curb-drop cycles until the scooter failed to determine its exact survival life. To compute the survival life we calculated the scooters equivalent cycles (ECs):

ECs= double drum cycles + 30*(curb-drop cycles)

Scooters that passed an EC score of 400,000 cycles was denoted as passing the minimum requirements of the ANSI/RESNA standards. To evaluate the cost effectiveness of scooters, we obtained the value of each scooter by normalizing the number of ECs by the manufacturer’s suggested retail price (unit of value=cycles /dollars). For additional information please referrer to ANSI/RESNA wheelchair standards [11, 12].

3.3.3.8 Power and Control Systems (Section 14)

Power and Control Systems are tests that set minimum requirements for the protection of the scooter during not only normal use but also in adverse conditions. All adverse behaviors that are potentially dangerous are reported. These tests are applicable to electrically powered devices intended to be used indoor and outdoor among people with mobility difficulties whose mass does not exceed 100Kg according to the standards. There are some scooter models, however, that can support higher loads, and in the future, scooters should be tested according to their maximum weight capacity. Similar to the fatigue tests the scooters are scored upon a pass or fail following the specifications determined by the standards.

3.3.3.9 Tiller test

After all scooters were tested until failure in Section 8, we tested the strength of each scooter tiller to identify the forward-directed load at which the tiller would move and ultimately collapse. This is a draft test which was recently proposed by the ANSI/RESNA standards committee. To conduct the test, the scooters were restrained on the double drum to prevent them from moving during the test, leaving the tiller free (Figure 8). They were restrained to prevent the rear end of the scooters from lifting due to the force being applied to the tiller. After the scooters were secure, a pulling apparatus was attached to tiller handles that includes a method to indicate force that is being used (+/- 2273N). The pulling apparatus would then pull tiller horizontally to ground plane in the direction towards the front of the scooter. We observed the maximum force applied to the tiller when we would notice modification on the tiller bar; following, we recorded the force at which the tiller' components failed. Lastly the forces when components failed completely were recorded.

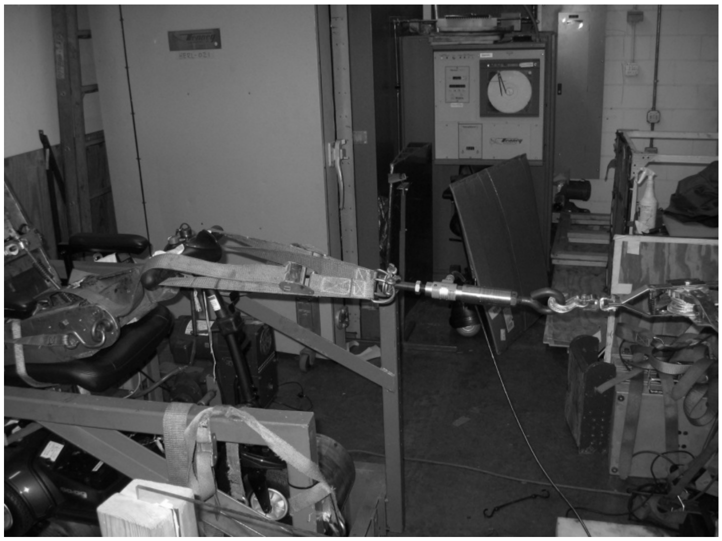

Figure 3. Set up of scooters to conduct tiller test

3.3.3.10 Data Analysis

Selection of statistical analysis (parametric or nonparametric) was based on data normalcy. Statistical analyses were conducted on the results of sections 1 to 4 of the ANSI/RESNA standards. For normally distributed data, Analysis of Variance (ANOVA) test was performed to evaluate each scooter (independent variable) within continuous variables such as static and dynamic test, effectiveness of brakes, energy consumption (dependent variables). Kruskal-Wallis 1-way ANOVA test was performed where data was not normally distributed (non parametric test for independent samples). The Mann-Whitney U test was used to perform post-hoc analysis with pair-wise comparisons of scooter groups. All statistical tests were performed using PASW v18 statistical software. The alpha level of .05 was set *a priori*.

3.4 RESULTS

3.4.1 Static Stability and Dynamic Stability

The results of static stability are shown on table 10 for the least stable set up of each scooter model. The higher the angle achieved the more stable the scooters were. There was no statistically significant difference among the 4 models in forward and left sideways stability tests. The Golden Companion II scooters were the most stable model in forward stability with wheels locked, followed by the Golden Companion I scooters. On the forward stability test with wheels unlocked, the Victory scooters were the most stable followed by the Golden Companion II. Statistically significant differences were observed on rear stability with wheels locked (p=0.025) and wheels unlocked (p=0.021) among scooters, where the Victory scooters were the more stable models with wheels locked and unlocked; in addition, they were more stable with the anti-tippers tests, followed by the Gogo scooters. Statistically significant results were observed (p=0.036) on the right sideways tests and overall, the Golden Companion I and II scooters were the most stable scooters on sideways tests. Post hoc analysis results (Table 9 superscript) showed grouping among the scooters tipping angle direction, the groups were represented by 1 lowest tipping angle (most stable condition) to the highest tipping angle 4 (lest stable condition).

Table 8. Static stability results

	Forward		Reward			Lateral	
	Front wheel lock	Front wheel unlock	Rear wheel locked	Rear wheel unlocked	Anti-tippers	Sideways left	Sideways right
Victory	38.76 ± 9.9^{2}	46.07 ± 1.84^{1}	$21.7 \pm 2.05^{*1}$	$23.33 \pm .058^{*1}$	$18.33 \pm 1.45^{*1}$	20.63 ± 2.0^{2}	$16.93 \pm 1.21^{*2}$
Gogo	38.6 ± 2.38^{2}	29.20 ± 15.15^{3}	$12.8 \pm 0.55^{*2}$	$13.77 \pm 0.55^{*2}$	$13.13 \pm 0.3^{*2}$	15.07 ± 1.33^{3}	$15.87 \pm 1.47^{*2}$
Golden Companion I	44.2 ± 3.86^{1}	39.70 ± 10.14^{2}	9.8 ± 1.62	11.27 ± 0.7^{2}	8.50 ± 1.9^{4}	21.60 ± 2.92^{1}	21.40 ± 2.53^{1}
Golden Companion II	45.73 ± 1.27^{1}	45^{1}	9.47 ± 1.51	9.60 ± 1.47^{3}	9.60 ± 1.85^{3}	22.40 ± 1.27^{1}	21 ± 1.0^{1}

NOTE Values are mean deg/mm $\pm$ SD, after Tukey post hoc analysis. If scores were the same among the scooters, SDs are not included.
*Statistically significant difference at $\alpha \leq 0.05$ based on Mann-Whitney post hoc analysis; Group 1 is has the higher tipping angle (most stable) and 2, 3 and 4 are the lowest tipping angles.

The Dynamic stability test showed the scooters' response while traveling on level surfaces of 0°, 3°, 6°, and 10° slopes. Results of the dynamic stability tests were not statistically significantly different among the scooter models. Scores that were not equally scored (e.g. all values = 4) were presented on table 10 with their mean and standard deviation values. Overall, the Gogo and Golden Companion I and II scooters were the ones that more frequently tipped. The Victory scooters were the most stable scooters in most positions, except during reward stability when traveling up a step transition (M= 3.67 $\pm$ 0.58).

Table 9. Dynamic stability results

Section	RHU(sta)			RUH(br)			RDH(br)				F(br)			
Scooter	3	6	10	3	6	10	0	3	6	10	0	3	6	10
Victory	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Gogo	4	4	4	4	4	2.67±2.31	4	4	3.67±0.58	2±1.73	4	4	4	2.67±2.31
GCl	4	4	4	4	4	4	4	4	3.67±0.58	3.3±1.15	4	4	4	4
GCll	4	4	4	4	4	3.67±0.58	4	4	3.67±0.58	3±1.73	2.7±2.3	4	4	3.67±0.58

Section	F(l)			LAT-TRN			R-TRAN			F-TRAN			LAT-TRAN		
Scooter	3	6	10	3	6	10	12	25	50	12	25	50	12	25	50
Victory	4	4	4	4	4	0	4	4	3.67±0.58	4	4	4	4	4	4
Gogo	4	4	2.7±2.31	3±2	3±1.73	0	4	4	4	4	4	4	4	4	3.3±0.6
GCl	4	4	4	4±1	1.33±2.3	0	4	4	3.67±0.58	4	4	4	4	4	4
GCll	4	4	2.7±2.31	4±1	4	0	4	4	4	4	4	3.7±0.6	4	4	3.7±0.6

Abbreviations: RUH(sta), rearward stability when starting uphill on a slope; RUH(br):rearward stability when braking after traveling forward on an uphill slope; RDH(br), rearward braking stability when travelling backward down a slope; F(br), forward braking stability when traveling forward; F(l), forward braking stability when traveling from sloped surface to a level surface; LAT-TRN, lateral stability when turning on a downhill slope; R-TRAN, reward stability when traveling up a step transition; F-TRAN, forward stability when traveling down a step transition; LAT-TRAN, lateral stability when 1 side of the scooter travels down a step transition

3.4.2 Effectiveness of Brakes

This test was performed to test effectiveness of brakes on 0°, 3°, 6°, and 10° test planes in both the forward and rearward direction (Table 11). A Kruskal-Wallis test was conducted to evaluate differences on braking distances between scooter models. Data values were in meters. Results showed that most results on the horizontal condition and 10 degrees slopes were statistically significant different between scooters ($p<0.05$). No statistically significant difference was observed between all scooters tested on 3° and 6° slopes. Considering the variability of the data, it was observed that for most 0°, 3° and 6° test planes the Golden Companion II were the scooters with the highest breaking distances, followed by the Victory scooters. The Gogo scooters had higher braking distances on 10^0 testing plane. Among the lowest braking distances, interestingly, the Gogo scooters were the ones with lower braking distances in most testing planes, except on the 10° testing plane.

Table 10. Effectiveness of brakes

Model	Horizontal						3 degree					
	Horizontal forward normal operation	Horizontal forward reverse command	Horizontal forward emergency power off	Horizontal reverse normal operation	Horizontal reverse command reverse	Horizontal reverse emergency power off	3° forward normal operation	3° forward reverse command	3° forward emergency power off	3° reverse normal operation	3° reverse command reverse	3° reverse emergency power off
Victory	1.89±0.13*	1.50±0.34*	1.75± 0.27	0.57±0.14*	0.42±0.18	0.67±0.12	2.26±0.35	1.96±0.39	2.24±0.28	0.88±0.11	0.66±0.17	0.91±0.17
Gogo	1.30±0.10	0.97±0.19	1.23±0.43	0.62±0.02	0.30±0.11	0.61±0.05	1.88±0.24	1.58±0.18	1.85±0.12	1.10±0.40	0.65±0.20	1.06±0.33
Golden Companion I	1.81±0.17	1.42±0.32	1.63±0.13	1.02±0.11	0.82±0.05	0.81±0.12	1.96±0.30	1.75±0.37	1.79±0.32	1.13±0.13	0.94±0.15	0.98±0.04
Golden Companion II	2.31±0.18	1.94±0.21	1.88±0.40	0.94±0.08	0.83±0.03	0.93±0.06	2.66±0.09	2.33±0.31	2.29±0.17	1.37±0.22	1.08±0.38	1.23±0.41

Note: values are mean meter± SD. Kruskal- Wallis test showed that most of the conditions tested were not statistically significant different.
*are values with p<.05

Model	6 degree						10 degree					
	6° forward normal operation	6° forward reverse command	6° forward emergency power off	6° reverse normal operation	6° reverse command reverse	6° reverse emergency power off	10° forward normal operation	10° forward reverse command	10° forward emergency power off	10° reverse normal operation	10° reverse command reverse	10° reverse emergency power off
Victory	3.06±0.39*	2.82±0.33*	2.92±0.36	0.96±0.23	0.80±0.21	1.13±0.09	5.02±0.73*	4.49±1.75	4.87±1.00*	1.16±0.15*	1.20±0.18*	1.18±0.07
Gogo	2.64±0.12	2.57±0.17	2.73±0.17	1.38±0.23	1.19±0.23	1.53±0.47	4.31±0.66	4.28±0.55	4.38±0.11	1.99±0.29	2.40±0.08	2.77±0.34
Golden Companion I	2.38±0.06	2.13±0.13	1.93±0.40	1.46±0.12	1.09±0.12	1.19±0.08	2.60±0.15	2.16±0.39	2.46±0.38	1.64±0.11	1.13±0.16	1.35±0.27
Golden Companion II	3.15±0.18	2.96±0.19	2.79±0.06	1.61±0.31	1.29±0.38	1.24±0.43	3.70±0.27	3.69±0.42	3.55±0.21	2.23±0.46	2.07±0.37	1.27±1.10

3.4.3 Energy consumption test

No statistically significant difference was observed between the scooters models. Table 12 shows the means and standard deviation of each scooter models. ANOVA results showed that the Victory and Golden Companion I scooters had similar results and higher theoretical ranges (30 and 30.33, respectively), followed by the Golden Companion II and Gogo scooters (24.67 and 17.67, respectively).

Table 11. Energy consumption by theoretical range

Range	Victory	Gogo	Golden Companion I	Golden Companion II
Theoretical ranges	30 ± 15.71	17.67 ± 0.577	30.33 ± 12.74	24.67 ± 3.05

Note: values are Km mean±SD

3.4.4 Maximum speed, acceleration and retardation tests

On a horizontal plane, the Golden Companion II scooters had higher speed in the forward direction, followed by the Victory scooters. Victory scooters showed higher speeds going downhill on 3° and 6° ramps. The Gogo scooters showed higher reward speeds, followed by the Golden Companion II scooters (Table 13). Acceleration results were similar among the scooters with higher overall and maximum acceleration from Gogo scooters (Table 14). The Golden Companion I scooter had the lowest overall retardation and the Victory had the highest overall retardation. The Golden Companion II had the lowest overall maximum retardation and the Gogo had the highest overall maximum retardation. The Golden Companion I had the lowest overall emergency reverse retardation and the Victory had the highest overall emergency reverse retardation. Maximum retardation during emergency reverse was the highest for the Gogos and lowest for the Golden Companion II. Overall emergency power off retardation was lowest for the Gogos and highest for the Victory. The Golden Companion II had the lowest maximum emergency power off retardation and the Gogos had the highest maximum emergency power off retardation.

Table 12. Average speed in forward and reward directions

Model	max speed forward horizontal	max speed uphill 3° ramp	max speed uphill 6°ramp	max speed forward downhill 3° ramp	max speed forward downhill 6° ramp	max speed rewards horizontal
Victory	2.46 ± 0.23	2.27 ± 0.51	1.98 ± 0.18	2.71 ± 0.34	2.88 ± 0.07	0.93 ±0.01
Gogo	1.91 ± 0.18	1.65 ± 0.38	1.51 ± 0.68	2.01 ± 0.08	2.37 ± 0.21	1.25 ±0.47
Golden Companion I	2.07 ± 0.01	1.79 ± 0.13	1.50 ± 0.07	2.31 ± 0.06	2.45 ± 0.09	1.04 ±0.01
Golden Companion II	2.51 ± 0.04	1.89 ± 0.54	1.50 ± 0.40	2.37 ± 0.68	2.27 ± 1.20	1.21 ±0.06

Note: Values are mean meter per second± SD

Table 13. Acceleration and retardation results

Scooter	Acceleration		Retardation					
	Overall acceleration	Maximum acceleration	Overall retardation	Maximum retardation	Overall emergency reverse Retardation	Maximum emergency reverse Retardation	Overall emergency power off retardation	Maximum emergency power off retardation
Victory	0.56 ± 0.08	1.12 ± 0.09	2.06 ± 0.22	-3.49 ± 0.61	2.02 ± 0.36	-3.14 ± 0.50	2.20 ± 0.20	-3.62 ± 0.63
Gogo	0.79 ± 0.04	1.91 ± 0.02	1.29 ± 0.44	-2.29 ± 0.22	1.82 ± 0.11	-2.03 ± 0.75	1.57 ± 0.05	-2.24 ± 0.09
Golden Companion I	0.54 ± 0.06	1.84 ± 0.34	0.91 ± 0.33	-3.01 ± 0.37	0.97 ± 0.41	-3.22 ± 0.13	0.99 ± 0.24	-3.64 ± 0.45
Golden Companion II	0.64 ±0.11	1.72 ± 0.13	1.62 ± 0.25	-3.56 ± 0.34	1.50 ± 0.74	-3.69 ± 0.18	1.98 ± 0.49	-4.14 ± 2.14

Note: Values are m/s^2 mean ± SD

3.4.5 Climate testing

All Gogo and one Golden Companion I scooters failed the rain condition test and one Golden Companion II failed the hot storage condition test (>65^o). The scooters that failed the rain condition test started to work again after we opened all the controller boxes and dried all the water retained. The Golden Companion II that failed the hot storage condition test started working again one hour after the test. On average, each Gogo scooter took around 3-6 weeks to dry completely and start functioning again. The Golden Companion I scooter started working again after a week. Abnormal responses observed on these scooters were a whistling sound coming from the controller box, the scooter would not move, or the scooter would not turn off.

3.4.6 Static, impact and fatigue tests

All scooters passed the impact and static load tests. The Victory and Golden Companion I scooters passed the fatigue tests achieving the 200,000 cycles on the double drum and 6,666 cycles on the curb drop test. The fatigue tests were stopped once the scooters suffered a Class III failure. All the Gogo scooters had motor failures during the double-drum test reaching a maximum of 87922 cycles. One Golden Companion II had structure failure with a seat structure breaking in curb-drop test after 1034 cycles (Figure 3 and 4). The other two Golden Companion II scooters had motor failures during the double-drum test reaching a maximum of 50162 and 173803 cycles. The average equivalent cycles of each scooter were: Victory – 1,178,230 cycles, Gogo – 62,512 cycles, Golden Companion I – 634,870 cycles and Golden Companion II – 151,662 cycles (Figure 5 and 6). The cost effectiveness of the scooters differed between scooter models. Values ranged from 41 to 527 cycles/$ (Table 15).

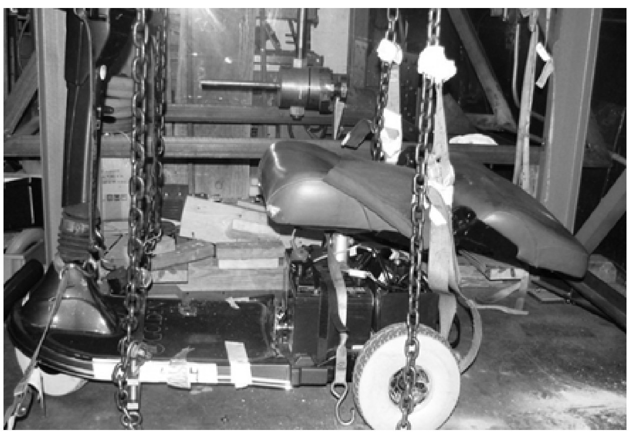

Figure 3. Golden Companion II after curb drop test with seat frame broken

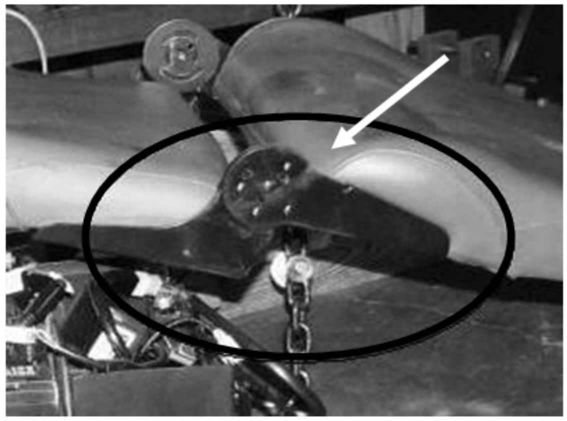

Figure 4. Close view of seat frame broken
after curb drop test

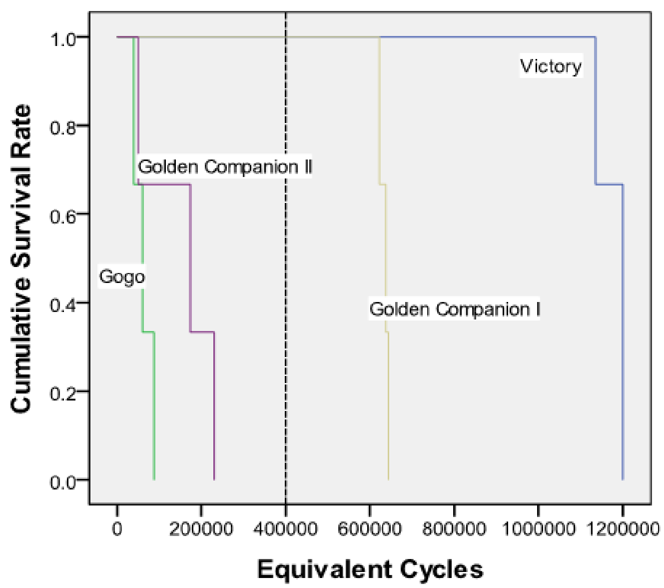

Figure 5**.** Survival curve of scooters. The broken vertical line indicates 400,000 equivalent cycles that indicates passing durability tests.

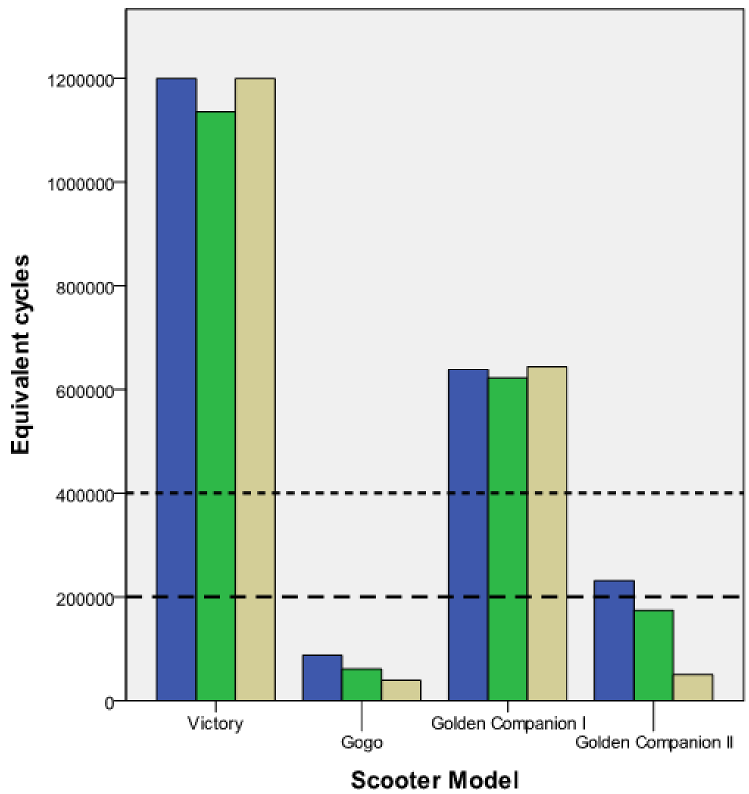

Figure 6. Equivalent cycles of each scooter in fatigue test. The first wide dash line represents 200,000 cycles required to pass double-drum test. The second narrow dash line at 400,000 cycles indicates the minimum request in ANSI/RESNA standards.

Table 14. Equivalent cycles and value

Scooter	**ECs (cycles)**	**Value (Cycles/$)**
Victory	1178230 ± 37602	527 ± 17
Gogo	62512 ± 24430	41 ± 16
Golden Companion I	634870 ± 11316	232 ± 4
Golden Companion II	151662 ± 92439	54 ± 33

Note: Values are in mean ± SD

3.4.7 Tiller Test

Results from this test showed that on average, the Victory scooters were more resistant than the other scooters. On average the Victory scooters needed a braking force of 1578 N (± 179), followed by the Gogo with an average braking force of 1466 N (± 422). The tiller of the Golden Companion II scooters broke with an average force of 1495 N (± 678) and the Golden Companion I scooters tiller broke with an average force of 1394 N (± 865) Force results are shown in Newton (N) (Table 16). In general, the cause of failure was the tiller tube snapping (n=10) or failure of the adjustment strut mounting bolt (n=2) located in the pivot of the tiller. When the failure was on the adjustment strut, the tiller tube would not separate completely however, the scooter still became unusable (Figure 7). Failures where the tiller did not separate completely from the scooter (N=2) occurred with one Gogo and one Golden Companion I scooters. All Victory, Golden Companion II, the two remained Gogo and Golden Companion I scooters had tiller failed completely after separating completely from the scooter as shown below on figure 8.

Table 15. Force values at tiller failure

Scooter Model	Force
Victory	1578 ± 179
Gogo	1466± 422
Golden Companion I	1394± 865
Golden Companion II	1495± 678

Note: values are in Newton (N) means ± SD

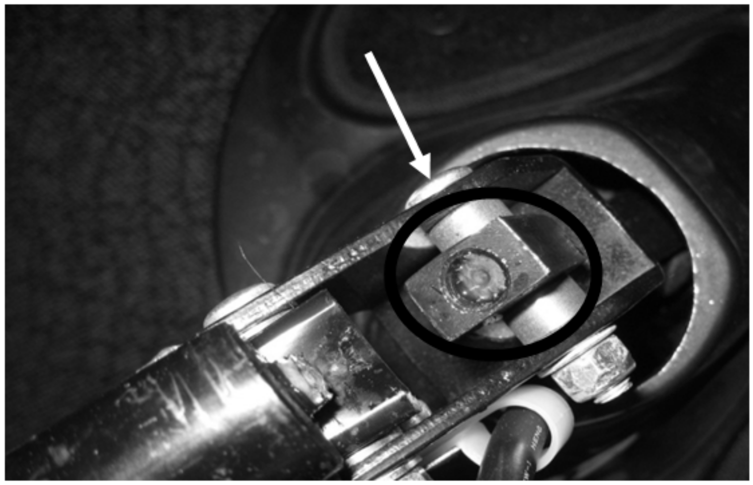

Figure 7. Close view of failure in tiller pivot. The bolt holding the adjustment strut to the tiller assembly snapped.

3.4.8 Power and control systems

Results from this section varied between manufactures. Given that this section is composed of a large number of tests, we are only reporting abnormal responses and tests where a scooter failed. The Victory scooters passed all the tests included in this section. On the other hand, the Gogo scooters failed the safety when charging batteries test. In this test, for user safety, the scooter should not move while charging the battery; however, all the Gogo scooters moved freely while plugged into the charger. This adverse response concerns us because a distracted user might forget that the scooter is being charged and start driving it with the potential of being involved in an accident. The Golden Companion I and II scooters had similar results and they failed few electrical systems tests. These failures include: there were no battery connection and circuit protection diagram; the wires connecting the batteries colors were orange and red instead of black and red; fuses and connectors were not found. Interestingly, on the Golden Companion I there was no labeling to indicate batteries rated capacity. No other adverse responses were observed with the scooters tested.

3.5 DISCUSSION

3.5.1 Static stability

Results from stability tests varied within scooters models in each test conducted. As expected, static stability was higher among scooters with larger dimensions such as the Victory and Golden Companion I and II scooters. Our static stability analyses were conducted with the scooters configured in the least stable condition. Stability tests conducted in forward and reward directions showed variable results, however, it was expected that scooters with bigger base and overall bigger dimensions would be more stable than scooters with smaller base. The Victory scooters were more stable in most directions particularly front wheel unlock, reward direction with wheels locked, with wheels unlocked and also stability on anti-tippers. This could have been due to its overall bigger dimensions, higher scooter mass or outer position of anti-tippers. The most stable scooters in front wheel lock and sideways were the Golden Companion I and II. Those scooters also have wider base and bigger dimensions, differing only on their wheel dimensions. The Gogo scooters were the least stable scooters in all directions, likely due to its smaller base, smaller wheel diameter and overall smaller dimensions. The characteristics that determine the scooter stability were based on the angles where the scooter wheels (front or rear depending on the test direction) would lose contact with the testing surface; therefore, the ones with higher stability would benefit the user in different situations found on a regular basis while driving their scooters over different terrains and surfaces.

3.5.2 Dynamic stability

Dynamic stability results varied between models and the Victory was overall the most stable scooter. Results varied between the Golden Companion I, Golden Companion II and Gogo scooters. The Golden Companion I and II, and Gogo scooters were most unstable in higher slope surfaces (e.g. 6^o and 10^o) in the forward and reward directions. All scooters scored 0 ("scooter tipped over completely") on lateral stability at a higher test-plane inclination of 10^o. The results of static and dynamic stability tests are important to consider when trying identifying which mobility device is safer and how they respond in different terrains during the prescription process.

3.5.3 Effectiveness of brakes

Overall, the Victory and Golden Companion II scooters were the fastest scooters to stop and the Gogo and Golden Companion I scooters were the slowest scooters. The Victory scooters were the slowest ones to stop while driven in reverse followed by the Gogo scooters. The Gogo scooters were fastest to stop on reverse command operations on 10^o testing plane surface, followed by the Golden Companion II scooters. Note that the device braking distance is also important for clinicians to know during the prescription process especially because the scooters do not have programmable controller options. Furthermore, the user ability to control the scooter has to be considered, particularly when stopping responses differ between scooter models. Inability to control the scooter when it stops can cause harm not only to the user, but also to other people.

3.5.4 Energy consumption

No significant differences were observed between scooter models energy consumption tests. The scooters in our study showed a theoretical range (17.67 - 30 Km) similar to results found by Pearlman et al (2005) with low cost electric powered wheelchairs (EPWs) energy consumption range (17.2 – 32.3 Km) [14]. Based on these ranges, researchers suggested that the EPWs tested would run for more than 5 days without recharging the batteries (when they are new) [21]. The Gogo scooters were the ones with the lowest theoretical range: a result that should be pointed out when considering prescription of this scooter model. Caution should be taken when prescribing a scooter; the user's lifestyle should also be considered in order to select a scooter model based on its energy consumption capacity.

3.5.5 Maximum speed, acceleration and retardation

Wheelchair related injuries can be caused by several factors such as components designs; environmental factor and user ability to control a mobility device [18]. Maximum speeds were highest among the Victory and Golden Companion II scooters on most testing planes in the forward direction. Gogo and Golden Companion I scooters showed the slowest maximum speed results in the forward direction. The Gogos showed higher maximum speed on reward direction in a horizontal plane compare to the other scooters. Even though we found a difference in maximum speed amongst the scooters, results ranges did not vary much between scooters models. Our study results present maximum speed as it is an important safety aspect to be considered especially because the scooters' controllers cannot be programmed by the clinicians, therefore they cannot pre select the maximum speed according to the user need. Hence, if the user cannot safely control the scooter at higher speeds, they might be at risk of not only hurting themselves but also other people while driving it. In addition, if a user does not have good postural strength while driving the scooter and it abruptly stops, the user might be at high risk of injury such as being thrown out of the scooter.

Another safety concern with the scooters tested is their responses on reverse commands. Amongst the scooter models tested, the Gogo showed to be the scooter with lowest braking distances during driving in reverse mode. In other words, the lowest the retardation response, the fastest the scooter will stop after a reverse command. Adverse responses of the scooter while driving in forward or reverse mode can affect the user safety, and therefore are an important issue to consider during a prescription process.

3.5.6 Climate test

The Gogos and one Golden Companion I failed the rain condition test and one Golden Companion II failed the hot storage test. For a user, it is very important to rely on a mobility device that can function especially in adverse weather condition, whether it rains or snows. If a scooter cannot sustain ten minutes under rain, the user might be at risk of be caught in the rain, with potential of jeopardizing their health and safety. In addition to potential health problems there is a possibility that the scooter will not function for at least two months and ultimately the user's mobility will be compromised. This will all involve potential need for a battery replacement or in some cases, a scooter replacement, which may interfere with the user mobility and ultimately conduction of daily activities.

3.5.7 Static, impact and fatigue tests

All scooters passed the impact and static tests. Conversely, fatigue test results varied among scooter models. All Victory and Golden Companion I scooters passed the fatigue tests. All of the Gogo scooters failed during the double drum tests and consequently they were not tested on the curb drop test. All of the Gogos had motor failures and none of them reached even half of the 200000 cycles on the double-drum. The maximum numbers of cycles achieved were 87922 cycles. These results suggest that the Gogo scooters do not meet minimum standards and are likely not durable enough to last 5 years of usage; the minimum number of years determined by Medicare to consider replacement of a mobility device. Durability and fatigue are important aspects to be considered when prescribing mobility devices, since it is a strong indication of expected reliability, and also conveys the relative value of the device. In the case of the Gogos, the nature of the failure suggests that a person may be stranded by the device. The Golden Companion II scooters did not pass the minimum number of equivalent cycles of 400000 (ECs= 151662 cycles). The variability of results observed between the Golden Companion II scooters is concerning and this low durability could force a scooter replacement in less than 3-5 years of usage. Moreover, it may cause user jeopardy in conducting daily activities in a safe and effective manner. The variability of types of failure may be a factor to be re-evaluated as with the device life expectancy being so variable and unreliable, users may be at risk of receiving a scooter that will not meet their needs, will not last for 3-5 years, and in some case of misuse hurt themselves. Overall results of equivalent cycles (EC) and values (cycles/$) were higher in Victory and Golden Companion I scooters, which is a critical result, suggesting significant cost benefits for the payors of these devices. On the other hand, the scooters with lower durability and lower value may result in insurance company not replacing the scooter in less than 5 years or they may pay for parts replacement, resulting in significant amount of paperwork to provide such replacements, resulting in a lengthy process for the user. The variability of EC results suggests that the life of scooters found on the market is still not reliable as expected. It is important to consider durability and safety are essential aspects to look for when prescribing scooters, the lack of adjustability with these scooters is another important factor to consider especially among users that have a progressive diagnosis. Our overall study results showed inconsistent results among scooter models and manufactures, in addition, it shows evidence that the Gogo and Companion II scooters do not meet minimum criteria as determined by the ANSI-RESNA standards.

3.5.8 Tiller test

The tiller load testing helps convey the resistance of the tiller to structural collapse when forward directed force is placed on the tiller. This could occur if the scooter is towed (e.g. if the battery dies) or if the scooter abruptly hits an obstacle and the user braces themselves to prevent falling.

All scooters showed similar resistance to failure. The nature of most of the failures was the actual tiller structure collapsing as opposed to the adjustment mechanism.

3.5.9 Power and Control systems

Overall, we did not observe significant adverse response on power and control systems with the Victory and Gogo the scooters, except the Golden Companions I and II. One concern was that if the user or someone else would try to replace a battery, with the wires having different colors than the standard determines, an electronic failure could happen and the scooter could stop working properly. Another adverse and concerning reaction was found among the Gogo. If the scooter is being charged, the user forgets that and starts driving it, they might pull out the cord from the wall, damage the scooter and cause harm not only to the user but also to others. This adverse response give us concern that a distracted user might forget that the scooter is being charged and start driving it with the potential of being involved in an accident or hurt someone else who might be under way. In addition to possible injury to the user and others, if a scooter starts moving while charging the battery, the scooter may crash into objects or rip something out of the walls resulting in need for repairs or parts replacement.

Our study results suggest that at least some commercially available scooters may not meet the minimum standards required by Medicare and the VA. There is a need to improve the scooters found on the market to better serve the users. Mobility devices are tools to improve the user's mobility, improve their quality of life and ultimately improve their performance in daily activities. Therefore, it is very important that the scooters, specifications and functions are reliable and that the scooter can be safely driven by the user.

It is important for clinicians and users to be aware that some scooters responses to ANSI/RESNA tests were adverse and inconsistent. The design of scooters require the user to have the ability independently transfer in and out of the device, conduct independent weight shifts and have sufficient upper extremity function to operate scooter tiller steering mechanism. Some scooters allow the user to adjust the seat height, armrest width, modify the tiller distance from the seat and in few models have a power seat elevator; however, these options do not accommodate the user need for postural changes, for instance. The inability to adjust the scooter seating system according to the users' need would, in some cases, rule out a clinical recommendation of this mobility device as it would compromise the user safety.

There is still a need for future studies on how those scooters respond to real life situations. Conducting qualitative studies might also benefit users, clinicians and scooter companies to improve the quality of devices produced. Our study is thus just one step in the process to improve the quality of the scooters available on the market.

The scooter manufactures and models selected were the ones delivered by the VA Healthcare System and some of them also are delivered through Medicare system. Our intention was to provide quantitative results of how the models being prescribed respond and what actual qualities or deficiencies they showed. Our main focus is, nevertheless, to educate clinicians, users and health insurance companies in the importance of providing reliable scooters to avoid further injuries and potential replacement of devices in less than a 3-5 years time of usage.

3.6 CONCLUSION

Our study results showed inconsistent responses of scooter models within each standard test. It raises concern that devices found on the market are not as reliable as should be and therefore may be putting users at potential risk of injuries. It is important for clinicians and users to be aware and understand the risks and benefits when looking for scooters in particular. With changes in Medicare regulations, and with the industry trying to develop affordable devices, there is a concern that the quality of durable medical equipment is at risk of being low. Our study results recommend caution when looking for scooters, it is important to reinforce that they are not as durable and reliable as they appear to be; in addition, they are not adjustable. Clinicians and users should be aware of not only the scooters specifications, but also the user's ability to operate it before considering a scooter as an appropriate and functional mobility option.

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4.0 CONCLUSIONS

This dissertation was based on three studies. The first study was a systematic literature review of research related to the use of mobility assistive technology (MAT) devices among persons with multiple sclerosis (MS). The second study investigated the impact of MAT devices on quality of life, community participation and satisfaction with MAT devices of this population. The third study investigated compliance of 4 scooter models with ANSI/RESNA standards.

The first study reviewed peer-reviewed articles that focused on the use of MAT devices among persons with MS and impaired mobility. Evidence-based literature provides the basis for the strongest method of measurable clinical performance; therefore, having a strong research study design is vital to justify prescription and reimbursement decisions when prescribing MAT devices. Fifty articles met the inclusion criteria and were categorized with a high level of evidence (LOE). Results showed that there is still limited number of research studies with high levels of evidence based practice investigating the use of MAT devices and their benefits for persons with MS. Therefore, based on the literature reviewed, there is a need for future studies with a high LOE investigating the use of MAT devices among persons with MS and their influence on users' daily activities.

The second study investigated the relationship of MAT device use with three outcome measures: the quality of life, community participation and MAT device satisfaction. The first part of the study evaluated the three outcome measures between participants who used non-wheeled vs. wheeled MAT devices. The results showed that participants using non-wheeled MAT devices reported higher quality of life, community participation and lower impairment level compared to participants using wheeled MAT devices. The second part of the study investigated if type of MAT device use was a predictor of the three outcome measures. Hierarchical linear regression analysis showed that impairment level was a predictor of the three outcome measures, and the type of MAT device was not a predictor. The third part of the study investigated if there were any changes in two of the outcome measures six months after prescription/modification of specialized seating and mobility devices. Results showed that participants who received new MAT devices reported to be more active in the community and reported a higher satisfaction with new MAT devices compared to their MAT devices used initially. There was no change in community participation and satisfaction with MAT device between the groups of participants who transitioned from non-wheeled to wheeled MAT devices vs. who transitioned from wheeled to wheeled MAT devices. With the wide variability of results and the small sample size, further investigation with larger sample size and case control study is needed to evaluate the impact of receiving a new MAT device in community participation and the satisfaction with MAT device among people with MS. In addition, suggestion of tools that evaluate the impact of a new MAT device used may include: wheelchair skills test (WST) or the functional evaluation of a wheelchair-capacity questionnaire (FEW C).

The third study evaluated compliance of four scooter models available on the market with ANSI/RESNA wheelchair standards. A total of twelve scooters were randomly evaluated and results of each test varied across scooter models. Half of the scooters tested failed on environmental condition and durability tests and did not achieve the cycles representative of 2 years of use. According to Medicare, mobility devices should last a minimum of 5 years prior to their replacement. The scooters models tested did not follow all the standard criteria which may represent risk of injuries especially between people with progressive diagnosis such as MS. Findings of this study indicate that the commercially available devices do not meet all of the ANSI/RESNA standards, and this has serious implications to the users who rely on these devices for their daily mobility. Results observed are in line with a recent research study that showed no significant improvements have been made with wheelchair testing results in the past 17 years. Future work may include revisions on the regulatory framework to ensure these devices are safe and reliable to users as determined by the standards.

In conclusion, the three studies combined initiated objective investigations on the impact of new MAT devices among persons with MS. The preliminary studies focused on the impact of MAT devices in community participation, user satisfaction and how reliable the scooters are according to the standards. Results suggested that further investigation is required to test the impact of the MAT devices on people with MS, since the symptoms of the participants varied from person to person. In addition, technical support on the reliability of scooters may assist in helping clinicians and users to identify the benefits and problems found with these types of MAT devices.