Use of personal mobility devices for first-and-last mile travel: The Macquarie-Ryde trial

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Abstract

Electric-motored personal mobility devices (PMDs) are appearing on Australian roads. While legal to import and own, their use is typically illegal for adult riders within the road transport system. However, these devices could provide an answer to traffic congestion by getting people out of cars for short trips ("first-and-last mile" travel). City of Ryde council, Macquarie University, and Transport for NSW examined PMD use within the road transport system. Stage 1 of the project examined PMD use within a controlled pedestrian environment on the Macquarie University campus. Three PMD categories were used: one-wheelers (an electric unicycle, the Solowheel); two-wheelers (an electric scooter, the Egret); and three-wheelers (the Qugo). The two-wheeled PMD was most effective in terms of flexibility. In contrast, the three-wheeled PMD was most effective in terms of speed. One-wheeled PMD riders were very satisfied with their device, especially at speed, but significant training and practice was required. Two-wheeled PMD riders had less difficulty navigating through pedestrian precincts and favoured the manoeuvrability of the device as the relative narrowness of the two-wheeled PMD made it easier to use on a diversity of path widths. The usability of all PMDs was compromised by the weight of the devices, difficulties in ascending steeper gradients, portability, and parking. This was a limited trial, with a small number of participants and within a unique environment. However, agreement has been reached for a Stage 2 extension into the Macquarie Park business precinct for further real-world trials within a fully functional road transport system.

Introduction

New alternative vehicles such as motorised mobility devices (MMDs) and personal mobility devices (PMDs) are rapidly entering the Australian road transport system and are becoming common features of Australian roads and footpaths. Their entry marks both a migration from in-home assistive technologies (MMDs), as well as opportunities offered by new materials and propulsive systems that have seen the morphing of existing vehicle types such as bicycles and toy vehicles into electric-powered devices (PMDs) [1]. MMDs were developed for mobility assistance within the home or a building as a motorised wheelchair, but have migrated into the road transport system and morphed into an alternative electric vehicle. PMDs were developed as mobility alternatives to other forms of transport (cars, motorcycles, bicycles, pedestrians) within the road transport system with the aim of enabling sustainable transportation including accessible links with public transport [2].

Rose and Richardson [3] have noted that:

> "The motor car continues to evolve but it is being complemented by alternative means of independent motorised mobility including personal mobility devices, low powered two wheel vehicles and small footprint four wheel vehicles. For road network managers, the growth of alternative vehicles can have a variety of impacts and implications, from the design of individual elements of the road system, such as parking bays, to the refinement of the regulatory structures that govern vehicle use." (p.1)

That sustainable transport futures will require significant reductions in use of the private car is uncontested. Whether and how existing patterns and volumes of personal mobility can be sustained through other modes is far more controversial, especially in light of strongly-held preferences for the independence afforded by the car [4]. Technological solutions to this dilemma are frequently proposed. Electric and hybrid vehicles, for example, are being explored as low emission means of getting around that work with, rather than against, the cultural, social and habitual appeal of the car [5,6,7]. Attention has also turned to electric bikes, and in particular their potential to offset some of the fitness and distance constraints of conventional bicycles [8]. Car and other vehicle manufacturers are also developing and marketing technologies to provide an alternative to the car, especially for shorter trips and to be used on footpaths as well as roads. The Segway is the most commonly used and known of such devices (see review in [9], but they also include a plethora of two and three wheeled 'scooters', known by the shorthand terms 'low speed private transport mode' [10] or 'low speed mobility devices' [11], or, as in this paper, 'personal mobility devices' (PMDs, [2, 3]. Such technologies, like electric bikes, allow an individual rider to travel short distances quickly without the physical effort required of cycling, and in some their small size makes transfers between transport modes possible. They therefore, in principle, have considerable potential as sustainable transportation alternatives [12].

This sustainability potential of PMDs is currently curtailed by the safety and regulatory aspects of PMDs. In many jurisdictions across the world it is not legal to ride PMDs on roads or on the footpath, with limited exceptions [2,13]. The speed of PMDs, and their interaction with both pedestrians and with other vehicles, are areas of concern [1]. Safety concerns, especially around the impact of the speed and weight of such devices on collisions with pedestrians, are regularly raised [14]. There are also concerns about the use of such devices upon urban pedestrian infrastructure designed for walking.

Research on PMDs has been sparse despite being raised as a sustainable transport alterative more than ten years ago [12]. There is, however, a growing body of scholarship focused on PMDs that emanates from perspectives ranging across psychology, engineering, road safety, urban planning and transport policy. These studies have myriad foci, including: the performance and characteristics of PMDs [9, 15], their safety dimensions [16,17], acceptability as a transport mode [18], regulatory impacts [15] and use in real world settings [19]. Three themes are especially pertinent to their sustainable transport potential.

A first theme is an explicit evaluation of PMDs as a sustainable transport solution. In this theme, the potential of small, powered, devices to bridge the 'first and last mile' – between home and transit and/or transit and work locations – is considered. San Francisco's 'EasyConnect' project assessed the perceptions and feasibility of low-speed modes (specifically the Segway) in facilitating movement around transit hubs, and found that users willingly adopted the Segway as a means of getting around during the work day (e.g. going out to lunch) but were more likely to use electric bicycles to bridge the first and last mile [12, 19]. More recently, Iryo and colleagues [20] have suggested that low speed modes enlarge people's final destinations around train stations and other transport hubs, and it car trips to and from transit trips were switched to PMDs then there will be reduced transport emissions from these trips [see also 10].

A second theme is the safety dimensions of PMDs. There is a voluminous literature on the risk of injury to both riders and pedestrians, especially of the Segway [21], but a safety dimension more relevant to sustainable transportation is the contours of PMD use on existing infrastructure [17,22]. Here, the question is how, if at all, can such devices be appropriately used in pedestrian environments such as footpaths, shared paths and separated cycleway. There is even more limited research here, though the broader literature on pedestrian-cyclist interactions provides some guidance. Recent empirical studies from Australia and the United Kingdom found that cyclists moderate their behaviour (especially speed and direction) in the presence of pedestrians, and that there is little conflict between pedestrians and cyclists [23,24]. PMDs are different to bicycles in their potential speed and novelty to pedestrians, thus it is necessary to conduct specific research on their use in pedestrian environments.

A final theme in existing PMD research is the usability and acceptability of the devices. Mirroring research on electric bicycles, a Japanese study found a low level of recognition of PMDs among the general public and that acceptance increased after use [25]. However, this research was based on only 10 minutes of riding a PMD. To better understand acceptability it is necessary to undertake a more comprehensive analysis in terms of both extent of PMD use and evaluation of acceptability.

Given these potentials and policy concerns, it is surprising that such devices have largely been ignored by scholars interested in sustainable transport and in road safety. Moreover, the little research that exists focuses on just one device – the Segway – that is unique in terms of weight, speed and requisite rider skill, and that is qualitatively different from the proliferation of motorised devices appearing in cities around the world [12,13,14,18,20]. This paper addresses these research and policy lacunae, reporting on a study that explored the operation of PMDs in a naturalistic setting. The paper begins with an overview of existing research on PMDs and identifies key factors to be understood if they are to be successfully implemented as sustainable transport solutions. The bulk of the paper evaluates the viability of PMDs in pedestrian environments, focusing on user experiences and perceptions, as well as interactions with pedestrians. The project tested PMDs in an authentic setting, with a focus on their acceptability and perception to those riding them (‘riders’), and their interactions with pedestrians.

Materials and Methods

For the purposes of the present article, a shortened method section will be presented. For more details regarding the device selection and the criteria used in assessing safety and user acceptability see the report of the pilot trial of personal mobility devices at Macquarie University prepared for the PMD Project Steering Committee [26].

Building on the methodological foundations of three separate research trials conducted in Canada, Germany and the United States [14,16,19], the authors conducted a naturalistic study of participants riding PMDs on footpaths and shared paths on a university campus. As it is currently not legal to ride a PMD on a road or footpath in New South Wales, insurance and regulatory concerns limited participants to university employees, and bounded PMD use to within the university campus. Nonetheless, where, how often and how far each rider travelled on a PMD was determined by the rider, not the research team. The university campus has an area of 126 hectares, with capacity for individual trips greater than five kilometres. This was adjudged to be of sufficient size to gauge perceptions of use, and the density of pedestrians (a daytime campus population of approximately 20,000) sufficient to evaluate interaction

Devices

Two different devices were used in the study, selected according to a set of criteria focused on the safety for riders and others users of the shared use paths (see Table 1). Weight criteria were established based on analysing the potential risk of injury to the riders and other path users, which was directly related to the kinetic energy, but also the potential risk of back injury if the rider was to lift or carry the device. Width was determined to be not greater than the width of a standard wheelchair. A two-wheeled device and a three-wheeled (the latter gyro stabilized) device were chosen, as depicted in Figure 1 below. The particular models chosen were those that were in commercial (not prototype) production and available to be imported to Australia. Commercial prices were paid for each device and the research was not sponsored by the suppliers or manufacturers of devices. The power output of each device was limited, enabling a maximum speed of 10 km/h as measured on level ground with a 80 kg loading mass. GPS units were wired to the PMD's battery and the units turned on and off by the same switch or key as the PMD activation circuit. The GPD units tracked the speed of trips, distance travelled, and the time and location of the PMD within the university campus.

Table 1:

Specification	Two-wheeled personal mobility device	Three-wheeled personal mobility device
Designed maximum speed (km/h)	6/ 12/ 20/ 35 km/h	25 km/h
Motor Output (W)	250 W	1000 W
Weight (with battery)	15 kg	33 kg
Maximum load (kg)	100 kg	120 kg
Width (mm)	560 mm	580 mm
Brake System	Motor-brake	3 disc brakes
Foldable version	Yes	handle bar only

Figure 1: The two-wheeled PMD (left) and the three-wheeled PMD (right). From the authors.

Participants

Riders were recruited as volunteers from among university staff, via advertisements and other campus coverage of the trial, with a preference for those staff who travelled across campus on a daily basis. Seventeen riders in total (nine men and eight women) were recruited. They underwent training on the device, including information on the trial protocols regarding compulsory helmet use and the requirements to give way to all pedestrians, and to dismount when crossing roadways. Participants then rode a PMD for one week in pedestrian zones, principally footpaths. After one week, most participants were trained on another device and trialled that one for a week. Riders had an average age of 37 years; three quarters had full drivers' licences and 70 percent came to work as either a car passenger or driver. Forty percent used a bicycle on a regular basis.

Data collection and analysis

User experiences and perceptions were gained from *pre-, mid- and post-trial questionnaires* that were administered to gain subjective reflections of participants' experiences of riding different PMDs (see Table 2). Questions covered perceptions of ease of use, weight and storage. Answers were coded and simple descriptive statistics calculated. The sample size was not large enough for further statistical analysis. Riders were encouraged to write about their experiences on a Wiki site open only to university staff and students. At the end of the trial these blog posts were collated and thematically coded in terms of: pedestrian interactions, safety, fun, attracting attention, hills and stairs, infrastructure, incidents, lack of power, secure parking, technical issues, time saved and the weight of devices.

Table 2: Research questions examined, methods of data collection, and methods of analysis

Research question	Data collection method	Method of analysis
User experiences and perceptions	User questionnaire Qualitative comments	Descriptive statistics Thematic coding
Device usage	GPS tracking of speed and distance	Mapping of trip routes Average speed
Pedestrian interactions	2 fixed and 1 mobile surveillance camera	

Device usage was traced through GPS tracking which supplied the start date, time and location and each update the unit made including speed, location and distance travelled (Table 2). Data were updated at intervals of one minute. Camera locations were entered into the software.

Information on interactions with pedestrians was gained through rider questionnaires, as well as through fixed surveillance cameras placed at two sites of high pedestrian activity supplemented by a mobile camera places at two different sites at different parts of the trial (Table 2). These sites were chosen on the basis of where the PMDs were being ridden. When a PMD passed in the vicinity of a camera an alert was sent to the PMD email address, logging time, place and device. Data related to PMD events captured on the CCTV cameras were extracted from the footage using the time and date stamping. One hundred and thirty video events were extracted and analysed. Video events were analysed using a coding scheme designed to capture pedestrian interactions with PMDs, identify PMD riders' level of compliance and observe the riders' experiences to complement the questionnaires. Each clip was numerically coded for: time and date; location; device type; number of pedestrians present that either interacted or were in close enough proximity to a PMD to potentially interact with the PMD; number of vehicles present including motor vehicles, bicycles and skateboards; whether the PMD rider or pedestrians had to move out of the way; whether pedestrians were using technologies such as mobile phones or music through headphones that could distract them; and whether any incidents were captured. Each of the 130 clips underwent analysis based on the above coding scheme. After the initial analysis, a second analysis based on the same coding was conducted by a second person to verify initial analysis results and maintain reliability, validity and accuracy. A summary of descriptive measures such as frequency counts was produced from the data contained in all 130 cases.

Results and Discussion

Summary of PMD usage

Because PMD use was confined to the university campus during the workday, total usage of the devices is not directly relevant to their potential in sustainable transport terms. Nonetheless, an overview of device usage provides important background to user perceptions and pedestrian interactions. The actual usage of PMDs varied from participant to participant, ranging from 1.5 km to 30 km in one week. The average distance travelled in each day of use was more than two kilometres for both devices, with 50 percent of trips covering distances between 500 metres and 1000 metres, and 25 percent of trips extending to more than 1000 metres. The average speed per trip was 6 kilometres per hour, which is a little over a fast walking pace [1].

Perceptions of riders using a PMD

Before the trial, only a small number of riders had heard of PMDs and none had ridden one. Nonetheless, all riders of the two-wheeled devices found them easy to use, while 16 percent of three-wheeled device riders found it hard to use, principally because of difficulties with balance. All stated the devices became easier to use with practice. Riders identified the advantages of the PMD compared to walking to primarily be about speed, rather than expending less energy. Ninety percent of riders found using a device very or moderately enjoyable, and the same percentage found it moderately or very comfortable to ride (see Table 3). Three-wheeled devices were more comfortable but less enjoyable than two-wheeled devices.

Table 3: Level of enjoyment and comfort experienced

	Two-wheeled device (%)	three-wheeled device (%)	All (%)
Very Enjoyable	53.3	33.3	44.4
Moderately Enjoyable	46.7	41.7	44.4
Not Enjoyable	0	25.0	11.1
Very Comfortable	26.7	58.3	40.7
Moderately Comfortable	73.3	33.3	55.6
Not Comfortable	6.7	8.3	7.4

Likewise, qualitative comments from the blog emphasised the fun experienced by some riders: PMDs were seen as a more enjoyable way of getting around campus.

- *Having fun on the two-wheeled device (it brings back loads of happy childhood memories of riding around on a scooter).*

There were, however, a number of identified problems with riding a PMD on campus. Riders were asked to identify disadvantages, summarised in the table below and addressed in turn. Essentially, ease of use was compromised by perceptions of limited power, device weight, storage and portability, stairs and infrastructure (Table 4).

Table 4: Identified disadvantages of PMD use

	Two-wheeled device (% of riders identifying)	Three-wheeled device (% of riders identifying)	All (% of riders identifying)
Underpowered	46.7	25.0	37
Heavy	20.0	50	33.3
Too wide	0	41.7	18.5
Secure parking	20.0	33.3	25.9
Stairs	20.0	16.7	18.5
Infrastructure	13.3	25.0	18.5
Pedestrians	6.7	0	3.7

The devices were limited to 10 kilometres per hour through a limitation on power. A consequence of this was that devices struggled going uphill, or had to be pushed, and a widespread perception by riders that they were 'underpowered'. Almost 50% of two-wheeled device riders identified hills and being underpowered as the most common problem with their use of the PMD on campus.

- *The two-wheeled device is a slug up hill , on the flat it maintains its 10kp/h , downhill it accelerates beyond the 10 kp/h and you have to brake heavily . Big downside is uphill it's got nothing, having more acceleration would help this immensely.*

The video analysis showed that in eight instances the participant was walking the PMD (mainly two-wheeled devices) and on five occasions two-wheeled device riders used their foot to either support their balance or to add leg power to the device to go up a pedestrian ramp designed for wheelchair access.

PMDs are intended as portable devices, and riders were provided with quality bike locks to secure the devices to bike racks. However, most preferred to take (wheel, rather than ride) the PMDs into buildings, offices, meeting rooms etc. On the university campus this often meant negotiating stairs at some point, and difficulties with stairs and carrying PMDs were often identified disadvantages of the PMD.

- *After using the two-wheeled device for the week, I found it good to get across campus quickly, but overall it was more trouble than its worth in many cases. The size and weight of it make it bad for anywhere that requires it to be carried. If it were smaller and lighter, or if it collapsed to a smaller size this may be different.*

Weight is a key component of perceptions of portability. At 15 kg, two-wheeled device riders also identified its weight distribution and ease of folding as important and difficult, and half of three-wheeled device riders identified its weight of 33 kg as a disadvantage. Storage and secure parking at diverse locations was also an issue; a device is not really portable if there is nowhere to store it at a destination.

The project design anticipated that road and path infrastructure, as well as connections between the two (kerb ramps, crossings, etc.) would be a determinant of ease of use. An initial infrastructure assessment was undertaken by property staff at the university and minor changes made. Despite this, changes in surface, uneven surfaces and the increased elevation (or "bump") often associated with kerb ramps were identified as issues. 'Bumpy' rides induced by certain types of paving across campus were not appreciated, for example:

- *It does not ride well over rougher terrain (eg, car park, cobbled areas) and can give your back a jarring, especially if you are an 'older' person (two-wheeled device rider).*

As a result of these difficulties, half of the riders (52 percent) used the PMD less than they had anticipated. The differences between the devices were stark here: two-thirds of three-wheeled device riders used the device less than anticipated, compared with 40% of two-wheeled device riders. The reasons for this reduction in use are shown in Table 5 below. Most notably, finding the device hard to use was not an issue for two-wheeled device riders, but was the third most important reason for using the three-wheeled device less than anticipated.

Table 5: Riders' reasons for using the PMD less than anticipated

	Two-wheeled device (% of reasons identified)	Three-wheeled device (% of reasons identified)	All (% of reasons identified)*
Walking was quicker	12.5	7.7	9.5
Walking was more convenient	37.5	7.7	19.0
PMD was too heavy	12.5	30.8	23.8
Problems with secure parking	25.0	23.1	23.8
Needed exercise from walking	0	7.7	4.8
Helmet use was annoying	12.5	7.7	9.5
PMD was hard to use	0	15.4	9.5

Pedestrian-PMD Interactions

PMD rider experiences with pedestrians were largely positive, with one third of riders never experiencing difficulties with pedestrians, and sixty percent only occasionally experiencing difficulties. Indeed, for almost all riders, interacting with others on shared paths was considered easy. This was more so for two-wheeled device than three-wheeled device riders (see Table 6 below). A certain level of frustration with sharing was evident with the three-wheeled device, presumably because of its larger size and weight.

Table 6: Riders' perceptions of interactions with pedestrians

	Two-wheeled device (%)	Three-wheeled device (%)	All (%)
Easy	92.3	50	86.7
Difficult	0	0	0
Frustrating	7.7	50	13.3

Riders' blog comments such as those below confirm these findings:

- *Pedestrians seem to be reasonably comfortable with two-wheeled device around. When they hear the sound of the bell/engine, they move to one side.*
- *I do reasonably well at weaving through pedestrians (two-wheeled device Rider).*

Several comments were made in regards to the devices attracting positive attention and three-wheeled device riders commented that pedestrians were more aware of its presence than the two-wheeled device, facilitating the ease of pedestrians moving out of the way.

- *There has been far more pedestrian/staff interaction with this device, but still, I've found it generally positive …The sound of it coming definitely helps with people being aware of it too (three-wheeled device rider).*

When asked to identify common problems experienced riding on campus, the most frequently identified problem was pedestrians (25 percent of problems identified). When asked to expand, problems included navigating around pedestrians when the path was crowded and pedestrians being unaware, unresponsive or distracted, as evident in the blog comments below.

- *Pedestrians are even more unpredictable than I expected - stopping suddenly, ignoring bells, etc (two-wheeled device Rider).*
- *I had one pedestrian texting on the phone that walked straight into me. I had slowed in general anticipation and eventually came to an abrupt halt … it's still hard to look into the faces to read expressions while also riding and anticipating walkers (two-wheeled device Rider).*

There was also one incident reported on a three-wheeled device due to the rider's attempt to give way to pedestrians on a narrow path. The rider lost balance when applying the brakes, ran a couple of steps then fell on the road resulting in minor scrapes and bruises.

Objective information from the video confirmed these subjective impressions (see Table 7). Of the 130 instances of PMD use captured on video, pedestrians were present on 104 occasions (87%). Overall, there was harmony between PMD riders and pedestrians as they passed each other. The majority (79%) of the time PMDs did not have to alter their direction, slow down or brake for pedestrians. Neither did pedestrians need to move out of the way (90% of the time). Even during times of significant crowding of 10-15 people in the proximity of a PMD, both the PMD and pedestrians appeared to seamlessly anticipate and navigate around each other. On five occasions the rider was observed to disembark in order to be cautious of oncoming pedestrians. The instances where pedestrians had to move out of the way were highest for the three-wheeled device (15%).

Table 7: PMD-Pedestrian Interactions

	Two-wheeled device (n=71)	Three-wheeled device (n=48)	All (n=119)
Pedestrians present	63	41	104
PMD rider changed course	15	7	22
Pedestrian(s) changed course	3	4	7
Both pedestrian and PMD rider changed course	2	3	5

Neither PMD nor pedestrian rider changed course	43	27	70

Concluding comments

PMDs are certainly a novel (and sometimes fun) form of transport has found that in specific environments users adopt small motorised devices as a means of getting to destinations more quickly than walking. This study, though small and exploratory in nature, has found that the barriers to the uptake of PMDs as a sustainable transport option are far from insurmountable. With controlled use in a real world setting, PMDs are perceived to be easy to use and valued for their ability to deliver people to destinations more quickly than walking. This study hence provides important lessons for policy makers concerned with the appropriate regulations and infrastructures for the general class of small, motorised devices. Principal here is minimizing weight given existing road and path infrastructure will almost certainly necessitate carrying or lifting the device at some stage. Another important consideration is ensuring that PMDs have adequate power to ascending ramps and other inclines, while limiting their speed. PMD users should not expect, or be permitted, to travel at speeds much greater that those of pedestrians. This means a maximum speed on open footpaths of 10 km/h, and a maximum speed of 5 km/h for areas where pedestrians are present (and 3 or 4 km/h is preferable as a 'tortoise mode' speed in busy areas of pedestrian movement) [1].

The design of the PMDs is an issue, as there is concern that human factors not fully taken into account with these devices (e.g., the weight and associated portability of the devices, as well as the width of foot plates, small diameter and narrow wheels, lack of a speedometer, lack of speed limiting, lack of storage provision and access to battery charging). Overall, the usability of all PMDs is compromised by the weight of the devices, their portability (particularly when used in conjunction with public transport), provision for parking and storage, and difficulties in performance with hill climbs and descents. That said, while PMD use is illegal for road use in Australia currently, these devices are largely compatible with existing road and pedestrian infrastructure (especially for the lighter and narrower devices).

Legal restrictions prevented the research from assessing PMD ability to bridge first and last mile distances. Nonetheless, the project tested PMDs in an authentic setting, with a focus on their acceptability and perception to those riding them (‘riders’), and their interactions with pedestrians. Subsequently, agreement has been reached for a Stage 2 extension into the Macquarie Park business precinct for further real-world trials within a fully functional road transport system. Lightweight, two-wheeled scooters are most appropriate from the perspective of riders, pedestrians and sustainable transport, and their functional use in bridging first and last mile distances will be an important consideration.

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