Comparative Tricycle Study: Results of Field Tests

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Abstract

This report presents the results of field test of seven tricycles organized in Yogyakarta, Indonesia, from December 9, 2013, through May 2, 2014. The tricycles were chosen based on those that are currently being used in less resource settings namely: APDK (Kenya), ALIMCO (India), Kien Tuong (Vietnam), Light Foot (USA), Motivation (UK), PET (USA) and Whirlwind (USA). The devices were first compared against each other on set criteria. This was followed by various performance tests (e.g. drive and maneuverability tests on rough versus paved road, turning, rolling resistance etc.). The participants (N=18), were then allowed to take the tricycles for the home trials. A focus group was conducted as a final step of the evaluation to obtain general feedback about the tricycles. The tricycles that satisfied majority of the users criteria were the devices by Lightfoot (USA), Motivation (UK), Whirlwind (USA) and PET (USA), with the Lightfoot device showing strongest performance in many tests. Overall the users rated the tricycle by ALIMCO (India) as having the poorest performance. The summarized results from this report will be disseminated to relevant stakeholders to aid in advancing technology design and thereby ultimately improve mobility aids for people with disabilities particularly in rural settings.

Executive Summary of Comparative Tricycle Study: Results of Field Tests

This report presents the results of a field test of tricycles organized in Yogyakarta, Indonesia, from December 9, 2013, through May 2, 2014.

Introduction

Background

A field test of seven manual tricycles was organised at UCPRUK in Yogyakarta, Indonesia. The aim of this test is to assess the function of the tricycles and assess the feedback from people with disability. Eighteen people with various abilities volunteered to participate in several performance tests and in an at-home test.

The aim of this report is to present the results of the tricycle test.

Protocol and Content of the Test

The test examined seven tricycles currently used in developing countries, six of them are already manufactured and distributed and one of them was a prototype. An experienced wheelchair product designer, who has significant experience with projects in developing countries and has managed several performance tests, developed the protocol. The protocol called for a bench test, track trials, user interviews, and focus groups. A biomechanical engineer and a social worker organized the implementation of the protocol.

Limits of This Tricycle Field-Test Methodology

There are limits on the protocol and implementation of this tricycle field test including: not all wheelchair user groups or ability groups were represented, not all user environments were tested, tricycles were not always set up with optimum fitting for users, and data was gathered over a period of months.

We recognize the limits on the protocol. However, we strongly believe that the users provided excellent, open and critical feedback that produced an informative overview of the function of the tricycles for the Indonesian rural context.

Participants

Users Test Group Population

Eighteen users joined the test, eleven men and seven women. The average and median age was 38 years old, ranging from 13 to 72 years. The users' median and average body weight was 50 kg, ranging from 25 to 78 kg. Two of the users are regular wheelchair users. The diagnosis of the users:

- 9 Post-Polio,
- 5 Cerebral Palsy (CP),

- 2 Amputees,
- 1 Paralysis post bone tuberculosis,
- 1 Post-fracture.

Justification of the Disability Selection for the Test

A review of the wheelchair users who received a wheelchair from UCPRUK shows that the majority of disability is due to CP and Polio. This supports the preponderance of users with CP and Post-Polio in the protocol, though with a different proportion. Paraplegic users were not included in the protocol. This is due to the severity of their impairments, which makes use of several tricycles impractical. No stroke survivors were included, however they represent up to 10% of the population.

Tricycles

Ref	***Model***	***Organization***	***Country***
APDK	APDK	APDK	Kenya
IS	Indian Standard	ALIMCO	India
KT	Kien Tuong	KT	Vietnam
LF	Light Foot	Light Foot	USA
MOT	Motivation	Motivation	United Kingdom
PET	PET	PET	USA
WW	Whirlwind	Whirlwind	USA

Bench Test

The Bench Test consists of recording the main technical characteristics of each tricycle and their functions.

Tricycle Characteristics

- Drive mechanism
- Wheel
- Chassis
- Cargo area
- Rider protection accessories

Braking Mechanism

The braking mechanism architecture (both stop and parking brakes) for all seven tricycles were studied and documented.

Rolling Resistance Protocol

The rolling resistance test was performed on two tracks: paved flat track and sand track.

The tricycle was allowed to coast down the test ramp and the **distance to stop** was measured. A test driver performed the test driver three times for each tricycle and the results were averaged for each tricycle.

Preparation of the Tricycle

As wear on bearings and tires can impact the rolling resistance performance and because this test was organized after other performance tests, it was decided to use a new tricycle as much as possible. We recognize that this was not possible for all models.

Conclusion on Rolling Resistance Test

- The Light Foot, Motivation and Indian Standard tricycles have the best rolling distance on a flat paved track.
- Whirlwind, Indian Standard, Motivation & Light Foot have the best rolling distance on a sand track.
- The PET tricycle has the worst rolling resistance on both tracks.
- Pneumatic tires have less rolling resistance (and longer rolling distance) and perform better than solid tires.
- Large diameter wheels have less rolling resistance and longer rolling distance.
- Pneumatic tires are also preferred for maintenance and availability of replacement parts.

Static stability test

The static stability test was based on the standard for wheelchair (ISO 7176-1 1999).

- The Stability Bench Test uses a flat plane, with 2 pivots fixed on the floor.
- The inclination is determined by measuring the height of the tangent of the plane.
- The error of inclination measurement is +/- 2°.
- The Stability Bench test was installed at the UCPRUK workshop.

Conclusion on Stability Test for Tricycles

- The APDK tricycle has the worst sideways stability.
- The Indian Standard tricycle has the best rearward stability and good sideways stability.
- The Kien Tuong tricycle's stability ranks in middle of the others.

- The Light Foot tricycle has the 2nd best backward stability and the 2nd worst sideways stability.
- The Motivation tricycle has the 2nd best sideways stability and the 2nd worst rearward stability.
- The PET tricycle stability is above the average for both in all directions.
- The Whirlwind tricycle prototype has the best sideways stability and the worst rearward stability.

Conclusion on Stability Test for Generic Tricycle Architecture

- The rearward static stability of the tricycles in this study is similar to wheelchairs.
- Due to vehicle architecture, a wheelie is more difficult to control on a tricycle when compared to a wheelchair.
- Rear wheel position and seat position effect ability or risk of wheelie. It is important to choose appropriate configuration.
- Sideways static stability of a tricycle is critical for safe use.
- The stability of a three wheel vehicle is more sensitive than a four wheel vehicle.
- Falling from a tricycle may be more difficult to control and more harmful to the user when compared to falling from a wheelchair.

Performance Test 0: Transfer and "Preflight Check List"

The posture assessment of the Physiotherapists, the tricycle's ergonomics and ability to be adjusted to fit a wide range of users is detailed in the report [UCPRUK/RD/2014/062].

There is a substantial difference in the ergonomic features between different tricycles.

- Can be adjusted at assembly: Motivation, Light Foot.
- Can be adjusted after assembly: Whirlwind, Kien Tuong.
- The APDK tricycle is available in 3 sizes, each of which are fixed and do not offer additional adjustability.
- Cannot be adjusted: Indian Standard, PET.

Performance Test 1: Track Test Results

To assess the performance on different tracks, the following tests were conducted:

- Paved road, 50 meters straight road,
- Firm level ground, 50 meters road with stones and bumps,
- Soft uneven ground, 20 meters of sandy, straight path,
- Paved hill: 12 meter course on small hill.

Conclusion of the Track Test Results

- The Light Foot tricycle performed the fastest on most of the track tests.
- The Light Foot tricycle is has an advantage due to low weight and a design that allows the user to sit in an effective posture for pedaling. Probably, performance is

improved because the user has the option of selecting the best gear ratio for the terrain.
- A higher gear ratio is an advantage for reaching a high speed on flat straight track.
- The PET has the worst performance. It is at a disadvantage because of low gear ratio and a heavier weight.

Performance Test 2: Maneuvers results

This part evaluation consisted on of assessing the maneuverability among on the following tests:
- A fast slalom "swerve", to test the ability to avoid an obstacle at regular speed,
- A slow slalom "market place", to test the ability to move around obstacles,
- A forward-backward U-turn, to test the space required to make a 180 degree turn,
- An interview with users on to collect feedback on maneuverability after the tests.

The final result was the median time of all the tests performed by the 18 users.

Conclusion on Maneuverability Test Results

- The **Light Foot** tricycle performed the best on the fast slalom "swerve", whatever it has a tendency to tip over.
- The **PET** tricycle performed the best at the slow "market" slalom, due to its small wheelbase and a low gear ratio.
- The **Motivation** tricycle performed the best during the forward-backward U-turn, due to a small track-width and a high range of steering motion.
- The **Whirlwind** tricycle has a good turning capability and good lateral stability, but a high drive ratio was a disadvantage on the slow slalom.
- The **Kien Tuong** tricycle has a poor turning capability and low range of steering motion, which caused poor performance on the slalom test.
- The **Motivation** tricycle was preferred during this maneuvering test.
- The **Indian Standard** tricycle was the least preferred and the poorest performing during the tests.

Performance Test 2e: Braking results

The tricycle braking test was performed using the following tests:
- Braking Ability - This test consists of performing three fast braking stops at low speed. The time is recorded and averaged for each user.
- Brake preference questionnaire – This test analyzed the brake architectural preferences by the users
- Braking Distance - The test driver, weighing 60 kg, goes down a ramp with the height of 0.7 m. The driver applies the brake when passing a line, which is 3 m after the end of the ramp. The test is performed three times and the results are averaged.

Conclusion on the Braking Test

- The users preferred to have the following brake architecture: one bicycle type lever for the stop brake, installed at the direction handle, and a separate parking brake lever.
- The Motivation tricycle has the best braking architecture and the best performance review for the users. Kien Tuong and Light Foot were also appreciated. Only Motivation and Kien Tuong possess the architecture preferred by the users.
- The APDK has the least preferred architecture, it has only one brake on the left rear wheel, and it is used for both stopping and parking.
- The APDK and Light Foot performed the best braking distance to stop. Their short braking distance is probably due to their low weight and the comparably high friction of the brake pad on a knobby tire.
- The Whirlwind has the third best braking distance favored by a braking system activating the two rear wheels.
- The Kien Tuong's parking brake performed better than the front stop brake.
- No data was collected for the Indian Standard tricycle because the brake mechanism broke repeatedly during testing.

Performance Test 3: Cargo Results

The main purpose of the cargo capacity of a tricycle is to carry goods and possibly to facilitate income generation.

From the seven tricycles tested, the cargo feature can be classified as:

- Four tricycles include a cargo capacity (APDK, Light Foot, PET, and Whirlwind).
- One (Kien Tuong) included a small platform, which could not carry the test load, a bag of cement.
- Two of them were not designed with a cargo function (Indian Standard and Motivation).
- The Whirlwind cargo prototype includes a central cargo below the seat and an optional front rack, which was not tested.

Summary of the Cargo Test Protocol

For the cargo evaluation, the tests were conducted in two villages with a 40 kg cement load, as complement of Track Test 1b (50 meters firm level ground) and 1c (20 meters soft uneven ground). The time required to complete the test track was measured for each user on each tricycle. The outcome measure "Payload Time" was calculated by subtracting the time required without cargo from the time required with cargo. "Payload Time" considered the performance degradation due to the cargo load. The final result presented is the median time of all the users.

Conclusion of the Cargo Test

- The Light Foot has the best timing performance with a 40 kg load during the village test.
- The good rolling resistance of this tricycle is an asset.

- The tricycle that performed the worst is the PET.
- The bad rolling resistance gets worse with the load being carried.
- The Light Foot's cargo carrying ability was most preferred by users.
- Users prefer a "Cargo Box" design with strong walls without holes and possibly a cover to protect goods from rain.
- Users noted the need to carry children, assistive devices like crutches, and goods to sell, farming tools, and various materials.
- Cargo capacity serves an important function and is a requirement for people with disabilities

Test 4: User interview results

Methodology of the Interview

The users completed a questionnaire to assess different functions after the test. The questionnaire was answered one month after the performance test and from one to three weeks after the end of the track and the brake test.

Each user was requested for a specific criterion to rank each tricycle, from 1 as the most preferred to 7 being the least preferred. The final score is the addition of all the rank. Therefore, the highest score is the least preferred. The questionnaires were completely answered by seventeen users.

Summary of User's Preference Results

Test	Feature	Users	Preference	Comment
4.9	Overall preference	17	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	Light Foot is the most preferred for each function but 2. This tricycle is the most preferred by 7 users. Indian Standard ranked last place.
4.1	Transferring	17	1/ Light Foot 2/ Motivation 3/ PET	The easiest type of tricycle to transfer into is the cargo type that has a large seat. On Light Foot and PET, it is possible to transfer while keeping feet on the ground.
4.2	For paved road	17	1/ Light foot 2/ Motivation 3/ Whirlwind; Kien Tuong	Light Foot is the most preferred and it also had the best time on test 1a. Rankings of the others did not necessarily follow the order of times on test 1a.
4.3	For market	17	1/ PET 2/ Light Foot 3/ Motivation	PET is the 1st preferred for the market place, which reflects its good performance on test 2b. The users appreciate the easy maneuverability of Light Foot and Motivation.
4.4	For use on road with a hill	17	1/ Light Foot 2/ PET 3/ Kien Tuong 4/ WW; MOT	Light Foot is again preferred. PET, KT, WW, and MOT were tied.
4.5	For use off road	17	1/ Light Foot 2/ PET 3/ Whirlwind 4/ Kien Tuong	Light Foot is considered the most appropriate for off-road. PET has a good position, which is not correlated with its performance test. The users noted the PET's tires which do not have the risk of going flat.
4.6 4.7	For heavy cargo For volume cargo	17	1/ Light Foot 2/ PET 3/ Whirlwind	Light Foot is preferred. The "Cargo Box" type is preferred.
4.8	Best appearance	17	1/ Motivation 2/ Whirlwind 3/ Kien Tuong	The Motivation tricycle is considered to have the best appearance. This product is mass-produced in a factory. Motivation, WW, and KT have a steel frame with a good power coating finish.

Test 5: Preference by Users Specificities Results

Methodology of the User's Specificities Analysis

The results of the interview overall preference was used to determine the preference of each category of Users. The following comparisons were studied:

- Men and women,
- Impairment,
- Type of assistive device used.

Summary of the Users' Preference by Disability and Group

Test	Users specificities	Users	Preference	Comments
5.1	Men	10	1/ Light Foot 2/ Whirlwind 3/ Motivation	There is difference of choice between men and women.
5.2	Women	7	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	One strong demand for women was the presence of a cargo.
Test	**Users specificities**	**Users**	**Preference**	**Comments**
5.3	Post-Polio users	9	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	
5.4	Cerebral Palsy users	4	1/ Light Foot 2/ Kien Tuong 3/ Whirlwind	
5.5	Amputee users	2	1/ Light Foot 2/ Whirlwind 3/ Motivation	
5.6	Post-fracture user	1	1/ Motivation 2/ APDK 3/ PET	
5.7	Paralysis Bone tuberculosis	1	1/ Light Foot 2/ Motivation 3/ PET	
5.8	Users without Assistive Devices	8	1/ Light Foot 2/ Whirlwind 3/ APDK	
5.9	Crutch users	4	1/ Light Foot Whirlwind 3/ Kien Tuong	Users need a way to transport their crutch. It can be stored in the cargo or maybe on the floor, or clamped near the seat.

5.10	Cane & Forearm crutch users	2	1/ KT 2/ Light Foot 3/ APDK	Idem crutch users.
5.11	Wheelchair users	2	1/ *tie* Light Foot Motivation Whirlwind	Light Foot is still appreciated. Two of the most preferred tricycles are the Whirlwind and Motivation one. Both are designed by wheelchair specialists, one is based on a wheelchair. Both have push rims. Wheelchair users are therefore confortable with theses two tricycles.
5.12	KAFO user	1	1/ Light Foot 2/ Whirlwind 3/ APDK	

Focus Group Results

Principle of the Focus Group

The final test of the evaluation was a focus group interview, within three groups of five to seven users. Users were asked to report the advantages and disadvantages of each tricycle and to describe the recommended use. Users were also asked about their expectations of a tricycle.

General Outcomes on Manual Tricycle

- The tricycle is considered to reduce time of travel (compared to other orthopedic devices),
- Tricycle is convenient mode of travel in the villages and the neighborhood,
- Tricycle is not a convenient mode to travel on a hilly road,
- Users plan to use manual tricycle for distances from 0 to 5 km,
- Above 5 km, users would rather use a motorized vehicle, preferably a motorcycle.

Appropriate accessories users would like to possess on a tricycle are:

- Push rim,
- Bell,
- Fluorescent mark for night travel.

Recommendations to the Tricycle Builders

Based on the test results, the positive features and recommendations will be provided to all involved manufacturers of tricycles.

APDK

Positive Features
+ Three sizes of this tricycle are available for the users,
+ Device has good manoeuvrability on a slow slalom and during a U-turn,
+ Device has good performance on uneven road and on a soft uneven road,
+ Device has a small cargo box.

Recommendations
=> Improve the front wheel geometry to make the front wheel more stabile,
=> Add a cover on the sprocket to protect the user's hands.

Suggestion
=> Study the implementation of brakes on other devices

Indian Standard

Positive features
+ Industry has a long history of implementing national standard since 1976,
+ Device has good static stability of this tricycle, both rearward and sideways,
+ Device has good rolling resistance.

Recommendations
=> In design, consider ergonomic and biomechanical criteria,
=> Consider the variation of user's body sizes and the need for size adjustability,
=> Improve the ease of transfer by removing obstacles,
=> Add a cushion (based on technical requirements of Indian Standards),
=> Check the mechanical resistance of the brake (based on technical requirements of Indian Standards)

Kien Tuong

Positive Features
+ Good overall architecture, appearance, and finish,
+ Good ergonomics of the steering handle combined with the propelling lever,
+ Brakes system includes both a stop brake at the steering wheel and an effective parking brake on the rear wheels,
+ Roof feature is appreciated by users for protection from sun and rain.

Recommendation
=> Improve the set up of the drum brake at the front wheel.

Suggestions
=> Installation of a push rim on the rear wheels to make maneuvering and staring easier for users,
=> Improve the cargo capacity with a closed box to transport goods.

Light Foot

Positive Features
+ The device has good overall performance, for all kind of roads, and small spaces,
+ The device has good performance on various kinds of surfaces,
+ Users appreciated the cargo box capacity and the box's architecture,
+ The footrest has good range of adjustment,
+ The gear change function allows the user to select the most appropriate gear ratio for the current terrain,
+ The device has ample and unobstructed access to the seat while transferring,
+ The test users preferred the tricycle,
+ The tricycle has good rearward static stability (without cargo load),
+ The tricycle has good rolling resistance.

Recommendations
=> Improve the lateral stability (track width, position of the center of gravity),
=> Assess the strength of the seat according to ISO 7176-8:1998,
=> For the seat and cargo feature, specify materials that are water resistant,
=> Improve the seat fitting range,
=> Improve the finishing and appearance to enhance the user's perceived value of the device.

Motivation

Positive Features
+ The tricycle has an excellent and robust overall design and appearance,
+ The tricycle has a good range of fitting, seat adjustability range, and postural support,
+ The tricycle includes a good cushion,
+ The footrest has good range of adjustment,
+ The combination of the steering handle, pedal and brake lever offers good ergonomics,
+ The push rim is useful for the user when propelling on a rough road or hill,
+ This tricycle product (based on a wheelchair) is CE marked. The manufacturer states that the tricycle conforms to the standards ISO 7176, ISO 13485 and ISO 9001 (not verified),
+ The tricycle has good static sideway stability,
+ The tricycle has good turning capacity in a limited space,

+ The tricycle has good rolling resistance,
+ The front wheel has a lock function.

Suggestion
=> Consider including a cargo box, which is preferred by users.

PET

Positive Features
+ The tricycle has a large volume cargo capacity,
+ Turning radius is small and allows use in tight spaces,
+ The tricycle can be used indoors or in a workshop to carry goods,
+ The tricycle has reflectors that help with nighttime safety.

Recommendations
=> Consider multiple sizes to fit a wider range of users (small, medium, large),
=> Implement a free wheel to improve safer for the user,
=> Investigate the availability of spare wheels in the destination countries. Possibly, a different wheel will improve rolling resistance performance and repair-ability,
=> Consider different frame material to decrease weight.

Suggestions
=> Consider the appropriateness of the current range of colors for the cultural preferences in the destination countries,
=> Check the water resistance of the wood paint.

Whirlwind

Positive Features
+ The device has excellent sideways static stability,
+ The device has good range of fitting: Seat adjustability range, and postural support,
+ The device includes a cushion,
+ The device includes a push rim feature,
+ The device has good rolling resistance,
+ The device has good braking capacity on both rear wheels,
+ The device has good overall appearance,
+ The device has good performance over longer distances (cruising speed).

Recommendation
=> Improve rearward stability.

Suggestions
=> Investigate implementation of a front brake and front brake lever,
=> For the cargo area, users prefer a box with walls to hold cargo in place.

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Abbreviations

Abbreviation	*Definition*
IDR	Indonesian Rupiah
USD	US Dollars
BT	Bench Test
APDK	The Association for the Physically Disabled of Kenya
IS	Indian Standard
KT	Kien Tuong
LT	Light Foot
MOT	Motivation
PET	Personal Energy Transportation
WW	Whirlwind Wheelchair
AD	Assistive Devices
CP	Cerebral Palsy
KAFO	Knee Ankle Foot Orthosis
UCPRUK	United Cerebral Palsy Roda Untuk Kemanusiaan

1 Introduction

1.1 Background

A field test of seven manual tricycles, which were diverse in design, was organised at UCPRUK in Yogyakarta, Indonesia. The aim of this study was to evaluate the function of the tricycles and assess the feedback from people with disabilities. The trials took place in communities surrounding Yogyakarta, Indonesia. The aim of this report is to present the results of comparative tests of several tricycles used in developing countries.

1.2 Protocol and Content of the Test

The test examined seven tricycles currently used in developing countries, six of them are already manufactured and distributed and one of them was a prototype.

The protocol consisted of the following trials[1]:

Bench Tests: Devices were measured against defined criteria (weight, length, etc.)

Track Trials: Devices were used in an artificial "test track" simulating environment of use. During the track trials performance was measured objectively (stopwatch, heart rate monitor, etc.) and subjectively (interviews). The track trial was performed before the home trials to familiarise the users with the devices. The protocol was then repeated after the home trials as well just prior to the focus group, to help refresh the riders' memory of all the devices.

1. **Home Trials**: Users used the tricycles in their homes and communities for approximately one week. During the home trials performance was measured subjectively by interview.
2. **Focus group**: At the end of the trials allowed the riders to share experience and elicit qualitative feedback.

1.3 Limits of this Tricycle Field Test Methodology

Limitation of the protocol are listed below:

- The size of the study group, which is always a limitation, was limited to eighteen users,
- Paraplegic wheelchair users were not included in this study,
- Wheelchair users in this evaluation were under represented, only two are daily wheelchair users, one is an occasional wheelchair user,
- Urban environments were not assessed, all users live in rural areas,
- Reliability and long term endurance of the tricycle was not part of the study,

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[1] Yogyakarta Tricycle Trial Protocol. [UCPRUK/RD/2013/001]

Protocol implementation of the tricycle user field test at Yogyakarta. [UCPRUK/RD/2014/042]

- Rough road, muddy, stone, and thin sand was not fully assessed,
- The tests and measurements were taken over a period during which some conditions changed,
- There is dispersion on the timing of measurements,
- The tricycles were not fitted to each individual users,
- The availability of replacement parts for repair was not assessed,
- The users performed the performance tests without a warm-up period.
- Also, the users' energy level could change toward the end of test periods on a given day when the outside temperature increased.

Although there were several limitations we however strongly believe that the users provided excellent, open and critical feedback. This resulted in an informative overview of the function of the tricycles for the Indonesian rural context that could be translated to other less resource settings.

2 Participants

2.1 Users in the Test Group

Eighteen users, eleven men and seven women, participated in the trial. The average and the median age was 38 years old, ranging from 13 to 72 years (as of 28/02/2014). The users' average and median body weight was 50 kg, ranging from 25 to 78 kg.

A summary of the diagnosis of the users is below[2]:

- 9 Post-Polio,
- 5 Cerebral Palsy (CP),
- Amputees,
- 1 Paralysis post bone tuberculosis,
- 1 Post-fracture.

2.2 General Statistics of People with Disabilities in Indonesia

Based on a recent distribution of wheelchairs by UCP in January 2014, we found the following breakdown of disabilities among wheelchair users[3] :

- 45.9 % had Cerebral Palsy,
- 14.9 % were Post-Polio,
- 11.5 % experienced a stroke,
- 11.5 % were paraplegic.

Among the smallest categories were:

- 1.3 % were post fracture,
- 1.3 % were paraplegic due to tuberculosis of the bones,
- 13.7% concerned others cases.

2.3 Justification of the Disability Selection for the Test

A review of the wheelchair users who received a wheelchair from UCPRUK shows that the majority of disability is due to CP and Polio. This supports the preponderance of users with CP and Post-Polio in the protocol, though with a different proportion. Paraplegic users were not included in the protocol. This is due to the severity of their impairments, which makes use of several tricycles impractical. No stroke survivors were included, however they represent up to 10% of the population

[2] Details of participants' characteristics (Table 1, UCPRUK/RD/2014/042).

[3] Data on Disability, January 2014. [UCPRUK/RD/2014/059]

3 Tricycles

3.1 Tricycles Tested

Table 1: List of the tricycles tested

Ref	*Model*	*Organization*	*Country*	*Production Plant*	*Production Country*	*Web Site*
APDK	APDK	APDK	Kenya	Unity Metro Product	Kenya	http://www.apdk.org
IS	Indian Standard	ALIMCO	India	Laxmi industries	India	http://www.laxmiindustriesindore.com
KT	Kien Tuong	Kien Tuong	Vietnam	Kien Tuong Factory	Ho Chi- Ming	http://www.kientuong.net
LF	Light Foot	Light Foot	USA		USA	http://www.lightfootcycles.com
MOT	Motivation	Motivation	United Kingdom		China	http://www.motivation.org.uk
PET	PET	PET	Canada		USA	http://petinternational.org
WW	Whirlwind	Whirlwind	US	N/A, prototype	Vietnam	http://www.whirlwindwheelchair.org

3.2 Tricycle Selection

The choice of tricycles was based on current usage in developing countries. The APDK tricycle is produced in Kenya, and is available in eastern Africa (Øderud 2006). The Indian Standard tricycle has been defined as the normalized tricycle by Indian law (Indian Standard IS 8088 1976). This assistive device is manufactured and distributed in India by ALIMCO (Agarwal et al. 1990). The KT tricycle by Kien Tuong is produced and distributed in Vietnam (McCambridge 2006). Motivation is an organization, which has designed various wheelchairs for developing countries, has distributed products worldwide, and has developed wheelchair service training on proper fitting. Motivation's tricycle is based on their three-wheeled wheelchair, which is adapted with Motivation's Clip-On front wheel drive. (Constantine 2006). Whirlwind has developed various wheelchairs for developing world, their latest model is the RoughRider™ (Hotchkiss 2006). This model is distributed in various countries, including Indonesia. During the study, a tricycle was in development process. Prototypes were provided for this field test. The Light Foot is produced by Light Foot in USA. The organization Personal Energy Transportation (PET) produces tricycles that are distributed to many countries in the developing world. Such donation has been reported in Tanzania (Winter 2005). Other products exist, but this selection is considered to be representative of the existing technology used in developing world.

3.3 Tricycles Overview

Figure 1: APDK

Figure 2: Indian Standard

Figure 3: Kien Tuong

Figure 4: Light Foot

Figure 5: Motivation

Figure 6: PET

Figure 7: Whirlwind

4 Bench Test

4.1 Bench Test Tricycle Characteristics

The Bench Test (BT) consists of recording the main technical characteristics of each tricycle and their functions. [4]

- Drive mechanism
- Wheel
- Chassis
- Cargo area
- Rider protection accessories
- Braking mechanism (discussed in detail in section 4.2)

[4] Tricycle Bench Test Measurement & Data processing. [UCPRUK/RD/2014/054]

4.2 Braking Mechanism

	Stop Brake				***Parking Brake***		
Tricycle	***Brake Location***	***Mechanism***	***Lever type***	***Lever location***	***Brake Location***	***Mechanism***	***Lever Type***
APDK	Left rear wheel	Stop lever; Wheelchair type	Long pulling lever	Rear wheel	Same as stop brake	Lever has hook locks to frame	Long pulling lever
Indian Standard	Front wheel	Bicycle type; Caliper on rim	Long pushing	On steering	No parking brake		
Kien Tuong	Front wheel	Bicycle type, drum brake	Bicycle type	Under steering wheel	Two, one on each rear wheel; Independent	Wheelchair type with long lever	Long pushing lever
Light Foot	Front wheel	Lever pad on tire	Pushing lever	Combined with direction under pedal	No parking brake		
Motivation	Front wheel	Bicycle type; caliper on rim	Bicycle type	On steering handle	Two, one on each rear wheel; Independent	Wheelchair type, with connecting rod locking mechanism	Short pushing lever
PET	Front wheel	Lever pad on tire	Pushing lever	Combined with steering	One on right rear wheel	Wedge between the tire and frame	Not applicable (Mobile wedge)
Whirlwind	Two, one on each rear wheel	Lever pad on tire	2 long pulling levers	2 pulling levers connected by an axle	Combined with stop brake	Connecting rod lock mechanism on left lever	Two pulling levers connected by an axle

4.3 Bench Test a: Rolling Resistance

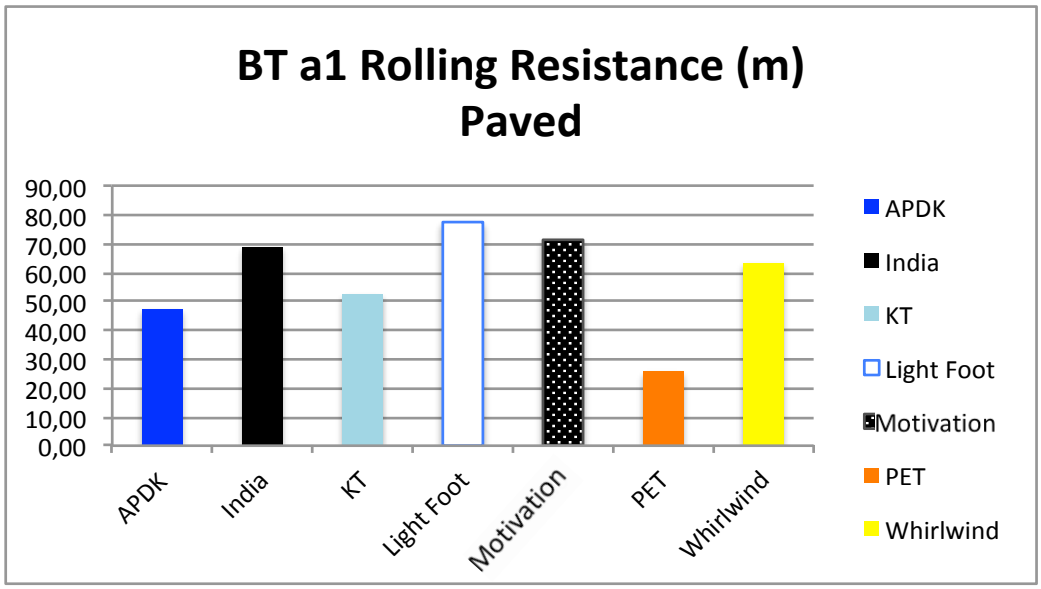
Protocol

The rolling resistance test was performed on two tracks: paved flat track and sand track. The tricycle was allowed to coast down the test ramp and the **distance to stop** was measured. A test driver performed the test driver three times for each tricycle and the results were averaged for each tricycle.

Preparation of the Tricycle Test

The rolling resistance protocol was conducted after the other performance tests. Since wear on bearings and tires impact the rolling resistance, an effort was made to use a new tricycles whenever possible. However this was not possible for all models. New tricycles were arranged for Motivation, Kien Tuong and PET. Whirlwind's tricycle was prepared with clean ball bearings on the rear wheels. The Light Foot tricycle had only light use and was not used during the performance test. Due to the lack of spare parts, the Indian Standard and APDK tricycles had been previously used during the performance tests. It was not possible to prepare these with new bearings or tires.

Results [5]



[5] Data processing details: Test BT (a) Tricycle Bench Test Results, Rolling Resistance. [UCPRUK/RD/2014/027].

Figure 8: Test BT-a1, Rolling resistance on paved track. Average distance to stop is shown in meters (m). High distance (m) means better performance of tires.

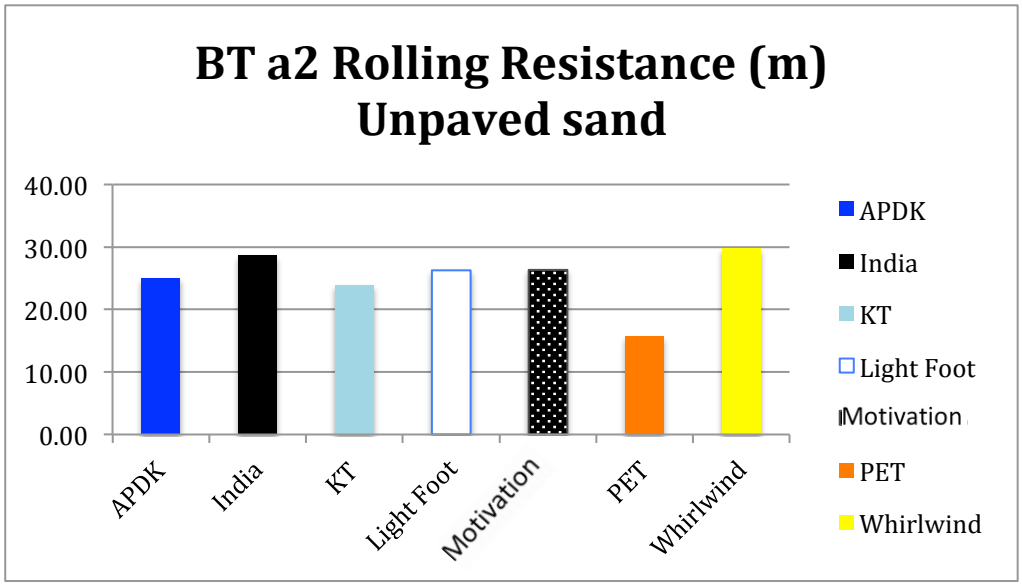


Figure 9: Test BT-a2, Rolling resistance on unpaved sand track. Average distance to stop is shown in meters (m). Highest distance (m) is best.

Rolling Resistance Results

The distance required for the tricycles to stop ranged from 25.7 m to 77.5 m on the flat paved track, and from 15.8 m to 29.8 m on the sand track. On the paved track, the Light Foot tricycle performed the best (77.5 m), followed by Motivation and Indian Standard (71.4 and 68.9 m respectively). On the sand track, the Whirlwind tricycle performed the best (29.8 m), followed by the Indian Standard (28.7 m). The Light Foot and Motivation tricycles placed 3rd with equivalent results (26.3 m). The PET performed the poorest rolling resistance (25.7 m on paved, 15.3 m on sand).

Impact of the Wheel Technology

Most tricycles use wheels, bearings and tires that are standard parts from the bicycle industry. These components influence the rolling resistance. A solid tire has more rolling resistance than a pneumatic tire, according to existing studies (Gordon, Kauzlarich, and Thacker 1989) (Kwarciak et al. 2009) (Sauret et al. 2012). On this test comparison the advantage of pneumatic tires is confirmed. The diameter of the wheel impacts the rolling resistance. Rolling resistance

tends to decrease when the wheel diameter increases. A smaller diameter wheel has higher rolling resistance than a higher diameter wheel (Sauret et al. 2012).

Air pressure of pneumatic tires impacts rolling resistance. An increase in pressure reduces rolling resistance and increases rolling distance. All tricycles were inflated with the maximum recommended pressure before the test. However, in normal use conditions on field, we expect that the pressure will be lower than maximum pressure recommended. The rolling resistance force of the tire increases as additional weight is applied to the axle (Gordon, Kauzlarich, and Thacker 1989). Therefore, the heavier the tricycle is, the higher the rolling resistance. Additionally, although it was not assessed, quality of ball bearing influences rolling resistance.

Table 2: Factors impacting the rolling resistance of wheels

Factors	***Variation***	***Rolling resistance (Force)***	***Cost down Distance to stop***	***Reference***
Pneumatic tire	***	Decrease	Increase	(Gordon 1989) (Kwarciak 2009)
Solid-airless tire	***	Increase	Decrease	(Sauret 2012)
Tire pressure	Increase	Decrease	Increase	(Sauret 2012)
Tire pressure	Decrease	Increase	Decrease	
Wheel diameter	Increase	Decrease	Increase	(Sauret 2012)
Wheel diameter	Decrease	Increase	Decrease	
Load applied	Decrease	Decrease	Increase	(Gordon 1989)
Load applied	Increase	Increase	Decrease	

PET

The PET is the only tricycle using a plain polymer tire. It has also the widest profile tire, and the smallest wheel diameter. These factors explain the high rolling resistance, and the short distance to coast-down measured on this tricycle.

Light Foot

The Light Foot tricycle performed the best rolling distance on the flat paved track. This tricycle is light, which reduces its rolling distance to stop.

Indian Standard

The Indian Standard tricycle has the largest wheel diameter. This large diameter explains a low rolling resistance on both tracks.

Solid tire versus pneumatic tire, impact on maintenance

- The advantage of a solid tire (or "airless tire") is that it is not subject to punctures. On pneumatic tire, punctures cause flats.
- For long-term use, it is necessary to have a supply of replacement parts available to the user at a reasonable cost and convenient proximity to the user's home. Punctures are a commonly experienced for pneumatic tires. This risk is considered to be acceptable as long as bicycle components are easily available.
- Solid tire wheels may not be available in some rural areas.
- Bicycle technology (tires, wheels, and bearings) offers an advantage for tricycle users.

Conclusion on Rolling Resistance test

- The Light Foot, Motivation and Indian Standard tricycles have the best rolling distance on a flat paved track.
- Whirlwind, Indian Standard, Motivation & Light Foot have the best rolling distance on a sand track.
- The PET tricycle has the worst rolling resistance on both tracks.
- Pneumatic tires have less rolling resistance (and longer rolling distance) and perform better than solid tires.
- Large diameter wheels have less rolling resistance and longer rolling distance.
- Pneumatic tires are also preferred for maintenance and availability of replacement parts.

4.4 Bench Test b: Static Stability Test

The static stability test was based on the standard for wheelchair (ISO 7176-1 1999), with slight adaptation for a tricycle. [6]

The conclusion of the stability test:

- The APDK tricycle has the worst sideways stability,
- The Indian Standard tricycle has the best rearward stability and good sideways stability,
- The Kien Tuong tricycle's stability ranks in middle of the others,
- The Light Foot tricycle has the 2nd best backward stability and the 2nd worst sideways stability,
- The Motivation tricycle has the 2nd best sideways stability and the 2nd worst rearward stability,
- The PET tricycle stability is above the average for both in all directions.
- The Whirlwind tricycle prototype has the best sideways stability and the worst rearward stability.

When compared to wheelchairs, we summarize the general characteristics observed across the tricycles as follows:

- The rearward static stability of the tricycles in this study was similar to wheelchairs.
- Because of the architecture of the vehicle a wheelie is more difficult to control on a tricycle compared to a wheelchair.
- Similar to wheelchairs, rear wheel position and seat position effect ability to perform a wheelie or risk being tippy. It is important to choose an appropriate configuration.
- Sideways static stability of a tricycle is critical for safe use.
- The stability of a three-wheel vehicle is more sensitive than a four-wheel vehicle.
- Falling from a tricycle may be more difficult to control and more harmful to the user compared to falling from a wheelchair.

[6] Static Stability Test protocol for Tricycle. UCPRUK/RD/2014/055

Static Stability Test Results: UCPRUK/RD/2014/058

Table 3: Test BT-b, Static stability results of the seven tricycles

Tricycle	*Rearward (degrees)*	*Right (degrees)*	*Left (degrees)*
APDK	17.2	7.7	9.9
Indian Standard	27.2	18.0	20.1
Kien Tuong Less stable	10.0	14.7	14.9
Kien Tuong Most Stable	14.6	15.9	16.0
Light Foot	24.2	17.5	10.6
Motivation	7.6	20.5	23.7
PET	18.2	20.9	17.0
Whirlwind Less stable	0.7	19.7	25.2
Whirlwind Most Stable	12.8	24.5	24.4
Summary			
Average Stability	16.2	17.4	17.4
Standard deviation	8.0	4.8	5.7
Less Stable Angle	0,7	7,7	9,9
Most Stable Angle	27,2	24,5	25,2
Uncertainty of Measurement	+/- 1.4°	+/-2 .0°	+/- 2.0 °

5 Performance Test 0: Transfer and "Preflight Check List"

The seating, ergonomics, and adjustability of each tricycle was examined by a Physiotherapist for the purpose of evaluating the tricycle's ability to be adjusted to comfortably fit a wide range of users. [7]

There is a substantial difference in the ergonomic features between different tricycles (Table 4). Tricycles varied in terms of adjustability features:

- Can be adjusted at assembly: Motivation, Light Foot,
- Can be adjusted after assembly: Whirlwind, Kien Tuong,
- Fixed Sizes: APDK tricycle is available in 3 sizes, each of which are fixed and does not offer additional adjustability,
- No Adjustability: Indian Standard, PET.

[7] Report on the fitting of users on tricycles. [UCPRUK/RD/2014/062].

Table 4: Summary of the main ergonomic features. Note: "+" indicates positive feature; "-" negative feature

Tricycle	*Seat base*	*Cushion*	*Backrest*	*Footrest*	*Armrest*	*Transferring*	*Comments*
APDK 3 Sizes	Solid type (wood) - Not adjustable	Foam cushion - Not removable	- Not adjustable above 90° - No lumbar support - At level of thoracic vertebrae	Wood platform - Not adjustable	Lateral frame tube offers support during transfers	- Front wheel is unstable - Handle contacts user	- No cover on the sprocket to protect the hands
Indian Standard	Solid type (steel) - Not adjustable	- No cushion	- Not adjustable - No support of the user's back	Steel plate - Not adjustable	No armrest	- Only left side - Very difficult	- Pedal position is not ergonomic - Handle & pedal hurt upper leg
Kien Tuong Adjustable	Solid type (wood) + Adjustable forward /backward	Hard foam cushion Not removable	3 angle options - Shoulder contact + Lumbar support	Full floor - Height not adjustable	Lateral tube with plastic pad	- Interference of drive rod and lever	+ Steering lever combined with propelling lever
Light Foot	Solid type (wood) - Not adjustable	Soft foam cushion - Not removable	+ At 90° - No support of the user's middle back	2 footrest platforms + Height adjustable	No armrest Side panel not suitable for armrest	+ Adequate space to access to the seat.	
Motivation Adjustable at assembly	Solid type (wood) Adjustable F./Back + 4 width, 3 length + Belt	Foam cushion + Removable + Water resistant + Pressure relief Hip abductor	Adjust at assembly + Recline + 2 height, 3 angle + Spine curvature + Sacral support	2 footrest platforms + Adjustable height & angle + Strap for feet	Lateral frame tube offers support during transfers	- Not easy due to central beam - Steering handle at level of chest	+ Seat range of adjustment + Good ergonomics of the steering-brake-pedal handle - Pedal too far forward for small user
PET	Solid type (wood) Not adjustable + Belt	Hard cushion Not removable	- Not adjustable Lumbar support for adult	Full floor - Not adjustable	No armrest	+ Adequate space to access to the seat	
Whirlwind Adjustable	Solid type (wood) +3 incline position + 4x2 height + Optional belt Adjustable F/Back	2 cushion option + Removable Flat foam or + Pressure relief with hip abductor	Sling type + 4 angle option + 3 height + Shape adjustable by the TAB	Full floor Knee to heel distance adjustable by the seat height	Lateral frame tube offers support during transfers	+ Lateral access over armrest - Steering handle at level of chest	+ Range of adjustment + Cushion feature + User can stand on the floor when transferring + Crank height adjustment

6 Performance Test 1: Track Test Results

To assess the performance on different tracks, the following tests were conducted [8]:

1a) Paved road: 50 meters straight road,

1b) Firm level ground: 50 meters road with stones and bumps,

1c) Soft uneven ground: 20 meters of sandy, straight path,

1d) Paved hill: 12 meter course on small hill.

6.1 (1a) Paved Road Results

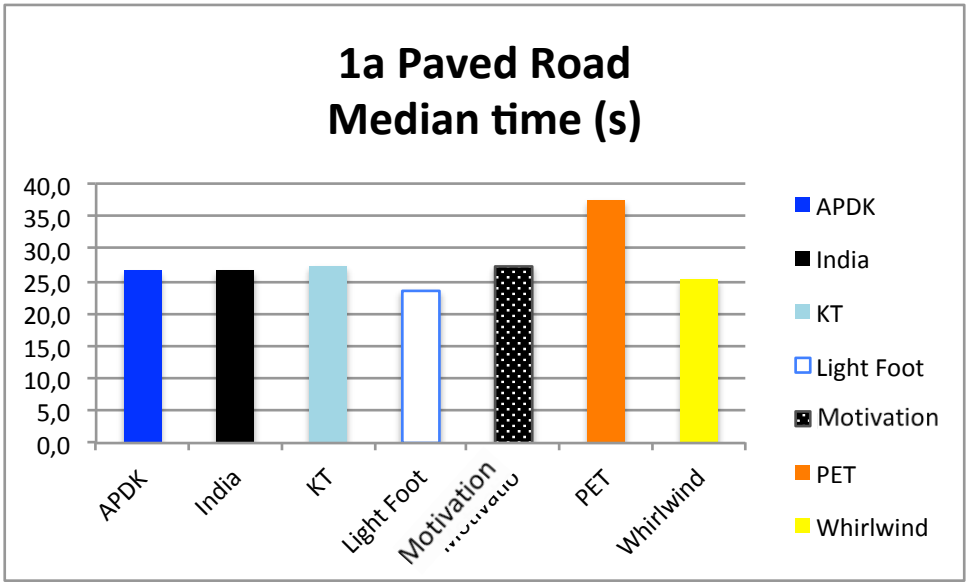


Figure 10: Test 1a, paved road track. The median time for each tricycle is displayed in seconds. Higher time means poorer performance.

[8] Test 1 Road tricycle test Results. [UCPRUK/RD/2014/032]

6.2 (1b) Firm Level Ground Results

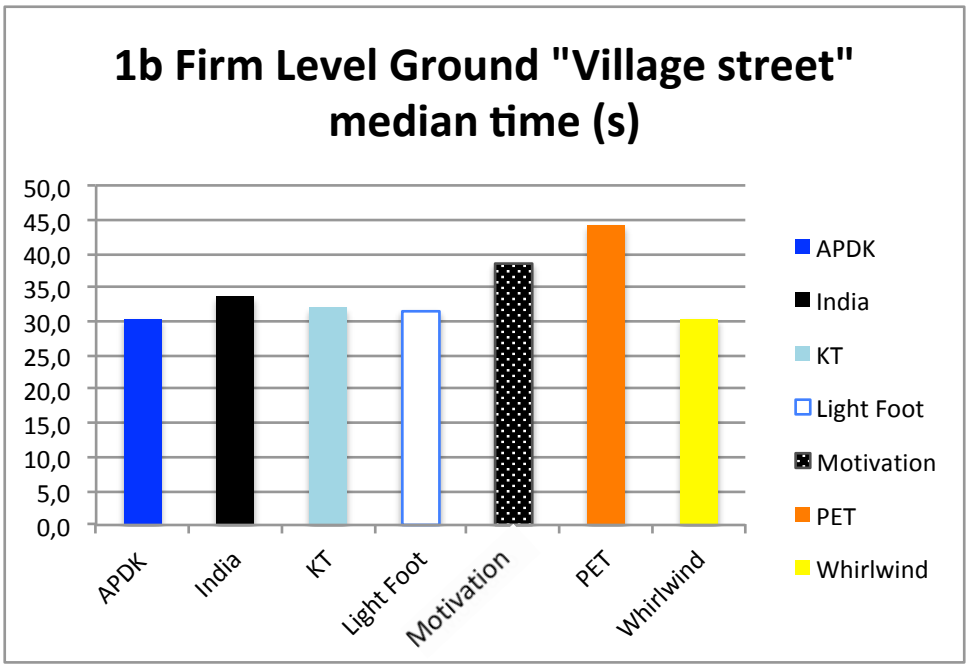


Figure 11: Test 1b, Track with firm level ground. The median time is displayed in seconds. Longer time means poorer performance.

6.3 (1c) Soft Uneven Ground Results

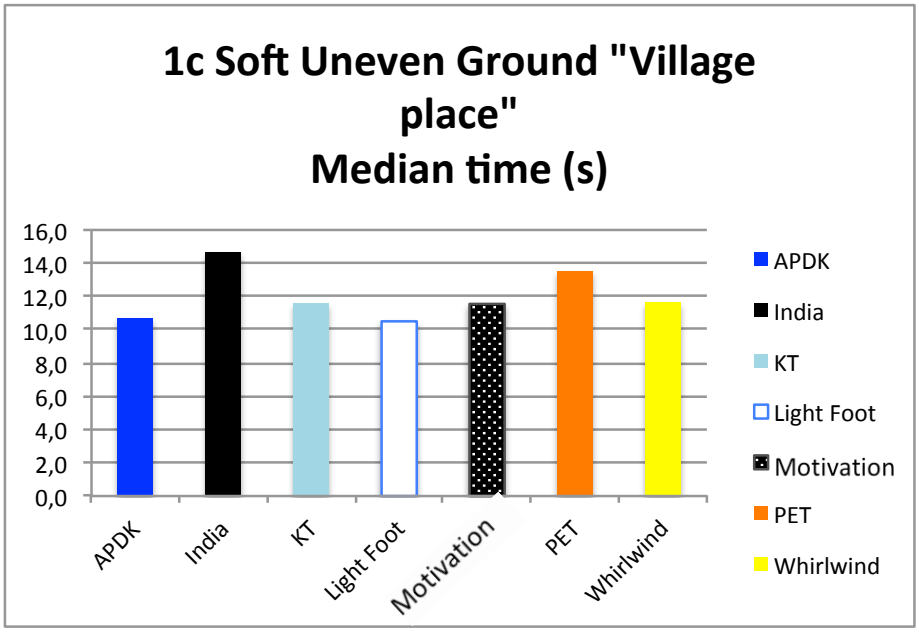


Figure 12: Test 1c, Soft uneven ground track. The median time result is displayed in seconds. Longer time means poorer performance.

(1d) Paved Hill results

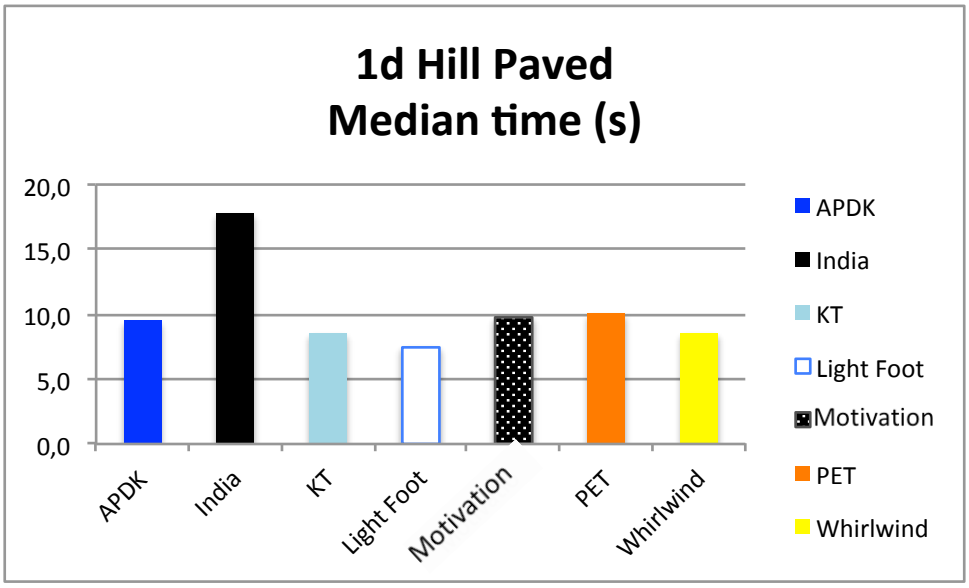


Figure 13: Test 1c, Hill paved track. The median time result is displayed in seconds. Longer time means poorer performance.

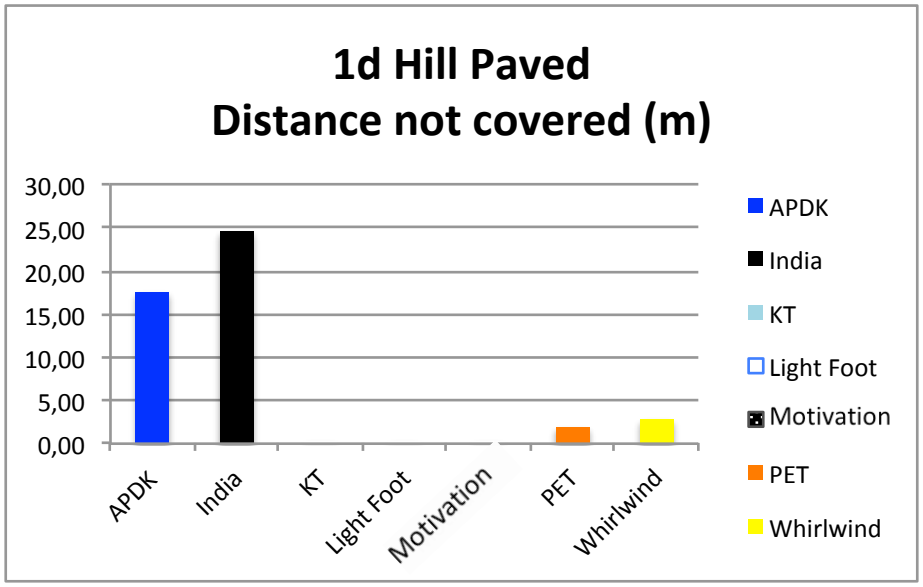


Figure 14: Test 1d, Hill paved track. Some users were not able to complete the paved hill track in some of the tricycles. This table shows the distance not covered. Larger distance means poorer performance – more distance not completed by users.

Track Test Results Discussion

Light Foot

Light Foot performed the best on the paved road, paved hill and soft uneven ground. It ranked the 3rd best on the firm level ground track. The advantage of the light foot is the gear change mechanism. Users can choose the best gear ratio for varied terrain, whether flat or hilly, paved or uneven, flat or bumpy. The Light Foot's seat, allows the user to keep an effective posture for propelling. Furthermore the lightweight of the Light Foot tricycle (27 kg) is advantageous specifically for the hill test.

Whirlwind

The Whirlwind tricycle ranks 2nd on the paved road 1a, 1st (tied with Light Foot), on firm level ground, 4th on soft uneven ground, and 3rd on the hill. The Whirlwind tricycle performed well on "straight tracks", which allow a high top speed. The Whirlwind tricycle has the highest gear ratio, which increases the maximum top speed. It ranked in the middle of the paved hill test scores; one user did not reach the end of the 12 meter course. This is the disadvantage of having a high gear ratio (2:4). The Whirlwind tricycle ranked in the middle on soft uneven ground. It was reported the front wheel tends to slide on sand when starting.

APDK

APDK tricycle ranked 3rd on the 50 m paved road; 1st (tied with Light Foot) on firm level ground; 2nd on soft uneven ground; and 4th on the paved hill paved with three users aborting the test. The APDK tricycle performed well on all performance tracks. The high gear ratio (1:9 ratio) can explain this score. The steering wheel was noticeably unstable, turning left and right, when pedaling, when stopped, and also when moving over a bump. This may explains the lower results on the hill test.

Indian Standard

The Indian Standard tricycle performed 4th on paved road; 5th on firm level ground; 7th on soft uneven ground; 7th on the paved hill course with 5 users aborting the test. The "good middle" performance of the Indian Standard tricycle on the flat paved road is attributed to a high gear ratio (2:2 ratio), the 2nd highest of all tricycles tested. The performance is limited by the ergonomics of the pedals, which are used to propel. Users are unable to pedal in an efficient way, as the design only offers a pedal on one side. This point was continuously observed, and continuously reported by all users. Due to the difficulty to propel and due to the high gear ratio, climbing the hill was challenging for the users.

Kien Tuong

The Kien Tuong tricycle performed 5th on paved road; 4th on the firm level road; 4th (tie) on the soft uneven ground; and 2nd on the paved hill road (No users aborted the test). The top speed of the Kien Tuong tricycle is limited. The propelling lever is hard to propel when starting and when moving on an uneven road. This tricycle is also hard to propel when moving over a bump on an uneven road.

Though users had difficulty at the start of the paved hill test, the Kien Tuong tricycle achieved remarkably good performance. Users were given a few meters to start up before passing the starting line at the bottom of the hill. After the start, it is noted the user has a "constant speed", and he uses his upper arm and trunk to propel.

Motivation

The Motivation tricycle ranked 5th on paved road; 6th on firm level ground; 3rd on soft uneven ground; and 5th on the hill test. The Motivation tricycle has a lower top speed due to a lower gear ratio (1:5 ratio). On the Motivation tricycle, a few users (user 2SE on test 1a; user 3WA on test 1d) propelled only with one hand and kept the other one on the steering handle. It was noted the front wheel can slide when starting, or on soft sand track.

PET

The PET tricycle performed 7th on the paved road; 7th on firm level ground; 6th on soft uneven ground; and 6th on the hill test (1 user aborted the test).

The PET tricycle's top speed is slow due to a small gear ratio (0:9 ratio), the smallest of all tricycles. The PET tricycle's low speed was also a disadvantage on the hill test. Though the small gear ratio should make hill climbing easier, one user aborted the test. On hill course, the PET tricycle is probably also at a disadvantage due to its higher weight (44 kg, the heaviest tricycle).

6.4 Conclusion of the Track Test Results

- The Light Foot tricycle performed the fastest on most of the track tests.
- The Light Foot tricycle is has an advantage due to low weight and a design, which allows the user to sit in an effective posture for pedaling. Probably, performance is improved because the user has the option of selecting the best gear ratio for the terrain.
- A higher gear ratio is an advantage for reaching a high speed on flat straight track.
- The PET has the worst performance. It is at a disadvantage because of low gear ratio and a heavier weight.

7 Performance Test 2: Maneuvers Results

This evaluation consisted of assessing the maneuverability on the following tests:

- A fast slalom "swerve" to test the ability to avoid an obstacle at regular speed,
- A slow slalom "market place" to test the ability to move around obstacles,
- A forward-backward U-turn to test the space required to make a 180 degree turn,
- An interview with users to collect feedback on maneuverability after the tests.

The final result was the median time of all the tests performed by the 18 users.[9]

7.1 (2a) Fast Maneuver "Swerve" Results

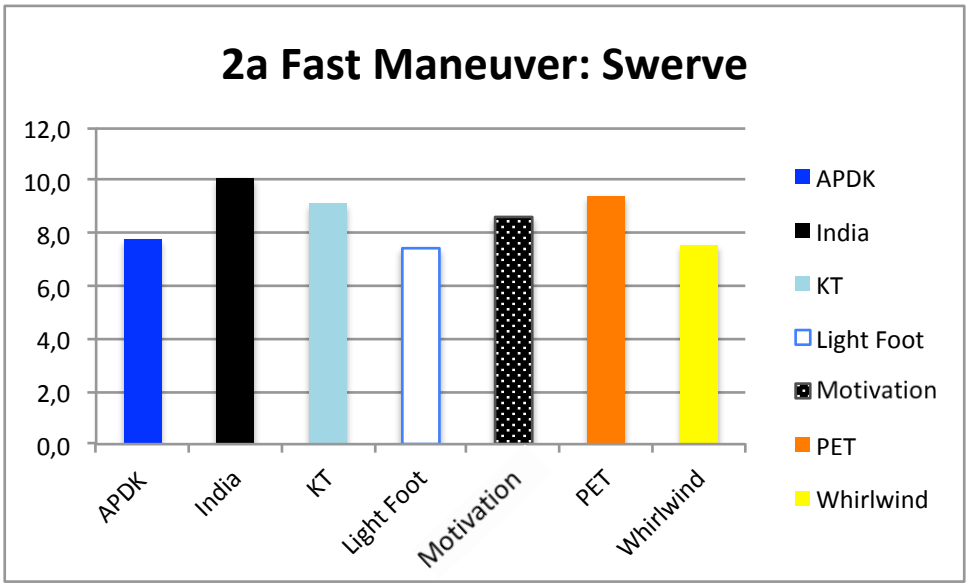


Figure 15: Test 2a, Fast maneuver slalom "swerve", the median time result is displayed in seconds. The lowest is the best.

[9] Tricycle Test, results of test 2: Slalom and Maneuverability. UCPRUK/RD/2014/013

Light Foot

The Light Foot tricycle was the best performing tricycle for the swerve test. The Light Foot tricycle performed well on this test, due to the maneuverability, and due to the ease of propelling the tricycle. It was easy for users to gain speed and then change direction for each turn. Also, users could easily accelerate at the end just before the finish after the three swerve corners. However, three users encountered a significant safety issue. They noted a tendency of the device to tip-over sideways during cornering. At high speed, a sudden left turn exerts a high centrifugal force on the user that is strong enough to cause tip-over or to throw the user out of the seat.

Whirlwind

The Whirlwind tricycle was the second best performing tricycle for the swerve test with similar median time. The Whirlwind tricycle had the following advantages on this test: ease of acceleration, ease of turning, and good sideways stability during cornering.

APDK

The APDK tricycle ranked third. The APDK tricycle had the following advantages on this test: ease of acceleration after completing the corners, ease of turning, and ease of propelling. One user reported also the risk to tip over during the turn.

Motivation

The Motivation tricycle ranked 4th.

Kien Tuong

The Kien Tuong tricycle ranked 5th.

PET

The PET tricycle ranked 6th. The small gear ratio limits the top speed of the tricycle.

One notable limitation and safety issue is the absence of a free wheel, which causes the pedals to remain in constant rotational motion when the tricycle is in motion. If the user looses contact with the pedals, the pedals continue rotating in close proximity to the user's face.

Because steering is accomplished by orienting the propulsion pedals and there is no free wheel, maneuverability above very slow speeds is significantly compromised. The user is forced to maintain contact with the fast moving pedals in order to change the orientation and achieve a turn.

Indian Standard

The Indian Standard tricycle ranked last. This tricycle is at a disadvantage due to a high gear ratio, and poor ergonomics for pedaling.

7.2 (2b) Slow Maneuver "Market" Results

The APDK and PET tricycles performed the best. The PET had the best median time. The Kien Tuong tricycle performed the worst.

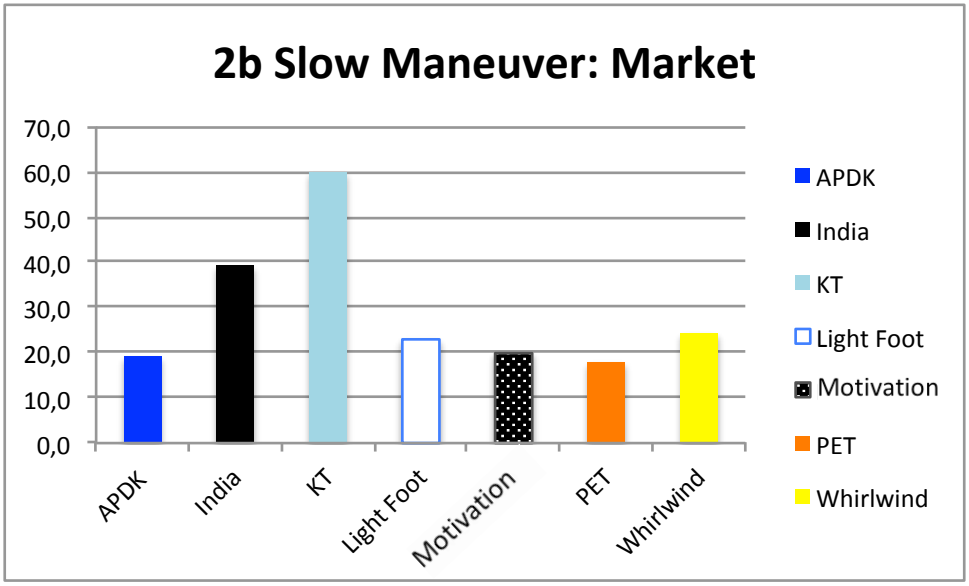


Figure 16: Test 2b, Slow maneuver slalom "market", the median time result is displayed in seconds. Shorter time equals better maneuverability.

Slow slalom results discussion

PET

The PET tricycle performed the best on the slow slalom. The excellent maneuverability performance is due to its small wheelbase. The small gear ratio (0:9 ratio) makes it easy to accelerate at the start, during corning, and after cornering.

APDK

The good performance of the APDK tricycle is due to small track width makes turning easy.

Motivation

The good performance of the Motivation tricycle is probably due to a small track width and to the range of the steering handle, which can turn 88 degrees to left and right. Maneuverability is also helped by a low gear ratio (1:5 ratio).

Light Foot

The Light Foot tricycle ranked in the middle of the scores. This is due to:

+ The good steering range (2nd best of all tricycles)

- The large total width

Whirlwind

On this test the Whirlwind tricycle is at a disadvantage due to a high gear ratio (2:4 ratio). Also, it has the largest overall width.

Indian Standard

The Indian Standard tricycle is at a disadvantage on the slow "market" slalom due to:

- A large wheelbase and track-width, which makes tight turns difficult,

- A high gear ratio, which makes acceleration difficult,

- Poor ergonomics for pedaling,

Two users aborted the test because they did not feel strong enough to complete it.

Kien Tuong

The Kien Tuong tricycle is at a disadvantage due to the high push/pull force required from the user to start from a stop and to accelerate at low speed when turning.

The turning capability of Kien Tuong tricycle is limited. Some users used the reverse function to complete the slalom maneuvers.

7.3 (2c-2d) Forward-Backward U-turn Results

7.3.1 (2c) Forward U-turn Results

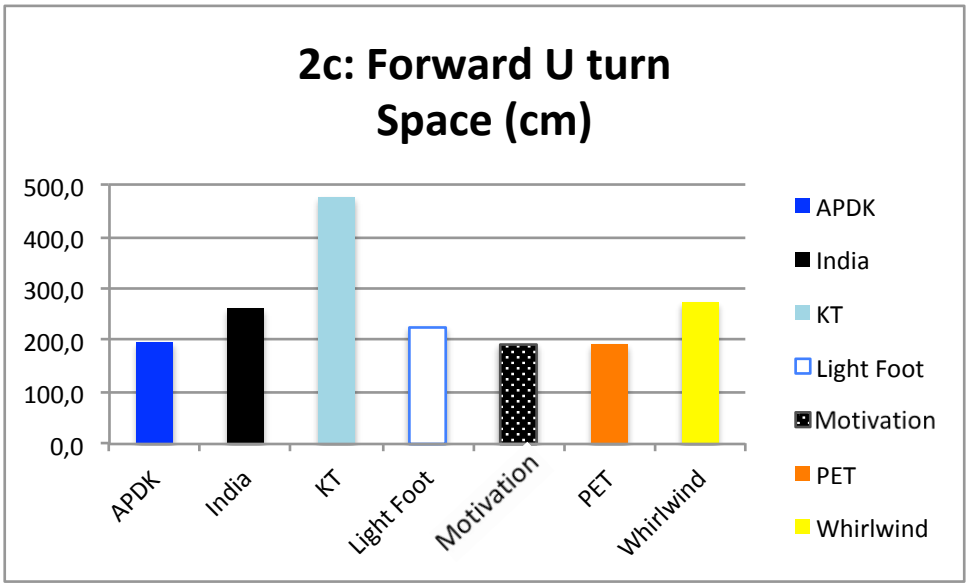


Figure 17: Test 2c, Forward U-turn, the median space result is displayed in centimeters. The lowest is the best.

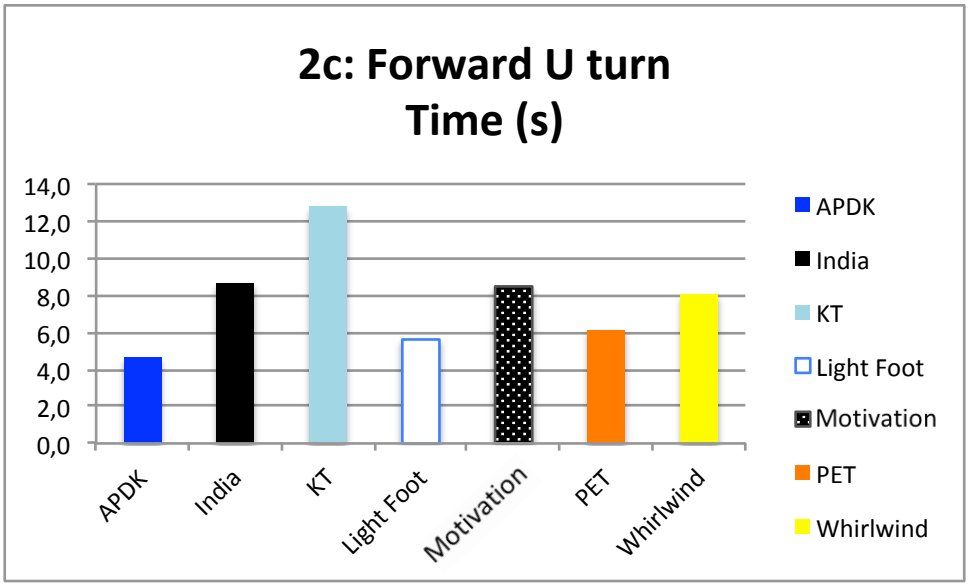


Figure 18: Test 2c, Forward U-turn, the median time result is displayed in seconds. The lowest is the best.

7.3.2 (2d) Backward U-turn Results

Only five tricycles were tested (KT, Light Foot, PET, Motivation, Whirlwind)

The Indian Standard and APDK tricycles were not assessed because the design does not allow users to move in reverse.

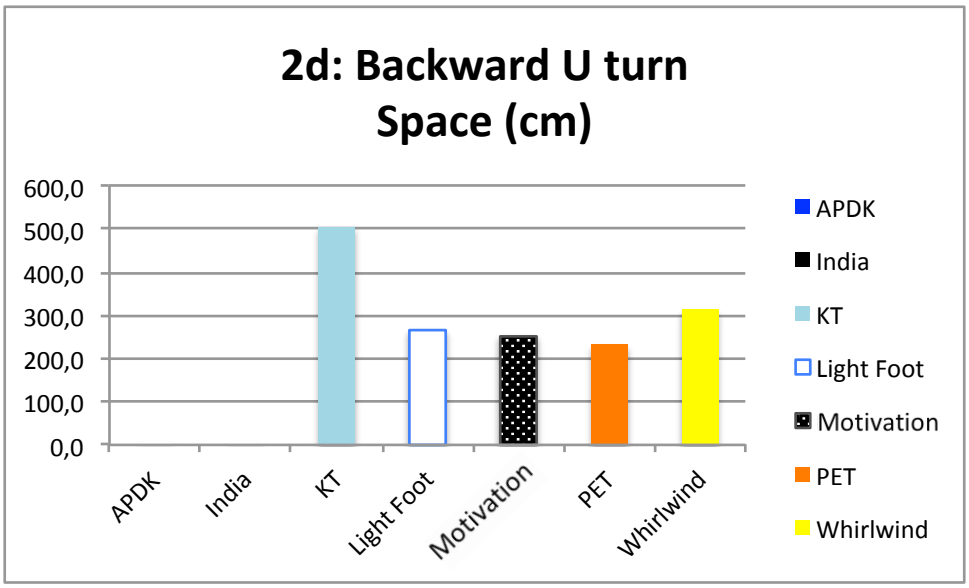


Figure 19: Test 2d, Backward U-turn, the median space result is displayed in centimeters. The lowest is the best.

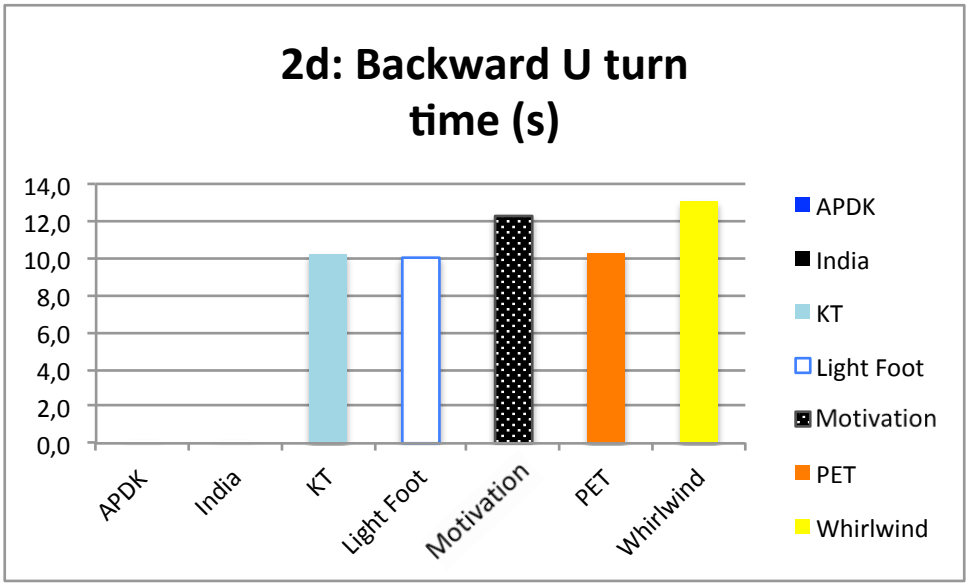


Figure 20: Test 2d, Backward U-turn the median time is displayed in seconds. The lowest is the best.

7.3.3 Forward - Backward space turning capacity discussion

Motivation

The Motivation tricycle ranked best on the forward U-turn, and 2nd on the backward U-turn.

The user can use the push rim to maneuver. The steering range of motion of the Motivation is 88 degrees to the left and to the right. The total range is 176 degrees, which is the largest range of all tricycles. The Motivation tricycle has the smallest track width (53 cm), which is an advantage for maneuverability.

PET

The PET tricycle ranked 2nd on the forward U-turn and best on the backward U-Turn.

The PET tricycle can move in reverse easily using the pedal because there is no free wheel.

The PET tricycle's turning capability is due to a small wheelbase (88 cm), which is the smallest of all tricycles.

Light Foot

The Light Foot tricycle ranked 3rd on both forward & backward U-turn test.

It can go in reverse because the user can reach the rear tires and wheel spokes.

The Light Foot tricycle has the 2nd best steering range of motion (146° of total range).

The Light Foot tricycle has also the 2nd smallest wheelbase (100 cm).

APDK

The APDK tricycle ranked 4th on the forward U-turn test. It cannot be propelled in reverse because the fenders prevent access to wheels and spokes. The APDK tricycle has the 3rd smallest overall width (70 cm).

Indian Standard

The Indian Standard tricycle ranked 5th on the forward U-turn test. It cannot be propelled in reverse. The Indian Standard tricycle is at a disadvantage due to a wide track-width (73.5 cm).

Whirlwind

The Whirlwind tricycle ranked 6th on the forward U-turn, and 4th on the backward U-turn.

Users can propel in reverse by using the push rims. The Whirlwind tricycle is at a disadvantage due to a wide track-width (71 cm).

Kien Tuong

The Kien Tuong tricycle ranked last on the forward & backward U-Turn. It has the worst turning capability. The user can propel backward using the primary push lever. The steering range is very limited (107° of total range).

7.4 (2z) User Interview on Maneuverability

At the end of the half-day maneuverability test, each user was interviewed and requested to rank the tricycle according to their preference.

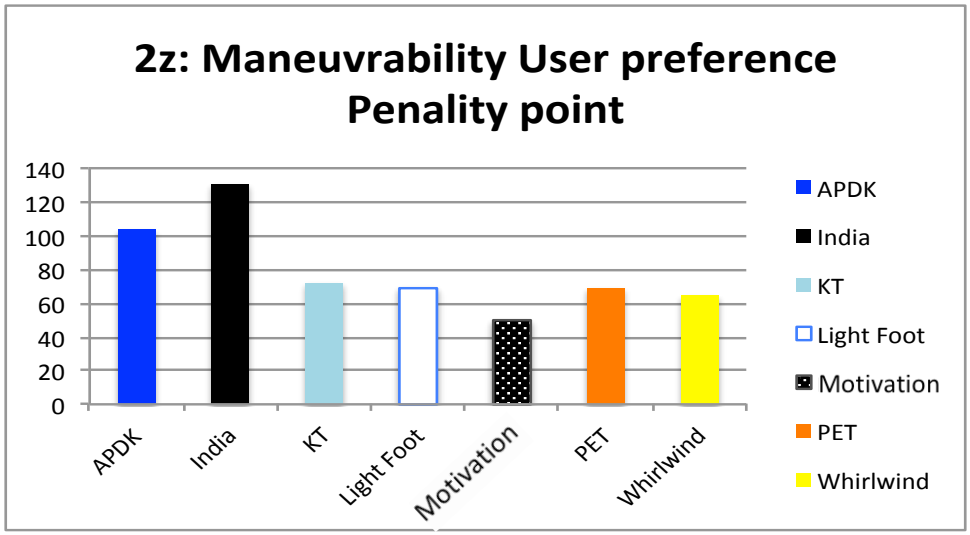


Figure 21: Interview 2z, User preference for maneuverability. The lowest score is the best.

7.5 Conclusion on Maneuverability Test Results

- The **Light Foot** tricycle performed the best on the fast slalom "swerve", however it has a tendency to tip over.
- The **PET** tricycle performed the best at the slow "market" slalom, due to its small wheelbase and a low gear ratio.
- The **Motivation** tricycle performed the best during the forward-backward U-turn, due to a small track-width and a high range of steering motion.
- The **Whirlwind** tricycle has a good turning capability and good lateral stability, but a high gear ratio was a disadvantage on the slow slalom.

- The **Kien Tuong** tricycle has a poor turning capability and low range of steering motion, which caused poor performance on the slalom test.
- The **Motivation** tricycle was preferred during this maneuvering test.
- The **Indian Standard** tricycle was the least preferred and the poorest performing during the tests.

8 Braking Test 2e Results

8.1 Test (2e-A) Braking Ability

This test consists of performing three fast braking stops at low speed. The time is recorded and averaged for each user. This represents the ability of the user to brake easily. [10]

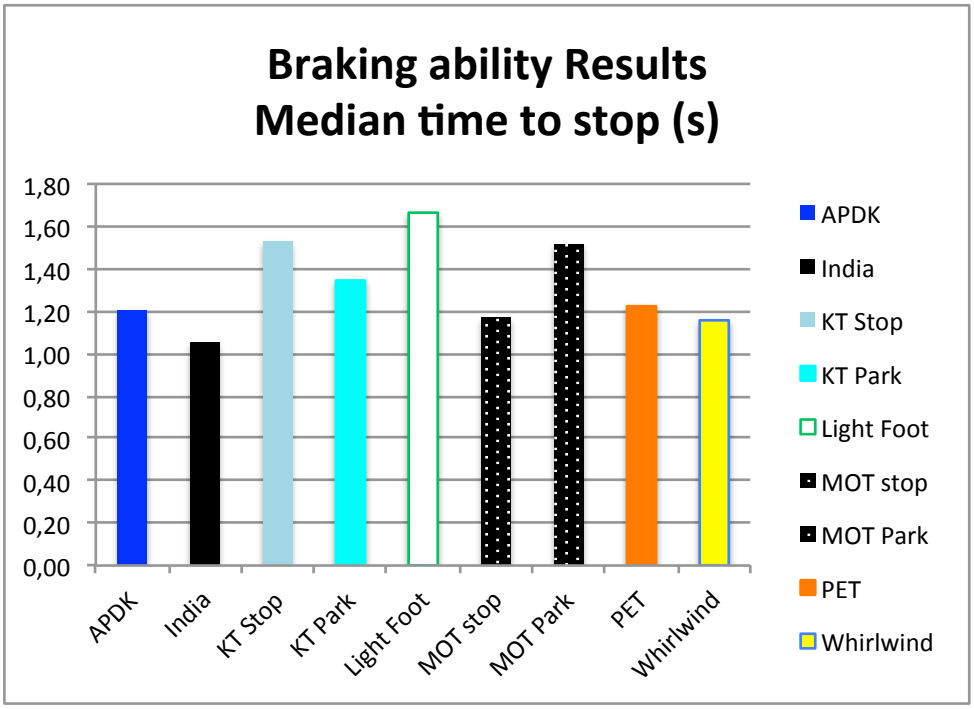


Figure 22: Test 2e-A, Braking ability results. The median time is displayed in seconds. Lowest is best.

8.2 Test (2e-B) Brake Preference Questionnaire Results

A. Brake Architecture Preference Results

The preferred braking lever type for 15/18 users is a bicycle type lever. The preferred lever location for 13/18 users is at the steering handle (direction lever). Three prefer close to propelling pedal and two prefer close to the seat. The preferred lever length for 15/18 users is a shorter lever versus a long brake lever. The preferred location for the

[10] Test 2e Tricycle brake test results Rev B. [UCPRUK/RD/2014/030]

parking brake lever is unclear with eleven users preferring the location at the wheel rim and seven preferring at the steering handle (direction lever). 16/18 users preferred a separate stop brake from the parking versus combining the two functions combined into one brake lever.

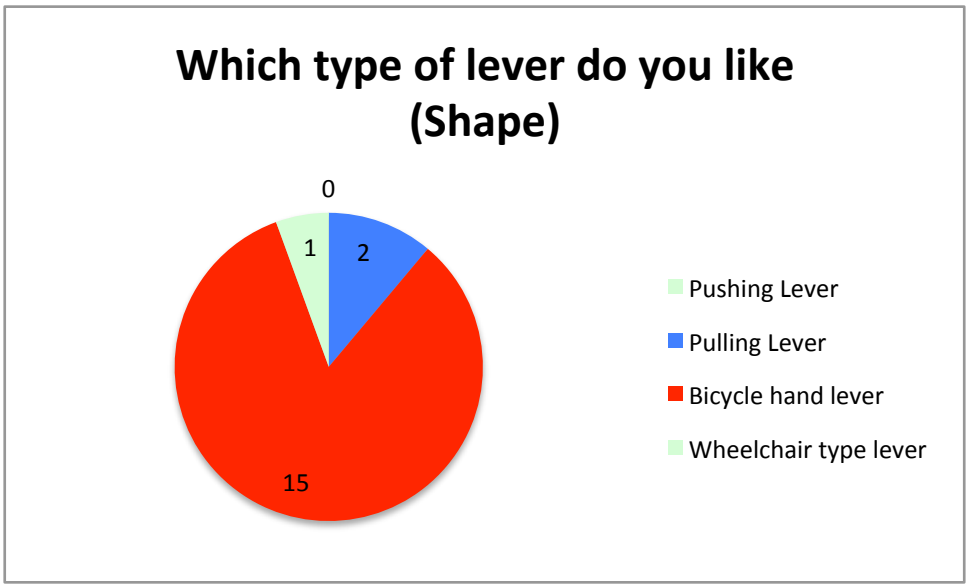


Figure 23: Brake questionnaire result, type of lever preferred.

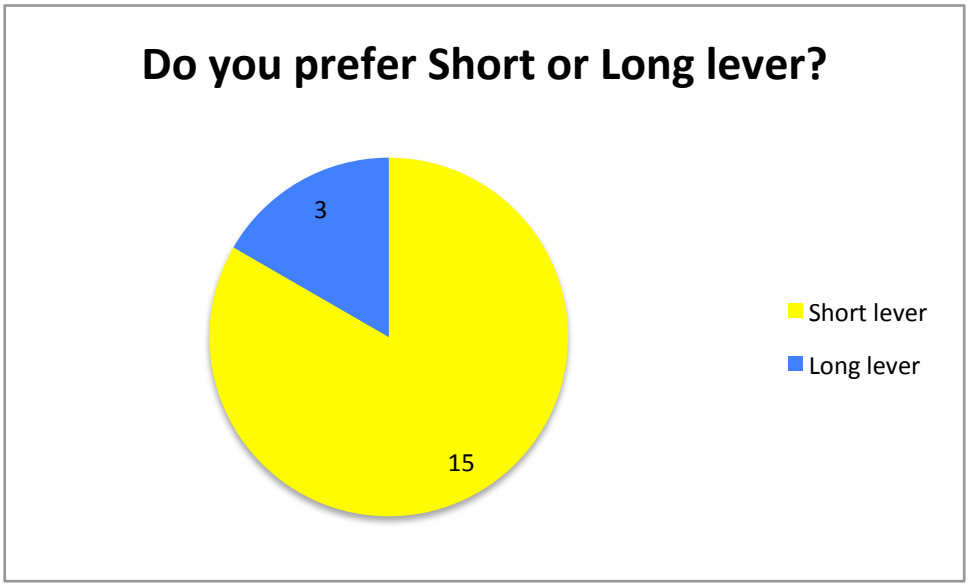


Figure 24: Brake questionnaire result, length of brake lever preferred.

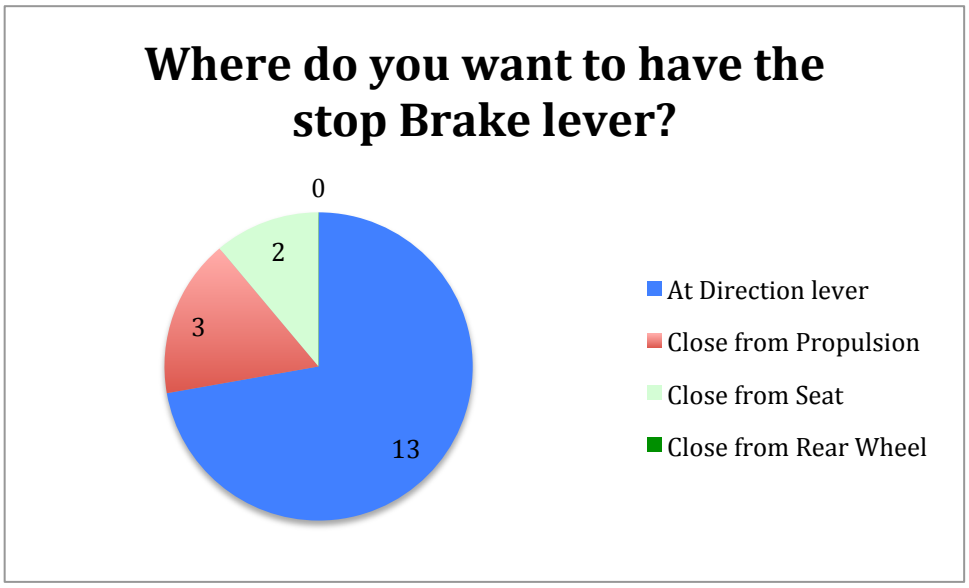


Figure 25: Brake questionnaire result, preferred location of the stop brake lever.

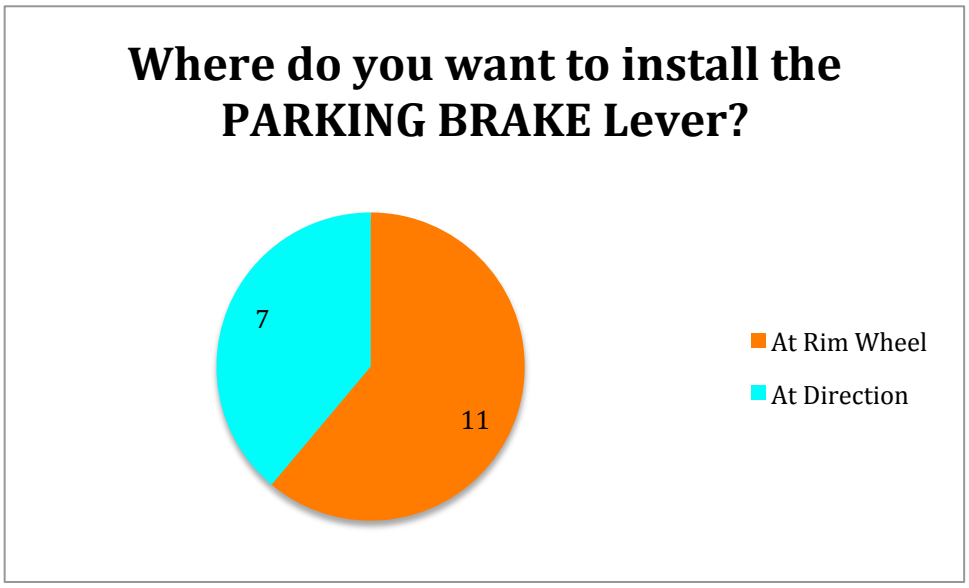


Figure 26: Brake questionnaire result, preferred location for the parking brake lever.

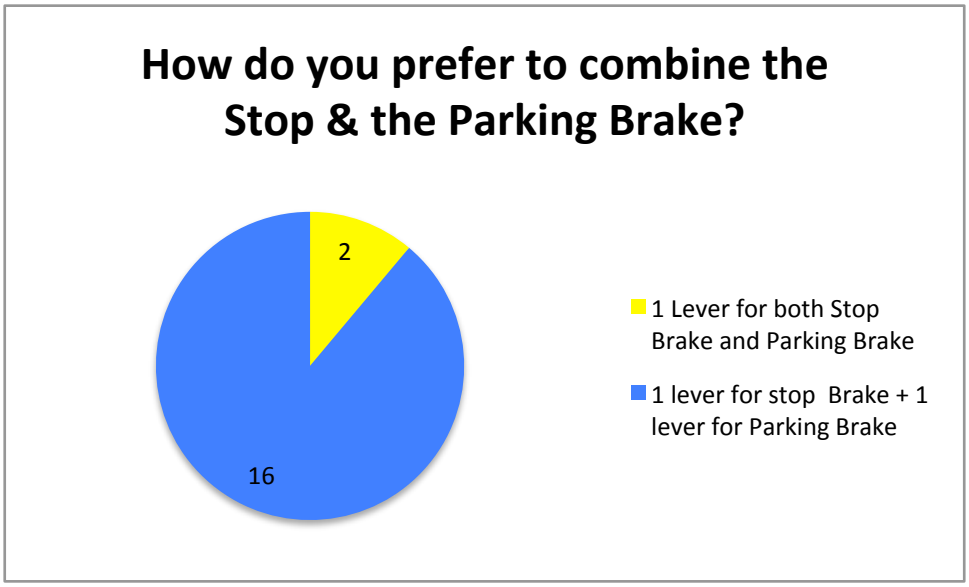


Figure 27: Brake questionnaire result, preferred combination for both stop & parking brake.

B. User Preference for Braking

Each user was asked to choose the best performing and worst performing tricycles for the following features: stop brake, parking brake, and overall brake performance.

Only the best and the worst preferences were recorded. A few users were firm about choosing multiple 'best' or 'worst' tricycles. One user did not choose a worst tricycle. As a result, the total number of preferences recorded does not correspond to the number of users (18).

The best brake stop lever was the Motivation brake according to 11 users, a large majority. Five users preferred the Light Foot brake. Three users preferred the Kien Tuong brake. One user preferred the Indian Standard brake.

The APDK brake was chosen as worst stop brake lever by10 users. Three users chose the PET brake as worst. Two users chose the Indian Standard and Whirlwind tricycles as worst. One user chose the Kien Tuong and Light Foot as worst.

The Motivation tricycle scored well again as the best performing parking brake for 15 users.

The Kien Tuong parking brake was chosen as the best by five users. The APDK parking brake was chosen as the worst by seven users. The PET parking brake was chosen as

worst by 5 users. Three users chose the Indian Standard as worst. The Whirlwind parking brake was chosen as worst by two users. One user chose each the Kien Tuong and Light Foot parking brakes as worst.

Then it was asked which tricycle has the best braking performance (i.e. stopping the fastest). The user feedback does not necessarily correspond to the braking distance. It is a subjective evaluation of brake performance. Motivation was the most preferred with 11 users rating it best. Three users rated the Kien Tuong and Light Foot tricycles as best. One user preferred the PET and Whirlwind tricycles.

Six users rated the APDK tricycle worst. The Whirlwind tricycle was rated worst for four users. The Kien Tuong tricycle rated worst by three users. Two users rated the Indian Standard, Light Foot and PET tricycles worst.

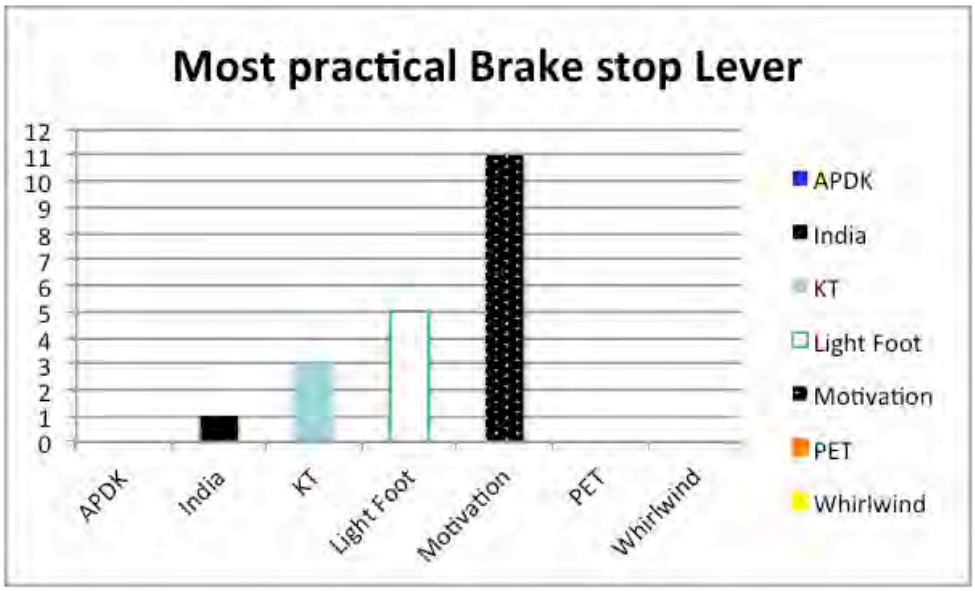


Figure 28: Brake questionnaire result, most practical brake stop lever.

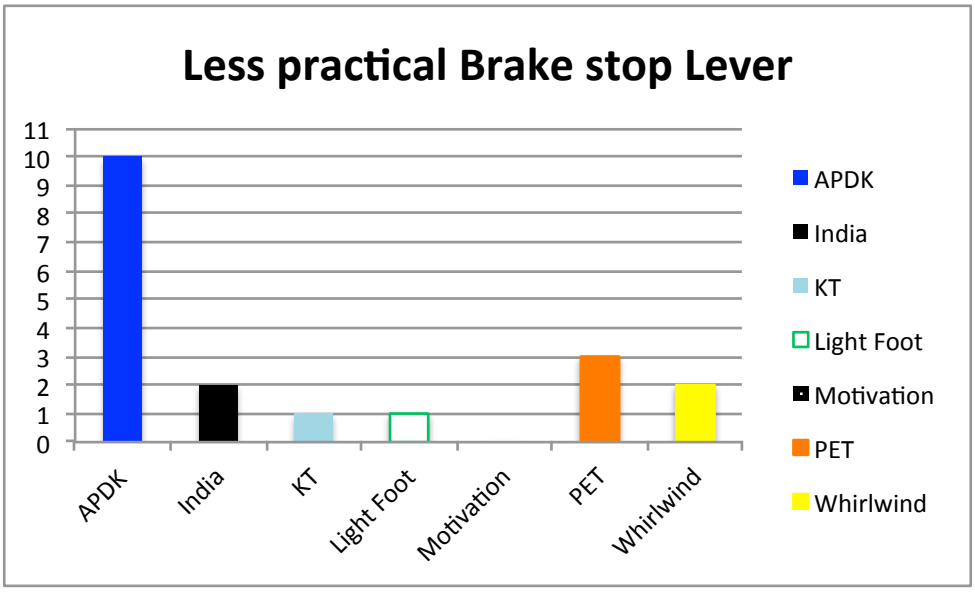


Figure 29: Brake questionnaire result, least practical brake stop lever.

Figure 30: Brake questionnaire result, most practical parking brake lever.

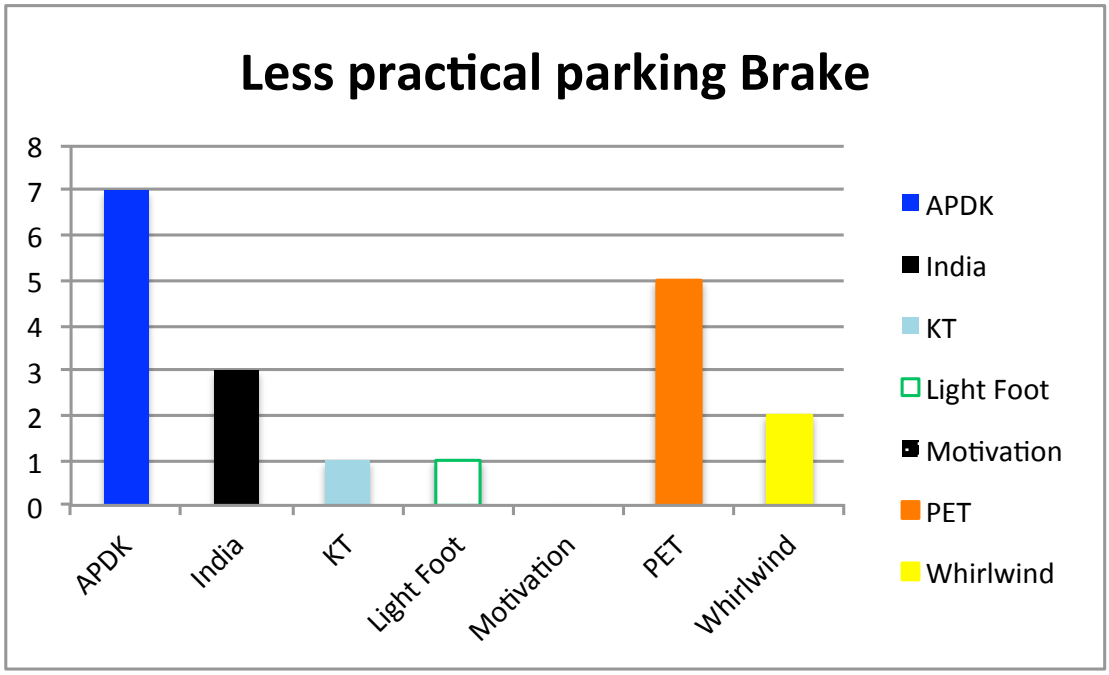


Figure 31: Brake questionnaire result, least practical parking brake lever.

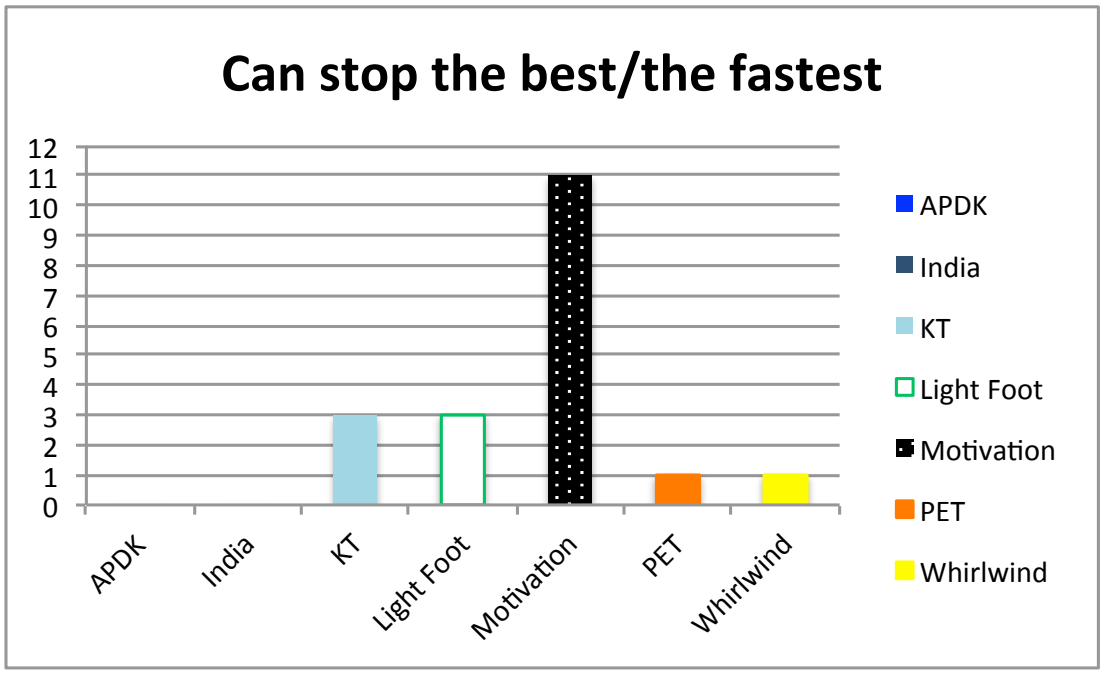


Figure 32: Brake questionnaire result, best performing brake.

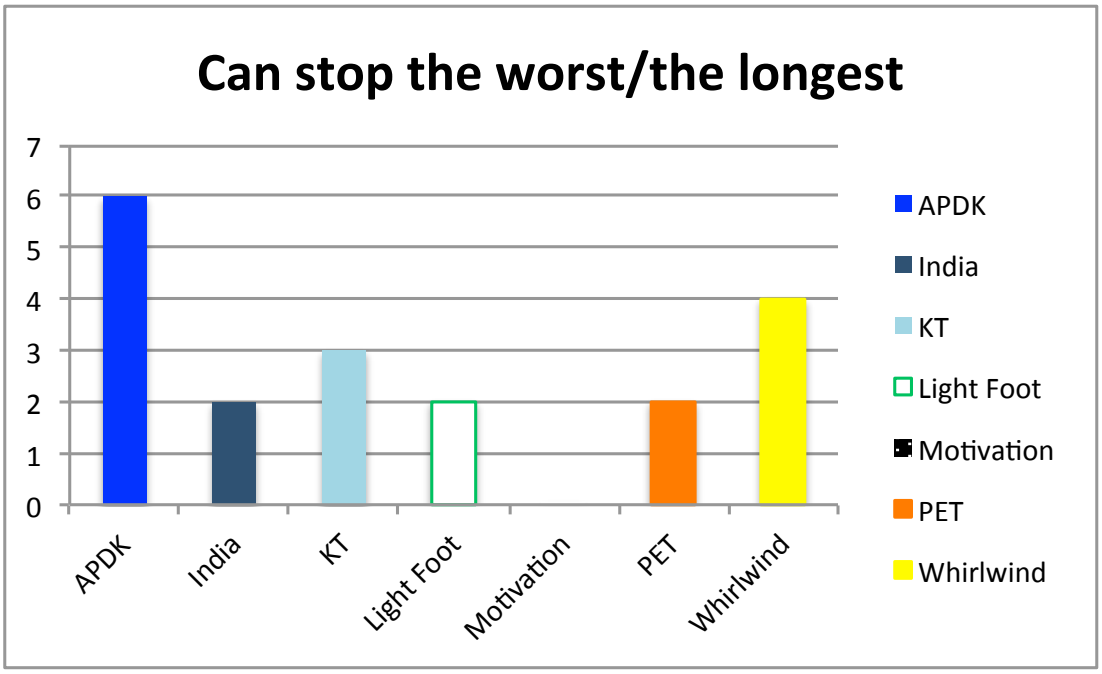


Figure 33: Brake questionnaire result, worse performing brake.

C. User Additional Comments

The users were free to provide feedback, which has been documented [Ref: UCPRUK/RD/2014/029]. Usually, the user comments confirmed their preferences. During the nine days of tests, some users expressed additional informal comments. These comments are included below (12.2.D).

D. Discussion on the brake preference interviews and observations of the testing engineer

Brake Lever and Its Installation

The user feedback strongly indicates a preference for a bicycle type brake lever placed on the direction lever. Users also preferred to have a separate lever for the stop brake and the parking brake. Only the Motivation and Kien Tuong tricycles use a bicycle lever placed on the direction lever. Both tricycles also have a separate brake system for parking. These two tricycles were the most preferred by users.

The APDK brake style was chosen as the worst brake design. On the APDK tricycle the brake lever position is near to the seat and far from the pedals. Each tricycle has only one lever, which causes only one rear wheel to stop. The lever is multi-functional for both stopping and parking. Users do not prefer this design.

We conclude there is a strong coherence between the brake lever installation answers and the tricycle preference for braking answers expressed by the users.

Motivation

The Motivation model was by far preferred by most users. Eleven users preferred the Motivation tricycle stop brake system, while fifteen users preferring its parking brake system. Furthermore eleven users considered the performance of its brake the best. The Motivation has the brake lever on the steering handle, which has an advantage in regards to ergonomics, as only one hand is used for both direction and brake. Its separate parking brake was also preferred as it uses two independent small levers on the wheel. This brake system is a proved mechanism system used on most wheelchairs. It consists of a small lever, therefore making the locking mechanism easy to lock and unlock with the wrist.

Light Foot

The Light Foot was considered as having the most practical stop lever by five users, but rated the worst by one user. It was considered as the best & most effective for stopping by three users, however two users considered it the worst. One user considered it to have the worst parking brake.

The positive observation on the system is with respect to the ergonomics, as the lever is part of the direction system, it is easily accessible to brake by pushing the lever, and as the propulsion pedal has a freewheel; the risk of getting one's arm hurt by the rotating pedal is low.

The disadvantage of the braking system is the brake pad is placed on the tire. As the tire is an "off road" type, the friction of the lever on the tire is irregular and the lever bumps along the tire nobs. The lever does not seem efficient enough to stop, making it necessary to push it hard in order to stop. The braking efficiency of the Lightfoot may be negatively affected when the road is wet. This tricycle has no parking brake.

Kien Tuong

In Kien Tuong tricycle the brake lever is placed below the steering wheel, which requires the use of both hands for direction and braking. The brake comprises of a bicycle lever placed below the steering handle. This explains the positive review from three users; whereas one user did not prefer this design. There is a separate parking brake, explaining the positive feedback from five users whereas one user did not prefer it.

The general braking performance and review of the Kien Tuong tricycle does not point strongly to a negative or positive preference. Three users preferred it the most and three users considered it to have the worst performance.

We suspect the reasons for negative feedback about the KT, could be either quality of the braking performance or the location. With regards to the latter, the position of the

braking lever causes it to move with the propelling lever. This may result in a struggle for the user to make contact with the brake as the lever moves.

PET

Three users rated the PET brake lever as the worst brake. The lever is placed on the direction lever. The brake pad contacts the tire and not the wheel rim. Though similarly designed, the brake lever arm is smaller than the Light Foot and much smaller than the Indian tricycle. Therefore, more effort is required while pushing the brake lever. This braking system may have a limited performance if the road and the tire are wet.

In term of ergonomics, the braking lever is very near to the pedals, which are constantly moving when the tricycle is in motion. When braking, the pedals can injure the user's hands.

Five users ranked the PET parking brake as worst. The parking brake is a wedge shaped stopper that must be placed between the cargo area wall and the rear wheel. Applying the parking brake requires significant range of motion in the torso and shoulders. Some users had difficulty applying the brake or even reaching it with their hands. Some users are required to exit the tricycle before applying the brake, which makes the exiting transfer dangerous.

For the braking performance, the PET tricycle was rated most preferred by one user and rated the worst by two users.

Indian Standard

The IS stop brake was rated as the most practical by one user and two users rated it as the least practical stop brake. Two users rated the IS brake system as worst.

The braking system is a long push lever positioned in the center of the tricycle. The lever also functions as the direction lever and functions similar to a tiller arm on a ship.

Because the lever is long with good mechanical advantage and is conveniently combined with the steering handle, the implementation received one positive review. When the tricycle is in use, users appreciated that the long lever requires less force to brake effectively. One significant safety issue was observed with the brake lever. When turning sharply, the long length of the brake lever brings it very close to the pedals. Several users injured their hands because of interference between the pedals and their other hand, which was operating the steering lever. This problem is easily noticeable and has been reported continuously by several users.

The Indian Standard tricycles examined in this study did not possess a parking brake, making it unsafe for users during transfers. This is not consistent with the Indian Standard (Indian Standard IS 8088 1976) §5.14 which requires a parking brake.

Whirlwind

Two users rated the Whirlwind tricycle's brake system as the least practical. The Whirlwind braking system's overall performance was rated best by one user and worst by four users. This feedback is not necessarily related with the braking distance or efficiency. The feedback is more related to the user's preferences for the location of the brake levers. Some users preferred the Whirlwind architecture because the lever is not placed on the steering handle. Instead, the brake arms are placed at the sides of the seat and are activated by pulling.

This brake position is different from other tricycles and wheelchairs. This caused confusion for the users and they tended to push the lever instead of pulling it. During the test, we observed users trying to push the lever to brake instead of pulling, even after one week of home test and three days of testing. This pushing action by the users seems to be a natural reflex.

The implementation of the parking lock system, which is a connecting rod on the brake arm, can cause a safety issue. Because users naturally push down on the brake levers, the connecting rod can become fully extended and jammed. This prevents the brake from being engaged and the tricycle is out of control until the jam is released.

APDK

The APDK brake was the least preferred by most users. The stop lever was the least preferred by ten users. The parking brake was the least preferred by seven users. Six users rated the APDK tricycle as having the worst braking performance.

The brake system has a single lever, on the left wheel. The lever is placed far from the steering wheel and the pedals, which makes it uncomfortable for the user to reach it effectively. We observed that the parking lock mechanism was not easy to use. The mechanism locks by hanging a ring, which is attached to the lever, over a pin that is attached to the frame. The user is required to adjust the ring over the pin, which is an unusual and cumbersome mechanism. One lever is not adequate for effective stopping or parking; and, one should be placed on each wheel.

8.3 Test (2e-C) Braking Distance

Principle of the Test

The test driver, weighing 60 kg, goes down a ramp with the height of 0.7 m. The driver applies the brake when passing a line, which is 3 m after the end of the ramp. The test is performed three times and the results are averaged. For tricycles with the brake lever positioned on one wheel, the left brake was used.

The brake force applied by the test driver was intended to reach the maximum force without causing skid. This level of braking force is considered much stronger than a force applied by a common user who is not necessarily an active user.

Results

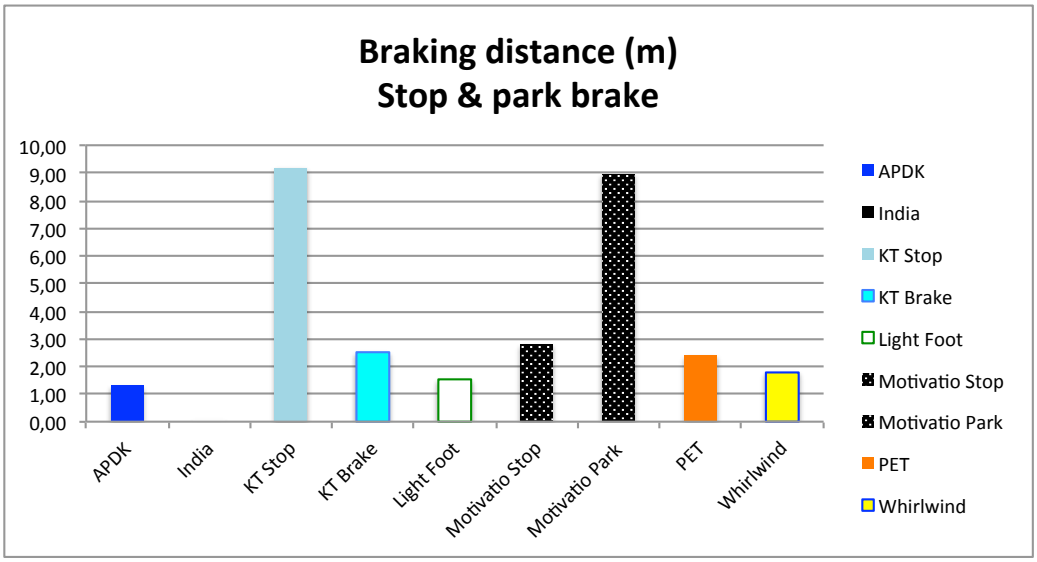


Figure 34: Test 2e-C, Braking distance result displayed in meter, the best is the lowest distance.

Discussion of the Braking Distance Test

APDK and Light Foot tricycles are the lightest in weight and performed the best amongst all the tricycles.

APDK

The APDK trike brake test result was the shortest braking distance; however because the brake is only on one side, it swerves to the left during braking. The APDK tricycle's braking performance is helped by the overall lightweight of the tricycle (28 kg). The APDK brake system is a pad on the left rear tire. The tire is a knobby type, which seems to produce a high amount of friction when braking.

Light Foot

The Light Foot tricycle's good performance is helped by the overall lightweight. Light Foot's brake uses a pad on the front tire and the front wheel supports most of the weight. Roughly 37% of the total weight of the user and tricycle is on the front wheel. The tire is a large knobby type, which produces probably a high friction when braking.

With all brake systems where a brake pad contacts a knobby tire, there is a possible disadvantage of poor tire wear and durability.

Motivation

Stop Brake

The Motivation stop brake uses a bicycle caliper at the front rim. This technology is inspired by the bicycle industry and is probably the most reliable design. The brake performance and longer stop distance is likely due to the comparatively low proportion of weight on the front wheel, only 14%.

Parking Brake

When used for stopping, the Motivation parking brake has a very poor performance. The braking system uses a pad on the rear tire. The tire is narrow, thin and slick, which produces low friction between the pad and the tire. The brake bracket tends to flex when maximum braking force is applied.

Kien Tuong

Stop Brake

The Kien Tuong tricycle's stop brake requires a very long distance to effectively stop and was ranked 6th. The distance required is approximately three times the distance of other tricycles.

Parking Brake

Surprisingly, the Kien Tuong tricycle's parking brake is more efficient in the stopping function than the stop brake. This may be due to the high proportion of weight on each rear wheel, approximately 40% of total weight. For the stop brake, the tricycle uses a bicycle type drum brake on the front wheel. During the evaluation by the test driver, it was not possible to lock the front wheel in a skid or nearly achieve a skid. When squeezing the brake lever, there appears to be considerable play in the brake cable that wastes braking force before fully engaging the brake drum pad. The tricycle tested was new, but this fact was also observed on the other two tricycles, which were already tested during the previous months.

Whirlwind

Whirlwind's stop brake acts on the rear tires and the good brake performance was helped because a high proportion of total weight is on each rear wheel, 40% per wheel. A central axle connects the brake levers, left and right. As a result, when the brake is engaged, both rear tires receive braking action.

PET

The PET tricycle's mediocre performance is due in part to its relatively high weight (45 kg empty). The brake pad acts on the front tire and the front wheel carries approximately 33% of the total weight.

Indian Standard

The Indian Standard tricycle's brake mechanism broke during the first trial. There is no data from the test because the test was cancelled due to the extreme difficulty of repairs. On two separate occasions, the brake cable broke at the connection between the lever and the cable. It is possible that the long brake lever arm produces more force than the thin steel cable can withstand.

8.4 Conclusion on the Braking Test

The users preferred a brake system architecture that consisted of a stop brake using one bicycle type lever which is positioned on the direction handle and a separate parking brake within convenient reach.

Only the Motivation and Kien Tuong tricycles possess the architecture preferred by the users.

The Light Foot tricycle's brake architecture was also appreciated. The Motivation tricycle has the best braking architecture and the best performance review by the users. The APDK tricycle has the least preferred architecture, as it has only one brake on the left rear wheel that is used for both stopping and parking.

The APDK and Light Foot tricycles performed best in terms of the braking distance to stop. Their short braking distance is probably due to their low weight and the high friction of the brake pad on a knobby tire. The Whirlwind has the third best braking distance favored by a braking system activating the two rear wheels.

As intended, the Motivation tricycle's stop brake performed better than its parking brake to stop. However, surprisingly, the Kien Tuong tricycle's parking brake performed better than the front stop brake. No data was recorded for the Indian Standard because the brake mechanism broke repeatedly.

9 Performance Test 3: Cargo Results

9.1 Objective of the Cargo Feature

The main purpose of the cargo capacity of a tricycle is to carry goods and possibly to facilitate income generation (McCambridge 2006).

9.2 Presentation of the cargo feature on the tricycles

Cargo feature of the seven tricycles tested can be described as follows:

- Four tricycles had cargo capacity: APDK, Light Foot, PET and Whirlwind,
- The Kien Tuong tricycle has a small cargo platform but it was not large enough to carry the bag of cement which served as a test load,
- Two of the tricycles, the Indian Standard and the Motivation tricycles, were not designed with any cargo carrying function,
- The Whirlwind cargo prototype includes a central cargo below and behind the seat, and an optional front rack. The optional front rack was not tested.

Therefore, only the APDK, Light Foot, PET and Whirlwind tricycles were tested. An overview of all cargo features is presented in the figures below (Figure 35 – Figure 40).

Figure 35: The APDK cargo basket at the rear of the seat.

Figure 36: The Light Foot cargo box.

Figure 37: The PET cargo box.

Figure 38: The Whirlwind cargo platform under and behind the seat.

Figure 39: Whirlwind optional rack platform. This front rack feature was not tested.

Figure 40: The Kien Tuong small platform rack behind the seat. This feature was not tested.

9.3 Summary of the Cargo Test Protocol

For the cargo evaluation, the tests were conducted in two villages with a 40 kg cement load. The tests complement the two track tests: Section 1b - 50 meters firm level ground, and Section 1c - 20 meters soft uneven ground.

The time required to complete the test track was measured for each user on each tricycle. The outcome measure "Payload Time" was calculated by subtracting the time required without cargo from the time required with cargo. "Payload Time" considered the performance degradation due to the cargo load. The final result presented is the median time of all the users.[11]

9.4 Cargo Performance Test Results

Initially, there was an assumption that there would be an increase in the time to perform the track tests due to the 40 kg load (i.e. positive Payload Time). However, some tricycles performed faster with cargo, resulting in a negative Payload Time.

[11] Protocol implementation of the tricycle user field test at Yogyakarta. [UCPRUK/RD/2014/042]

9.4.1 Results of cargo test performance on firm level and soft level ground

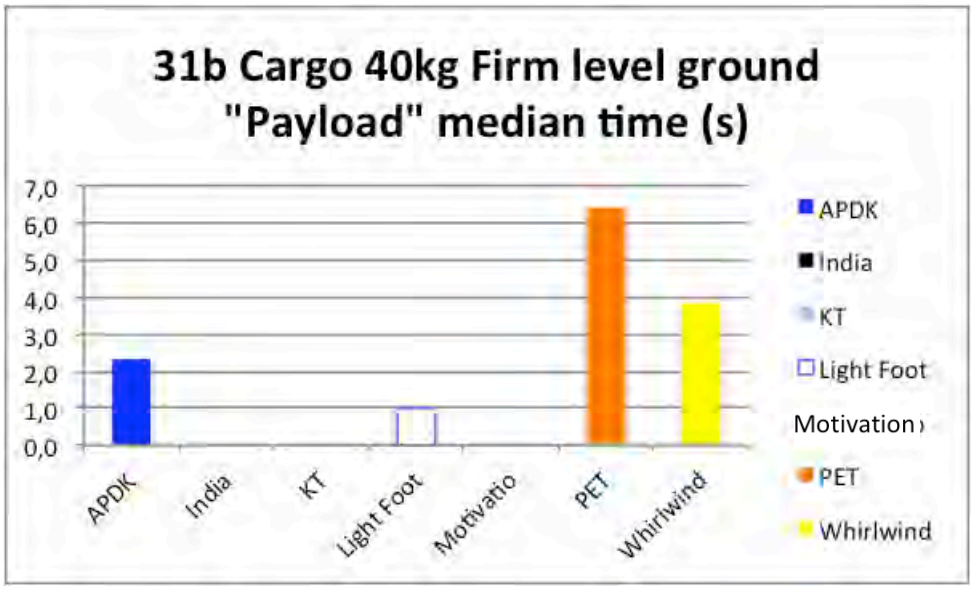


Figure 41: Test 31b, Cargo Payload Time, on firm level ground. The median time is displayed in seconds. The highest time is worst.

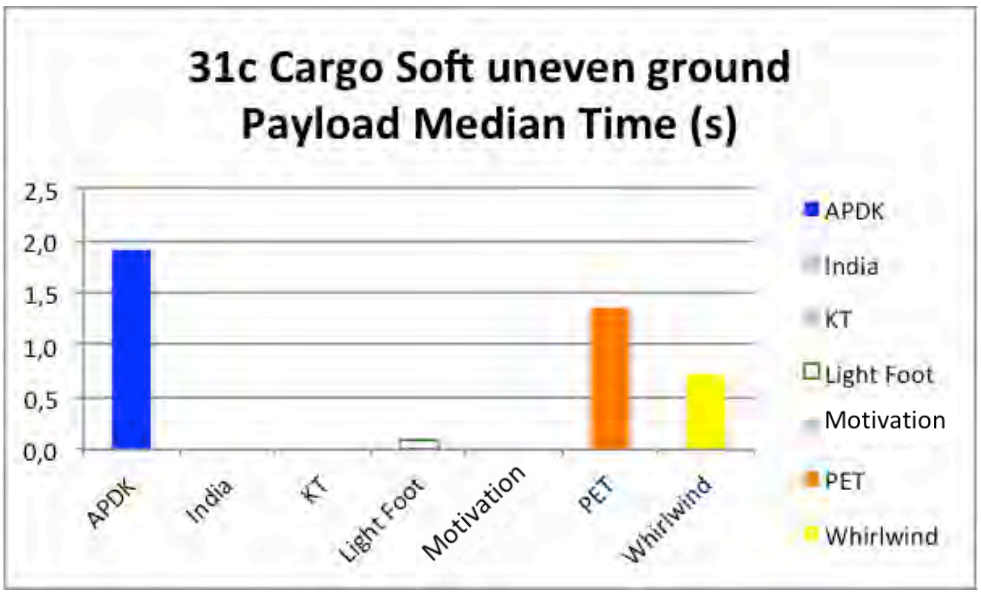


Figure 42: Test 31c, Cargo Payload Time, on soft uneven ground. The median time result is displayed in seconds. The highest time is the worst.

9.4.2 Cargo Performance Test Discussion

Light Foot

- On the 50 meters firm level ground (test 31b), the Light Foot performs the best.
  - Light Foot Payload Time ranges from (-5.0 sec. to 5.1 sec.), with a median of 1.0 s.
- On the 20 meters soft uneven ground (test 31c), Light Foot performs the best.
  - Light Foot Payload Time ranges from (-8.4 sec. to +3.4 sec.) with median time of 0.1 sec.
- The time to perform the test was not impacted by the 40 kg load.
- When the tricycle is loaded with the cargo load, active users did not have difficulty crossing the bumpy streets of the village.
- The user's gear selection was not recorded, but the option of selecting the best gear ratio is, generally speaking, a benefit when carrying a load.
- The tricycle's good rolling resistance may have been an advantage.

Whirlwind

- On the 50 meters firm level ground (test 31b), Whirlwind is placed third.
- Whirlwind Payload Time ranges from (-1.2 sec. to 14.3 sec.), with a median of 3.8 sec.
- On the 20 meters soft uneven ground (test 31c), Whirlwind performs second best.
- Whirlwind Payload Time ranges from (-2.4 sec. to +3.4 sec) with median time of 0.7 sec.
- Whirlwind has a good rolling resistance on sand, which explains these results.

APDK

- On the 50 meters firm level ground (test 31b), APDK is placed second
  - APDK Payload Time ranges from (-10.4 sec. to 15.9 sec.), with a median of 2.3 s.
- On the 20 meters soft uneven ground (test 31c), APDK ranks fourth
  - APDK Payload Time ranges from (-1.4 sec. to 9.1 sec.) with median time of 1.9 sec.
- When the tricycle was loaded, some users found it hard to propel.
- The steering handle tends to be unstable, causing the user to slam left and right.
- Users experienced difficulty in overcoming bumps on the village street.

PET

- On the 50 meters firm level ground (test 31b), PET performance is placed fourth.
  - PET Payload Time ranges from (-1.2 sec. to 34.8 sec.), median time of 6.4 sec.
- On the 20 meters soft uneven ground (test 31c), PET is placed third.
  - PET Payload Time ranges from (- 1.0 sec. to 7.3 sec.) with median time of 1.4 sec.

- The PET tricycle has the highest loss of rolling efficiency. The rolling resistance of the tires increases with the load applied (Gordon, Kauzlarich, and Thacker 1989). The airless tire may be comparatively more impacted by the load, due to a higher hysteresis (i.e. internal energy lost due to damping). Therefore, the tricycles having a high rolling resistance will have a significantly degraded performance when carrying a load. Good rolling resistance is an important characteristic for effectively carrying cargo.

9.5 Users Preference for the Cargo

The user's preference for the cargo was determined during the final interview (Test 4.6 & 4.7).

- The Light Foot has the cargo architecture was most preferred by the users.
- The PET cargo is the second most preferred by users.
- Whirlwind cargo is placed third.
- APDK cargo is placed fourth.
- The "Box type" cargo is the most preferred architecture.

See the cargo feature preferred by the user on Figure 52, Figure.

9.6 Feedback of the User on the Cargo Function

From the comments expressed by the users during all the tests and the focus group, we noticed the following categories for cargo.

- They expect to carry:
  - Goods to sell,
  - Goods for farming,
  - Children, particularly if user is a mother,
  - Crutches for ambulating people.

- The following architecture was preferred by the user:
  - Cargo box.

- The following feature request was expressed by some users:
  - A cover on the box to protect the goods in case of rain.

- The following architecture was the least preferred:
  - Combination of cargo and footrest.
    - The combination of a cargo and the footrest on the floor is not accepted in Indonesia. Contact between feet and cargo, especially food, is considered improper. This is a common cultural belief in South-East Asian countries. The cargo area design should separate the footplate area from the cargo area.

Figure 43: Whirlwind cargo, User 1SUK shown. Crutch users need to carry their crutch on the tricycle.

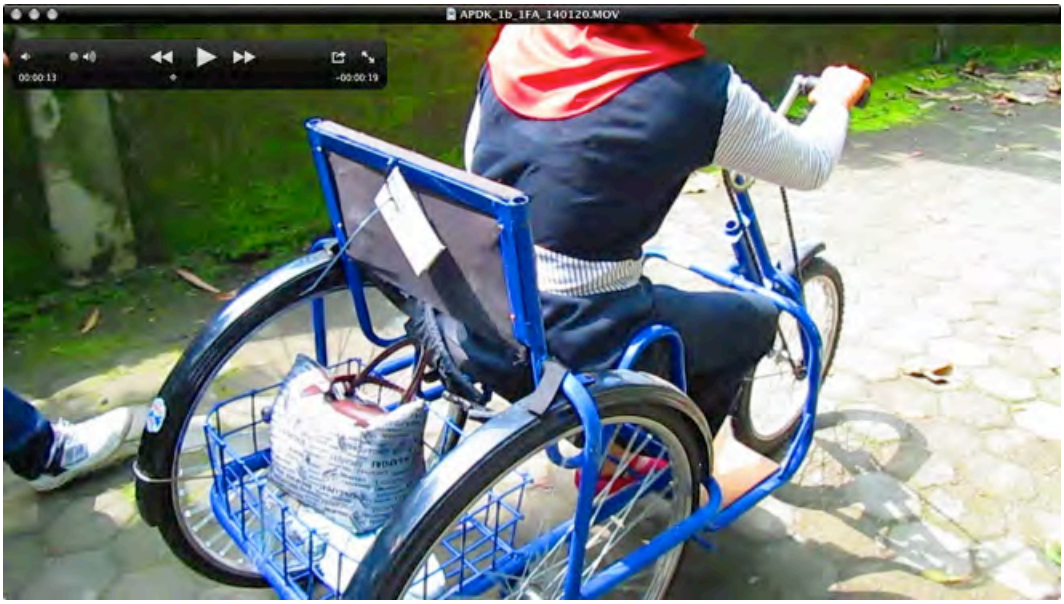


Figure 44: APDK cargo, User 1FA shown. A basket is convenient for small objects such as a handbag.

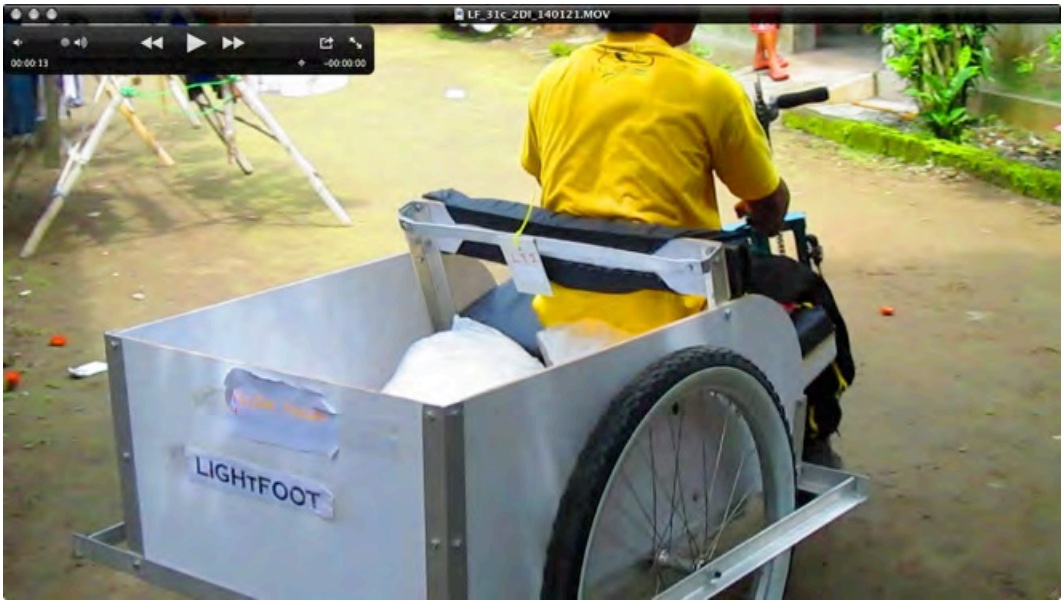


Figure 45: Light Foot cargo, User 2DI shown. This cargo area has a large capacity for goods. A load of cement is shown.

Figure 46: PET cargo, User 2AR shown. For this tricycle the cargo capacity is limited but the strong cargo area walls allow even heavy goods to be packed.

9.7 Conclusion of the Cargo Test

- The Light Foot tricycle has the best time performance with a 40 kg load during the village test.
- The Light Foot tricycle's good rolling resistance is an advantage.
- The PET tricycle performed the worst.
- Tricycles with poor unloaded rolling resistance are at a greater disadvantage when loaded with heavy cargo.
- The Light Foot's cargo area design is most preferred.
- Users prefer a "Cargo Box" design with strong walls without holes and possibly a cover to protect goods from rain.
- Users noted the need to carry children, assistive devices like crutches, and goods to sell, farming tools, and various materials.
- Cargo capacity serves an important function and is a requirement for people with disabilities.

Table 5: Summary of the cargo feature on the tricycles

	APDK		***Light Foot***	***PET***	***Whirlwind***	
Type	Basket		Box	Box	Platform	
Figure						
Dimension & Volume	Depth (cm) 27 Width (cm) 45 Height (cm) 12 Volume (cm^3) 14 580		Depth (cm) 47 Width (cm) 51 Height (cm) 37 Volume (cm^3) 88 689	Depth (cm) 34 back; 80 all Width (cm) 50 Height (cm) 27 Volume (cm^3) 45 900	Depth (cm) 107 Width (cm) 51 Height (cm) 0 Volume (cm^3) **	
Position	Back / At level of seat		Back / At level of seat	Back / Under seat	Back / Under seat	
Uneven ground test	*Test 31b*	2nd	1st	4th	3rd	*Test 31b*
Soft ground test	*Test 31c*	4th	1st	3rd	2nd	*Test 31c*
Users preference	*Test 4.6 & 4.7*	4th	1st	2nd	3rd	*Test 4.6 & 4.7*
Advantage	+ Good for small object. + Can be repaired in a workshop. + Not sensitive to the rain.		+ Large volume available. + Closed walls, no holes. + Preferred by the users. + Can carry the children. + Time performance not affected by the load carried.	+ Volume available. + Closed edge, no holes. + Can carry the children. + Strong and thick wood.	+ Large area dimension. + Low position, better stability. + Strong steel material.	
Inconvenient	- Hole, risk to loose object. - Small volume.		- Wood material is easily damaged by the rain - Strength of the box walls is unknown.	- Wood material may be damaged by the rain - Poor performance time due to the load carried.	- No walls to hold loads in the cargo area. - The platform extends 25 cm behind the rear axle. This may decrease rearward stability.	
Note			Wood was locally bought.		Front rack not tested.	

10 Test 4: User Interview Results

10.1 Methodology of the Interview

The users completed a questionnaire to assess the tricycles' functions. The questionnaire was answered after the home trial period, one month after the performance test, and from one to three weeks after the end of the track and the brake test.

Each user was asked to rank each tricycle according to various criteria. The ranking scores are from 1 to 7 with 7 as the least preferred. The final score for each tricycle is the sum of each respondent's rank score. Therefore, the tricycle with the highest score is the least preferred. The questionnaires were completely answered by seventeen users. One user could not complete the questionnaire, due to difficulties in communication and in writing (a young active CP WC user) and is not included in the interview results. [12]

[12] Tricycle Test, results of test 4: Interview Rev. B. [UCPRUK/RD/2014/069]

10.2 Summary of Users Preference Results

Table 6: Summary of users preference for each feature

Test	Feature	Users	Preference	Comment
4.9	**Overall preference**	**17**	**1/ Light Foot** **2/ Whirlwind** **3/ Kien Tuong**	Light Foot is the most preferred for each function but 2. This tricycle is the most preferred by 7 users. Indian Standard ranked last place.
4.1	Transferring	17	1/ Light Foot 2/ Motivation 3/ PET	The easiest type of tricycle to transfer into is the cargo type that has a large seat. On Light Foot and PET, it is possible to transfer while keeping feet on the ground.
4.2	For paved road	17	1/ Light foot 2/ Motivation 3/ Whirlwind; Kien Tuong	Light Foot is the most preferred and it also had the best time on test 1a. Rankings of the others did not necessarily follow the order of times on test 1a.
4.3	For market	17	1/ PET 2/ Light Foot 3/ Motivation	PET is the 1st preferred for the market place, which reflects its good performance on test 2b. The users appreciate the easy maneuverability of Light Foot and Motivation.
4.4	For use on road with a hill	17	1/ Light Foot 2/ PET 3/ Kien Tuong 4/ WW; MOT	Light Foot is again preferred. PET, KT, WW, and MOT were tied.
4.5	For use off road	17	1/ Light Foot 2/ PET 3/ Whirlwind 4/ Kien Tuong	Light Foot is considered the most appropriate for off-road. PET has a good position, which is not correlated with its performance test. The users noted the PET's tires which do not have the risk of going flat.
4.6 4.7	For heavy cargo For volume cargo	17	1/ Light Foot 2/ PET 3/ Whirlwind	Light Foot is preferred. The "Cargo Box" type is preferred. See section §9.4
4.8	Best appearance	17	1/ Motivation 2/ Whirlwind 3/ Kien Tuong	The Motivation tricycle is considered to have the best appearance. This product is mass-produced in a factory. Motivation, WW, and KT have a steel frame with a good power coating finish.

10.3 Users Preference for Specific Tricycle Function

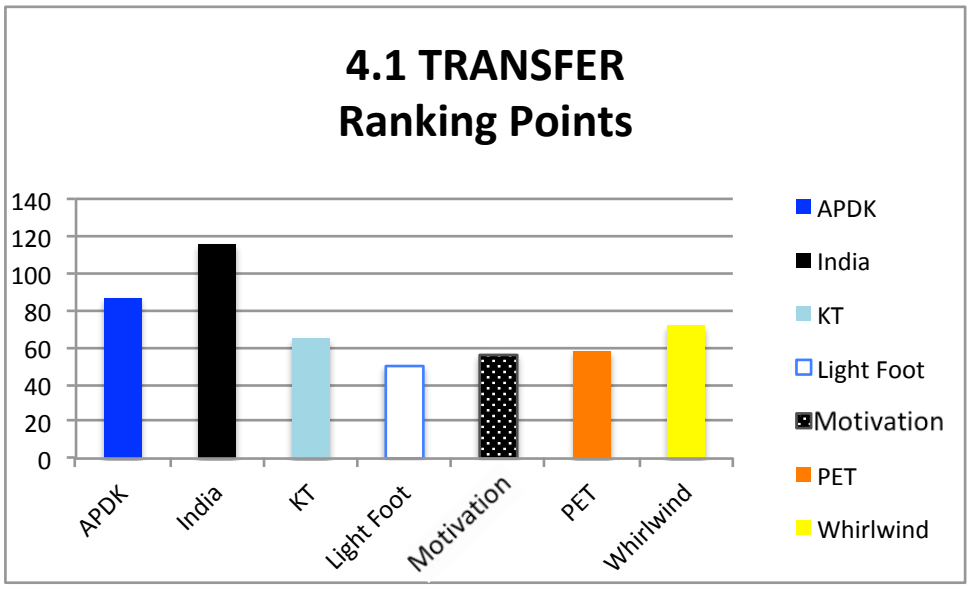


Figure 47: Interview 4.1 for Transfer. Note: Higher point scores indicate that the device is less preferred by users.

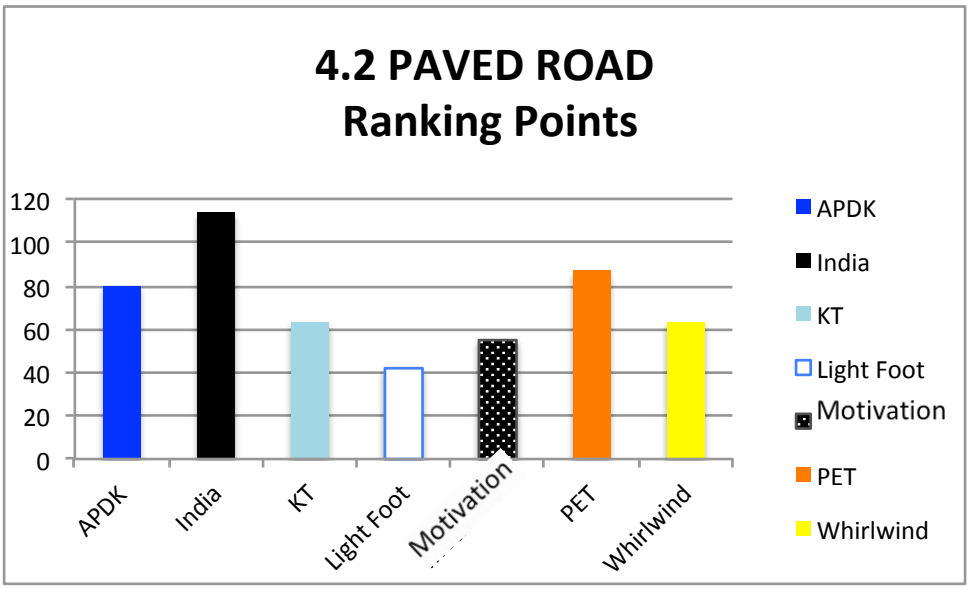


Figure 48: Interview 4.2 for Paved road. Note: Higher point scores indicate that the device is less preferred by users.

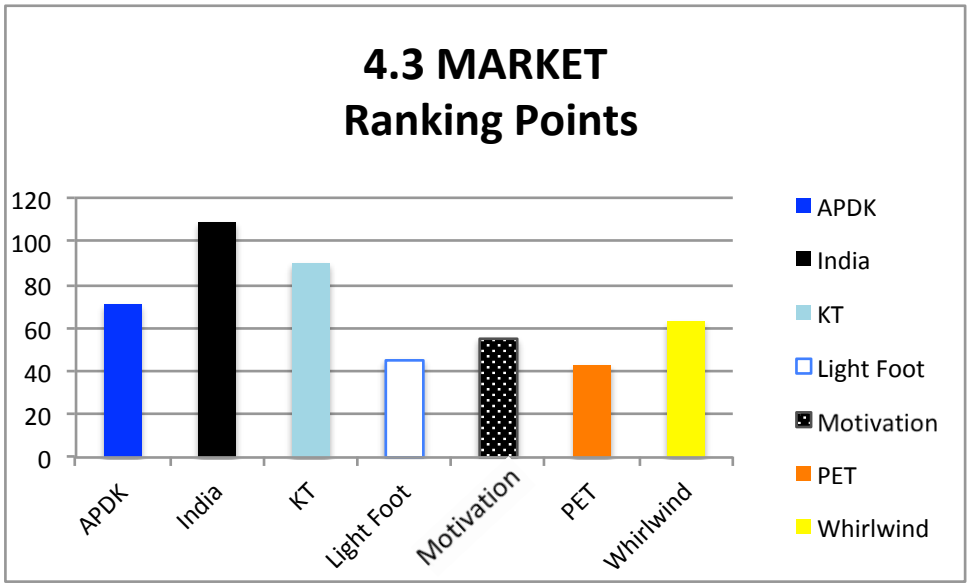


Figure 49: Interview 4.3 for Market. Note: Higher point scores indicate that the device is less preferred by users.

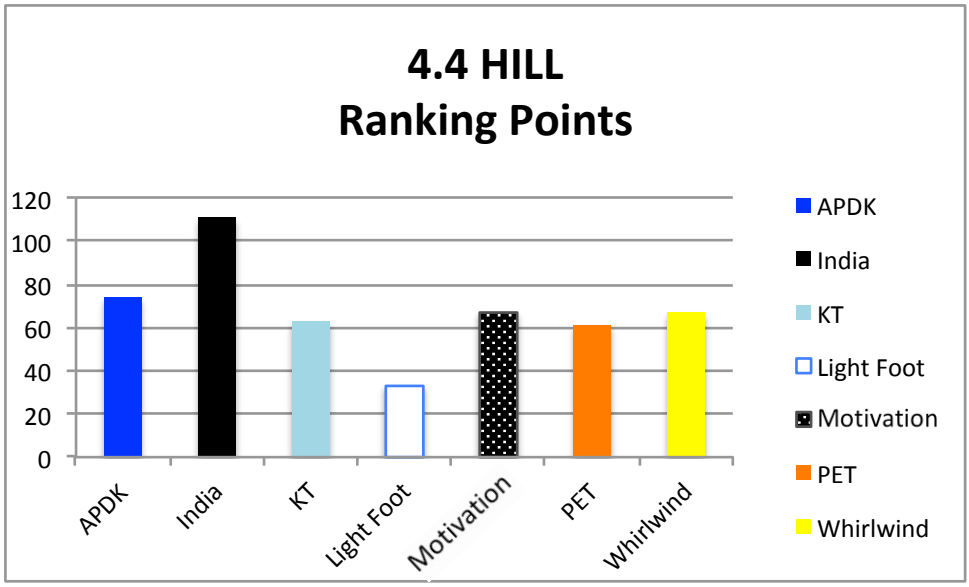


Figure 50: Interview 4.4 for Hill. Note: Higher point scores indicate that the device is less preferred by users.

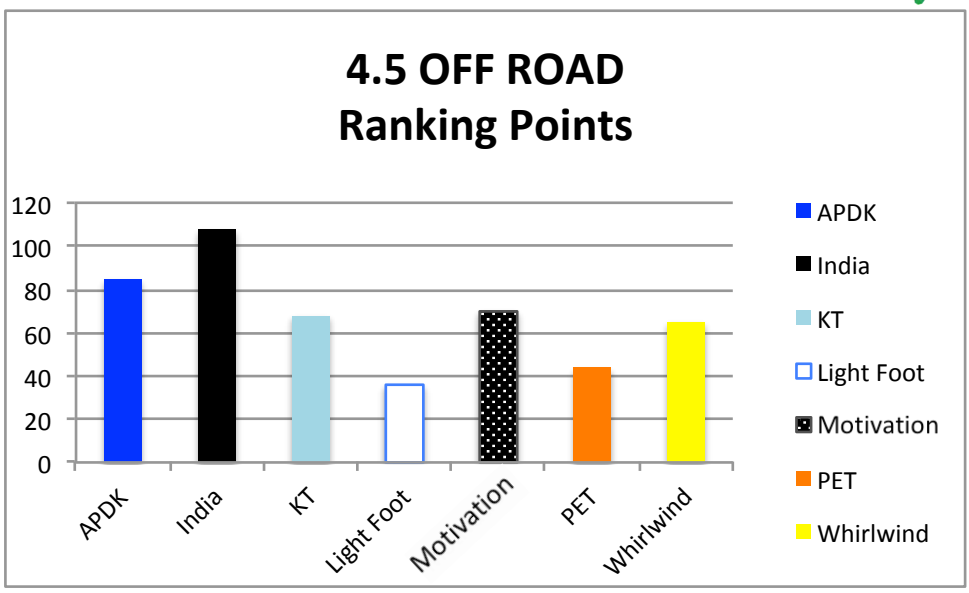


Figure 51: Interview 4.5 for Off-road. Note: Higher point scores indicate that the device is less preferred by users.

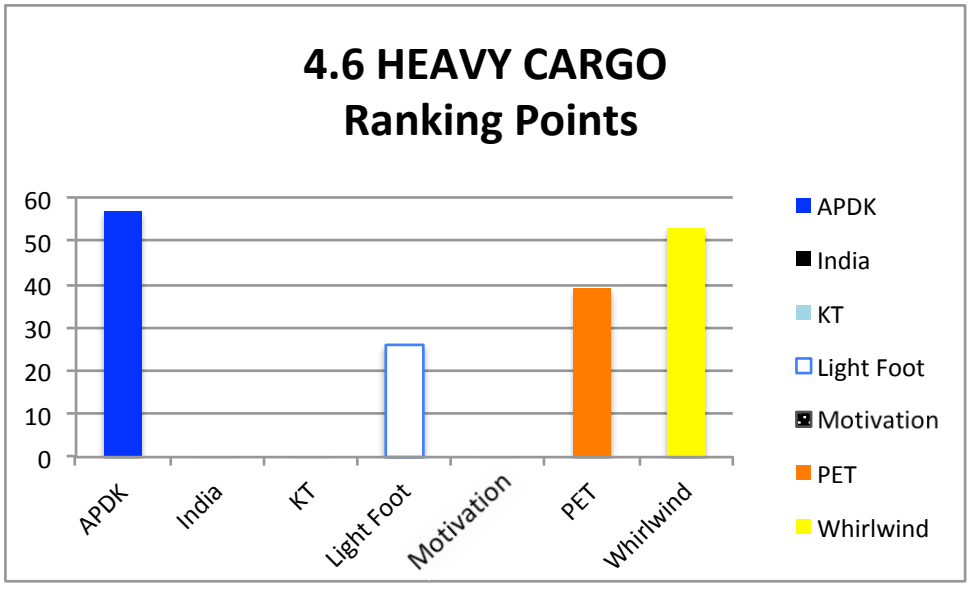


Figure 52: Interview 4.6 for Heavy cargo. Note: Higher point scores indicate that the device is less preferred by users.

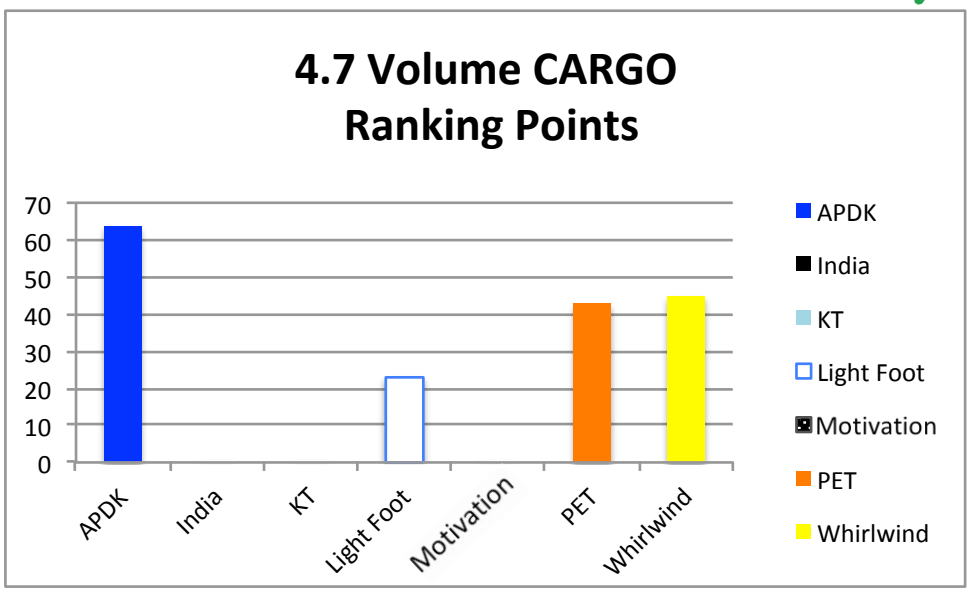


Figure 53: Interview 4.7 for Volume cargo. Note: Higher point scores indicate that the device is less preferred by users.

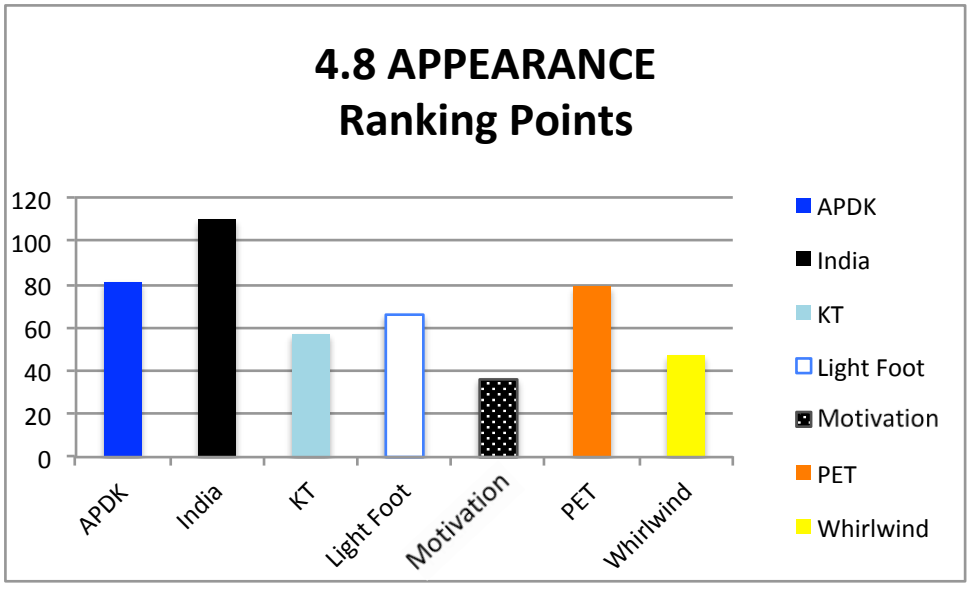


Figure 53: Interview 4.8 for appearance. Note: Higher point scores indicate that the device is less preferred by users.

10.4 Overall Preference of the Users

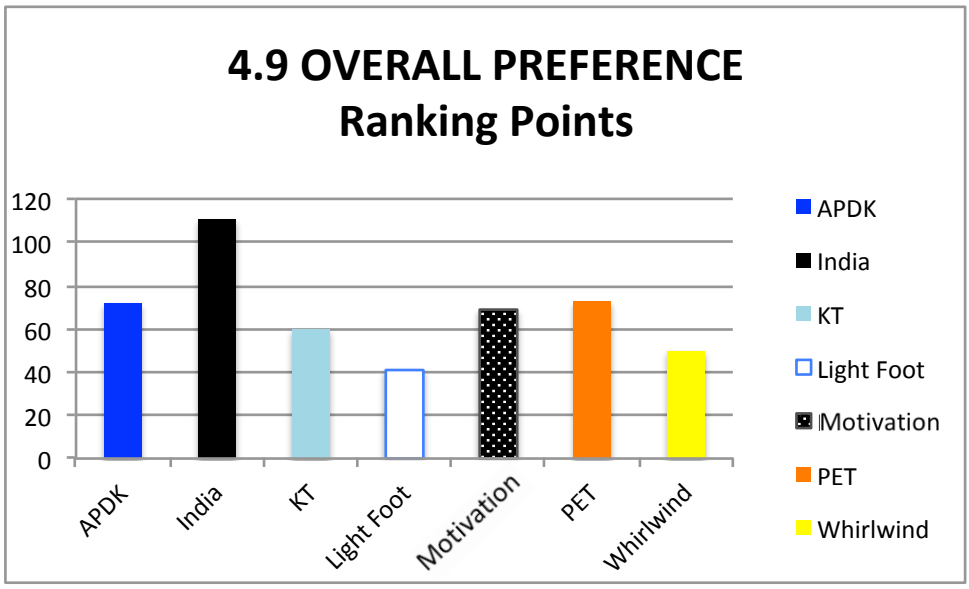


Figure 54: Interview 4.9 for Overall preference. Note: Higher point scores indicate that the device is less preferred by users.

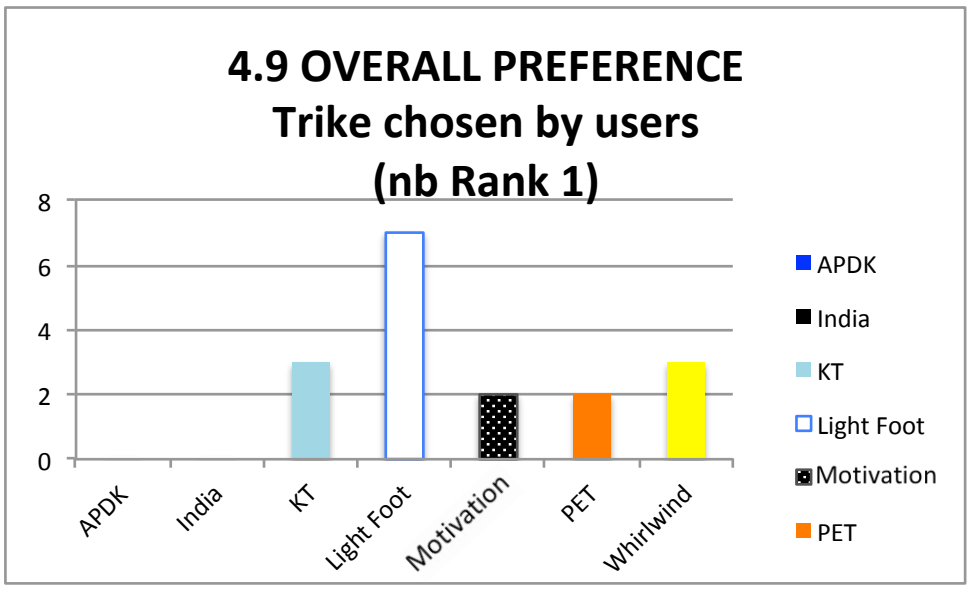


Figure 55: Interview 4.9 for overall preference. Note: High points indicate that the device is MORE preferred by users.

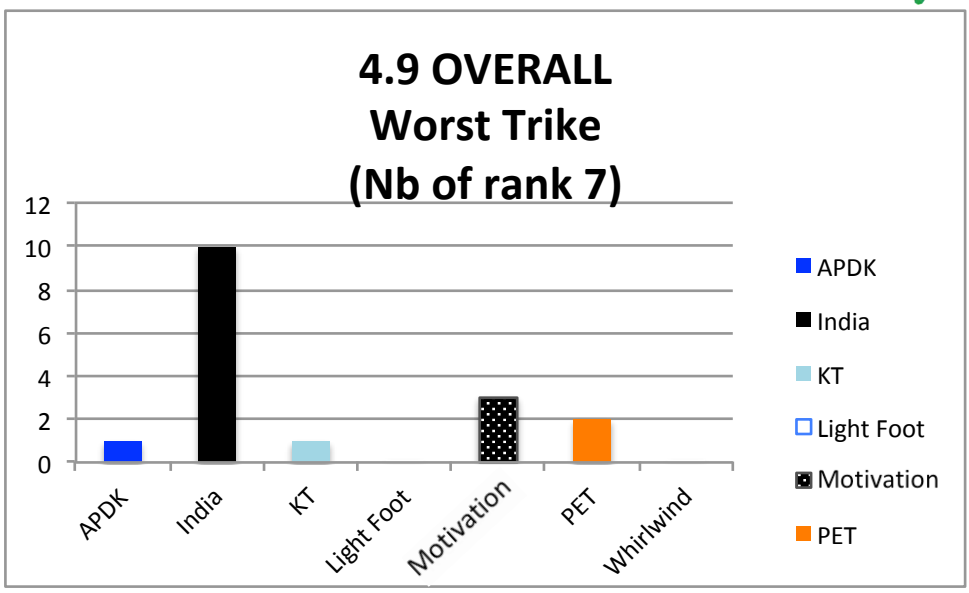


Figure 56: Interview 4.9 for Overall preference. The Y-axis shows the number of users who ranked the device as worst among devices tested.

10.5 Participants "Willingness to pay" for Weekly Rental of the Tricycle

The users was asked to evaluate the amount they would pay per week to use each tricycle. Only thirteen users answered this question (adolescents did not answer). The Median price for all tricycle is 10,000 IDR. For reference, the cost of a common breakfast meal in the user's area is 8,000 IDR.

The average for each tricycle is:

1. Motivation: 16385 IDR
2. Whirlwind: 15077 IDR
3. Kien Tuong: 13 846 IDR
4. APDK: 13 846 IDR
5. Light Foot: 12692 IDR
6. PET: 11923 IDR
7. Indian: 11077 IDR

This result does not relate to the overall preference ranking. From conversation with users, it appears that aesthetics and appearance are highly valued by users in comparison to simply pragmatic and functional concerns. Tricycles that have stylish designs, good quality finishing, and attractive appearance justify a higher cost of ownership for the users.

This explains why the Motivation, Whirlwind and Kien Tuong tricycles, which have high quality paint finishing, are valued higher than the Light Foot, which is the most preferred, but has an unrefined appearance with some unpainted metal stock parts and low quality plywood materials.

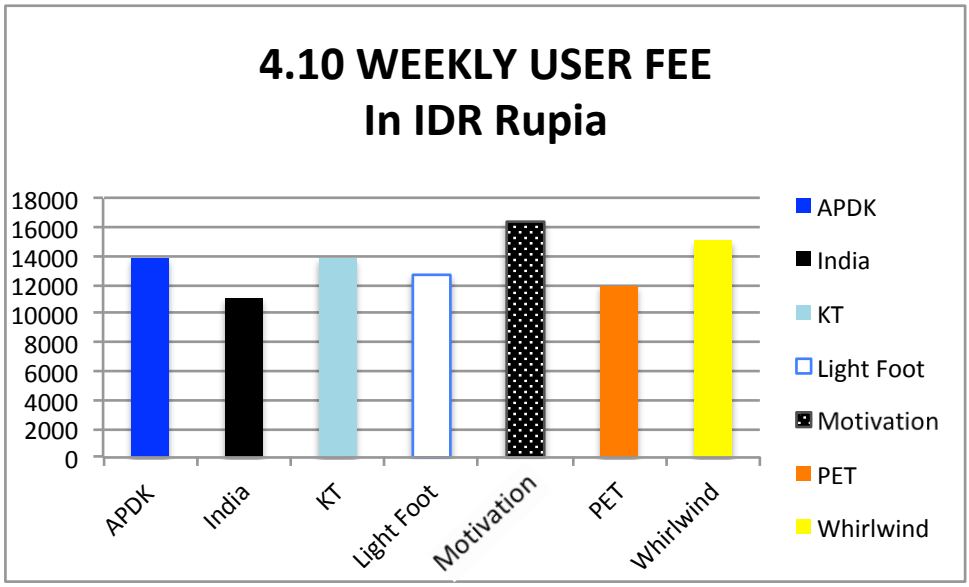


Figure 57: Interview 4.10 on the Weekly user fee, in Indonesian Rupiah. The highest price is the most valued.

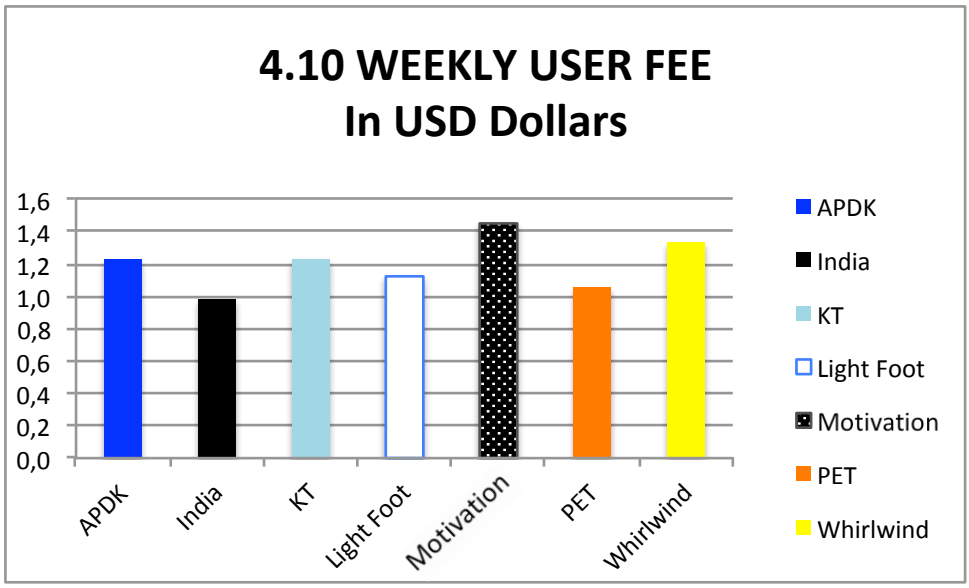


Figure 58: Interview 4.10 on the Weekly user fee, in US Dollars. The highest price is the most valued.

11 Test 5: Preference by users specificities

11.1 Methodology of the Users Specificities Analysis

The results of the Overall preference interview were used to determine the preference of each category of users. The following comparisons were studied:

- Men and women,
- Impairment,
- Type of Assistive Device used.

For the analysis by users' specificities, the results are based on a limited number of users. We invariably notice a strong preference towards the Light Foot tricycle. The comments will focus on specific needs of the users. [13]

[13] Tricycle Test, results of test 4: Interview Rev B. [UCPRUK/RD/2014/069]

11.2 Summary of the Preference

Table 7: Summary of users preference by disability and group

Test	Users specificities	Users	Preference	Comments
5.1	Men	10	1/ Light Foot 2/ Whirlwind 3/ Motivation	There is difference of preference between men and women.
5.2	Women	7	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	Women prefer a tricycle with cargo capacity.
5.3	Post-Polio users	9	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	
5.4	Cerebral Palsy users	4	1/ Light Foot 2/ Kien Tuong 3/ Whirlwind	
5.5	Amputee users	2	1/ Light Foot 2/ Whirlwind 3/ Motivation	
5.6	Post-fracture user	1	1/ Motivation 2/ APDK 3/ PET	
5.7	Paralysis Bone tuberculosis	1	1/ Light Foot 2/ Motivation 3/ PET	
5.8	Users without Assistive Devices	8	1/ Light Foot 2/ Whirlwind 3/ APDK	
5.9	Crutch users	4	1/ Light Foot 2/ Whirlwind 3/ Kien Tuong	Users need a way to transport their crutch. It can be stored in the cargo area, put on the floor, or clamped near the seat.
5.10	Cane & forearm crutch users	2	1/ KT 2/ Light Foot 3/ APDK	Same with crutch users.
5.11	Wheelchair users	2	1/ *equal scores* Light Foot Motivation Whirlwind	Light Foot is still appreciated. However, note that both Whirlwind and Motivation are wheelchair specialists. The MOT is based on a wheelchair. WW & MOT have push rims. Wheelchair users appear to be more comfortable with theses two tricycles.
5.12	KAFO user	1	1/ Light Foot 2/ Whirlwind 3/ APDK	

11.3 Preference of Men and Women

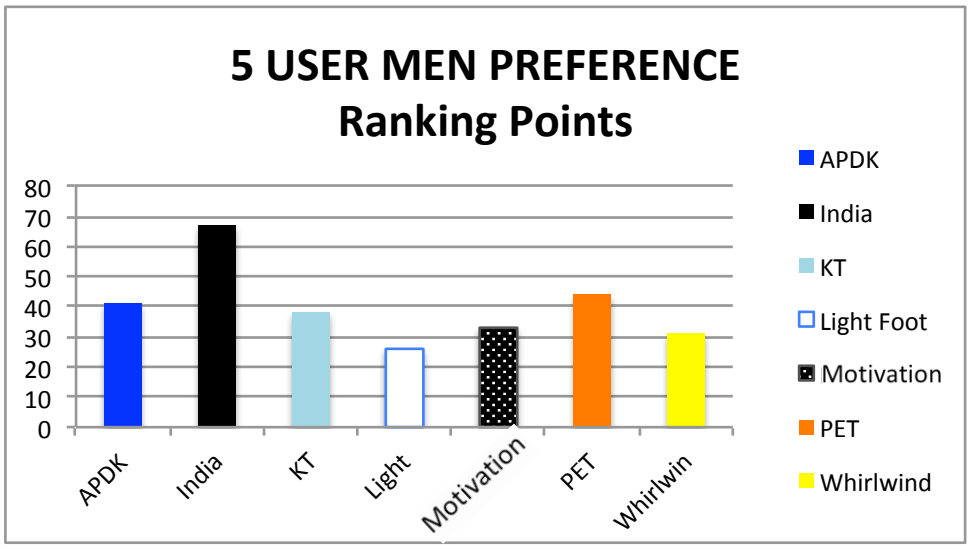


Figure 59: Test 5.1, Preference of five men. Ranking points. Higher points means less preferred.

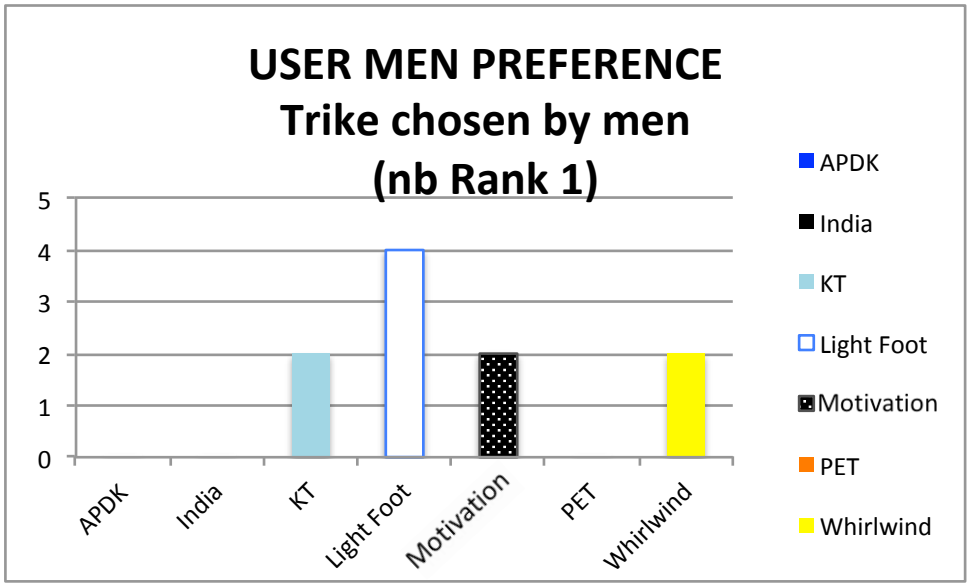


Figure 60: Test 5.1, Preference of ten men. Highest points show tricycle most commonly ranked first.

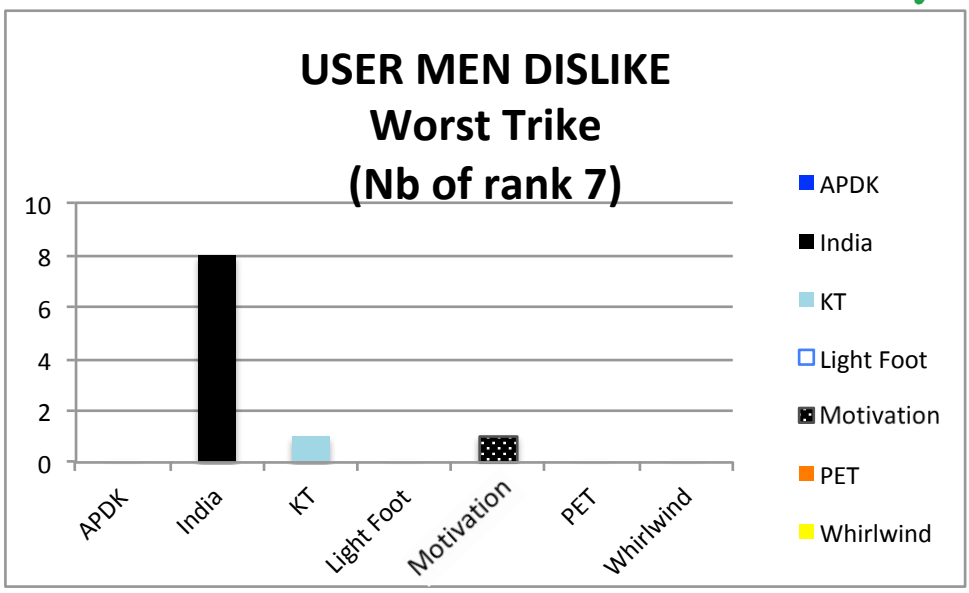


Figure 61: Test 5.1, Least preferred amongst men (n = 10). Highest points show tricycle most commonly ranked worst.

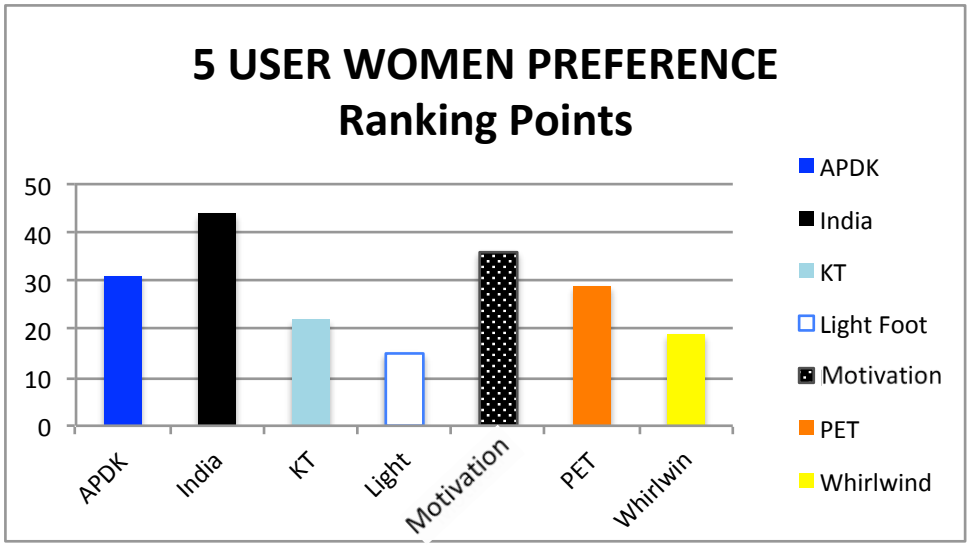


Figure 62: Test 5.2, Preference of five women. Ranking points. Higher points indicate less preferred.

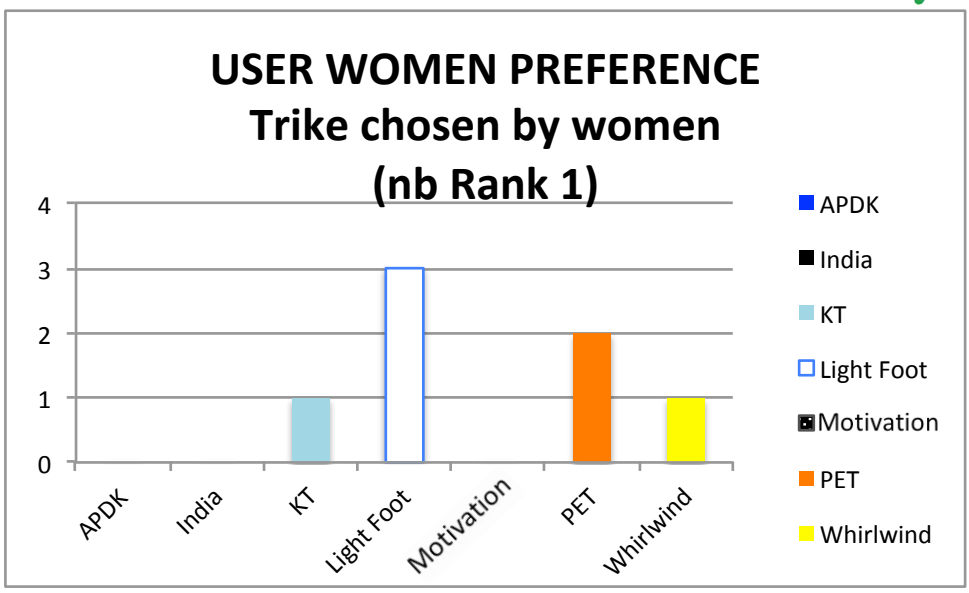


Figure 63: Test 5.2, Preferred tricycle amongst women (n = 7). Highest points show tricycle most commonly ranked first.

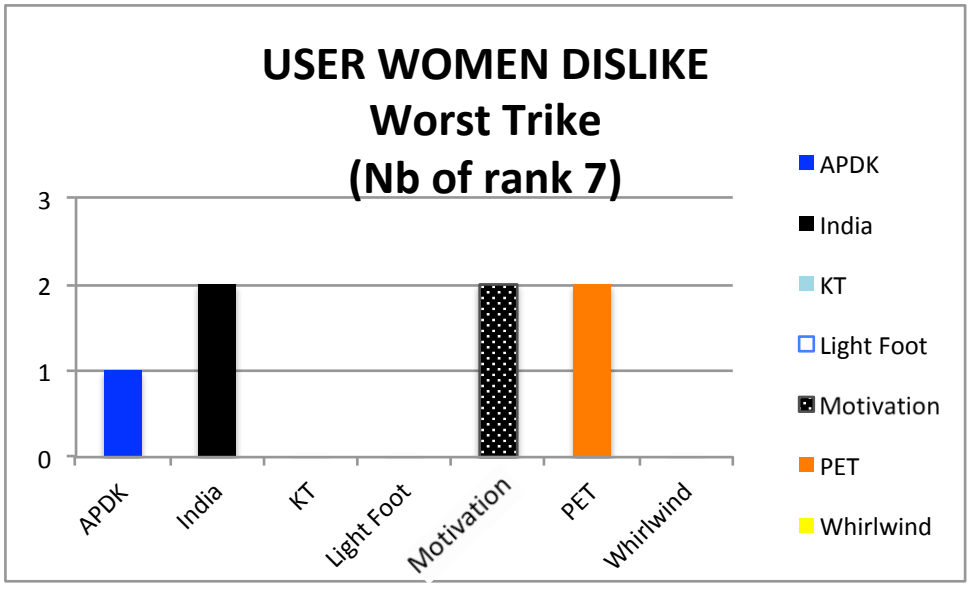


Figure 64: Test 5.2, Least preferred tricycle among women (n =7). Highest points indicate the tricycle most commonly ranked worst.

11.4 Preference of the Users by Impairment

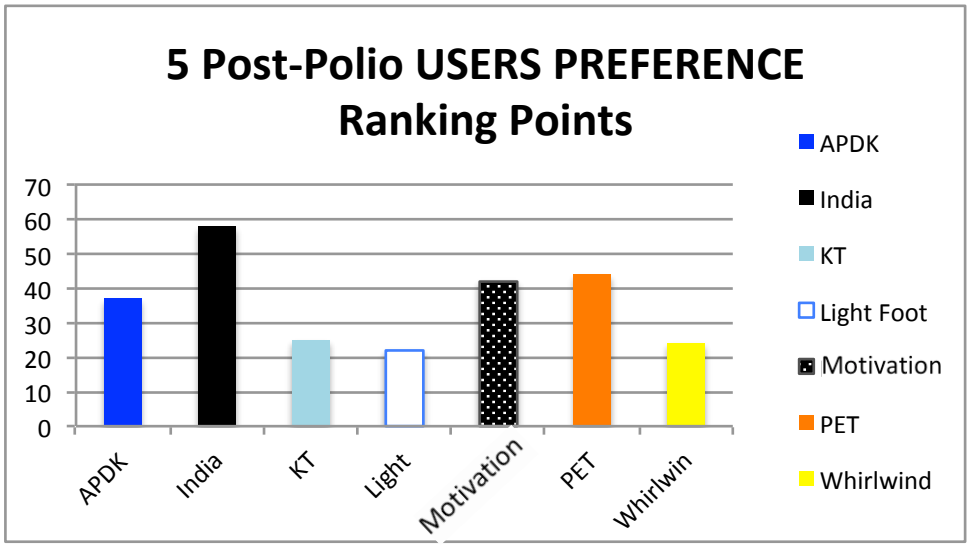


Figure 65: Test 5.3, Most preferred tricycle amongst users (n = 9) with Post-Polio. Higher points means less preferred.

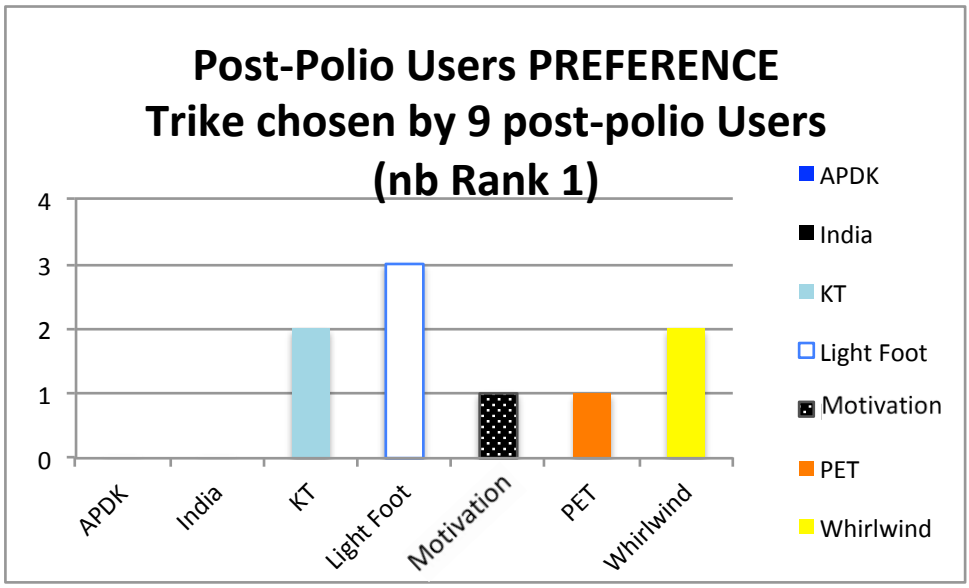


Figure 66: Test 5.3, Preference of nine Post-Polio users. Highest points indicate the tricycle most commonly ranked first.

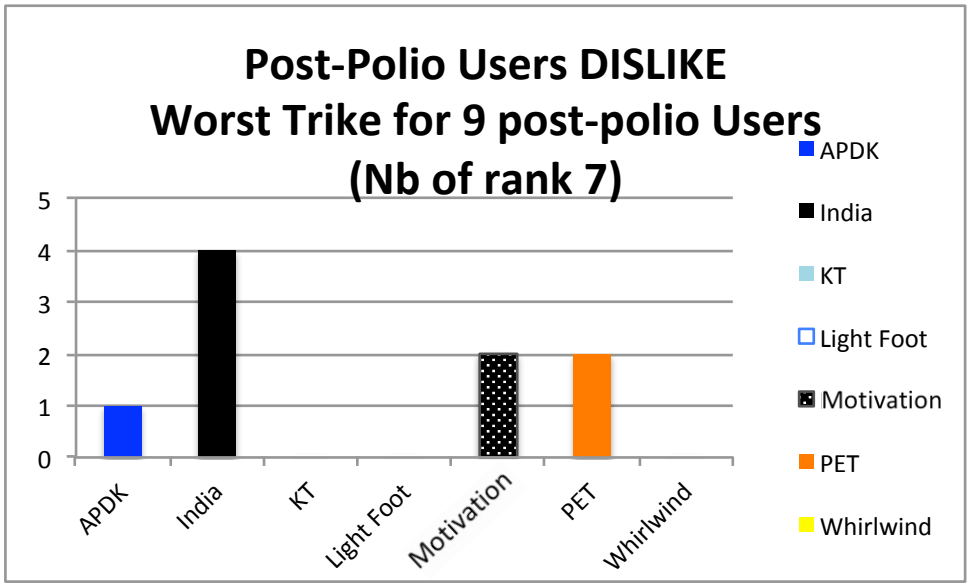


Figure 67: Test 5.3, Least preferred tricycles among Post-Polio users (n = 9). Highest points indicate the tricycle most commonly ranked worst.

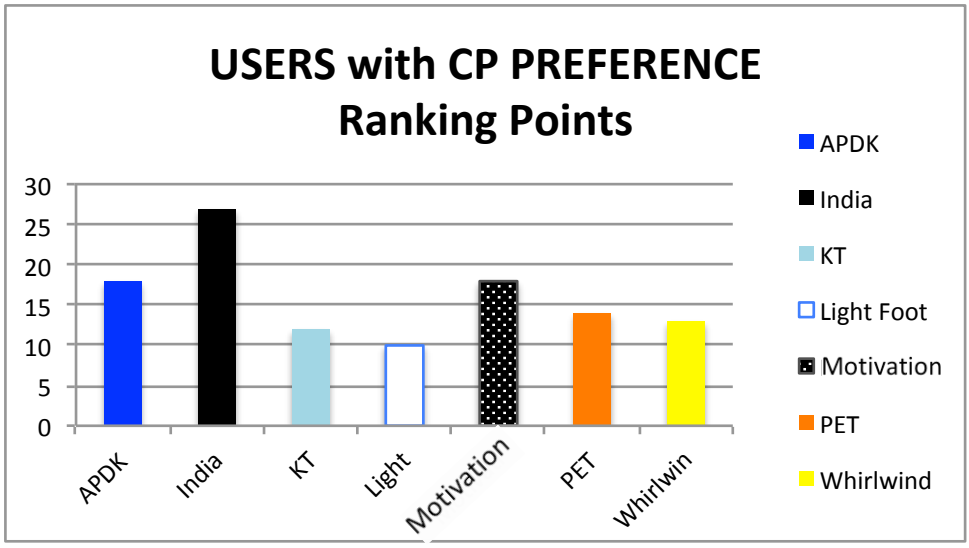


Figure 68: Test 5.4, Most preferred tricycles among users (n = 4) with Cerebral Palsy. Ranking points. Highest points means least preferred.

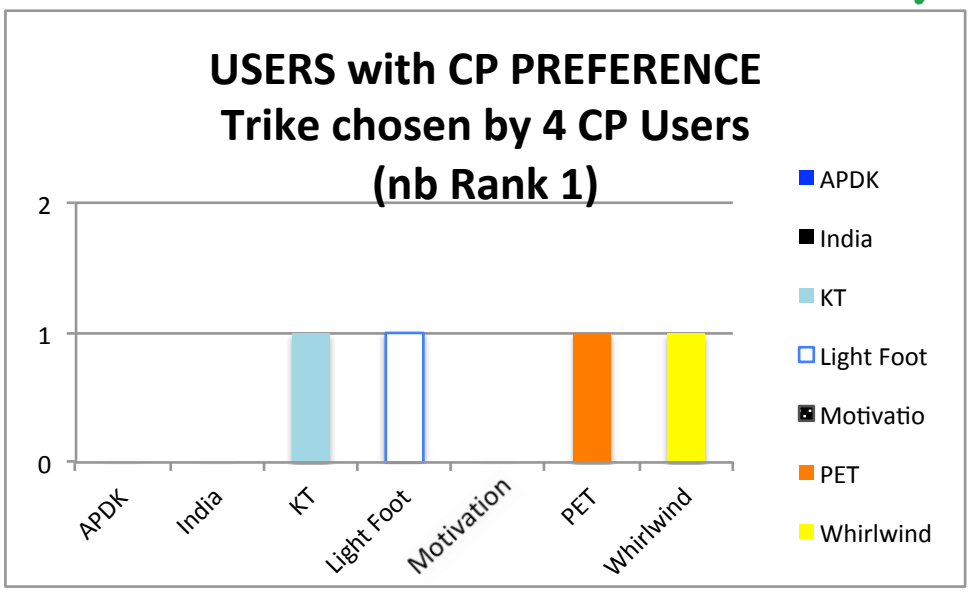


Figure 69: Test 5.4, Preference of four users with Cerebral Palsy. Higher points indicate the tricycles most commonly ranked first.

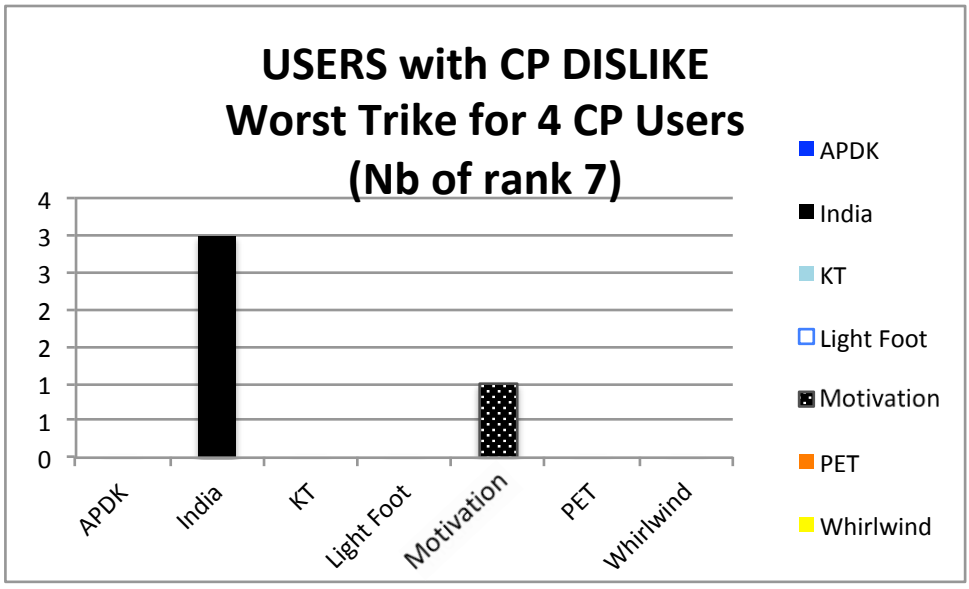


Figure 70: Test 5.4, Least preferred tricycles amongst users (n = 4) with Cerebral Palsy. Higher points indicate the tricycle most commonly ranked worst.

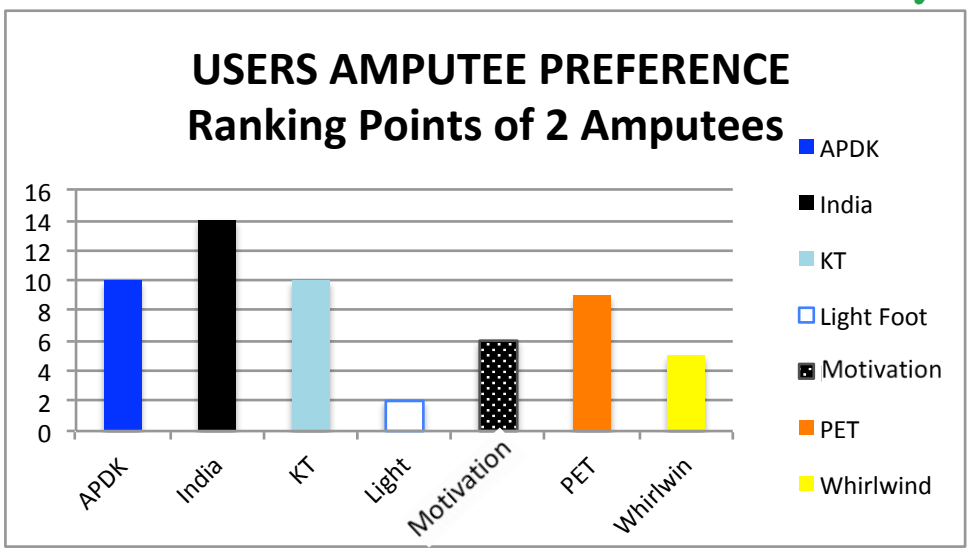


Figure 71: Test 5.5, Most preferred tricycle amongst users (n = 2) who are amputees. Ranking points. Higher points means less preferred.

Test (5.6) Post-fracture user

The tricycle preference for a post-fracture (male) user is:

- Motivation, 1st rank,
- APDK, 2nd rank,
- PET, 3rd rank.

Test (5.7) Paralysis Bone Tuberculosis user

The tricycle preference for a user with post Paralysis Bone Tuberculosis (male)

- Light Foot, 1st rank,
- Motivation, 2nd rank,
- PET, 3rd rank.

11.5 Preference of the Users by Type of Assistive Device Used

Test (5.8) Users without assistive device

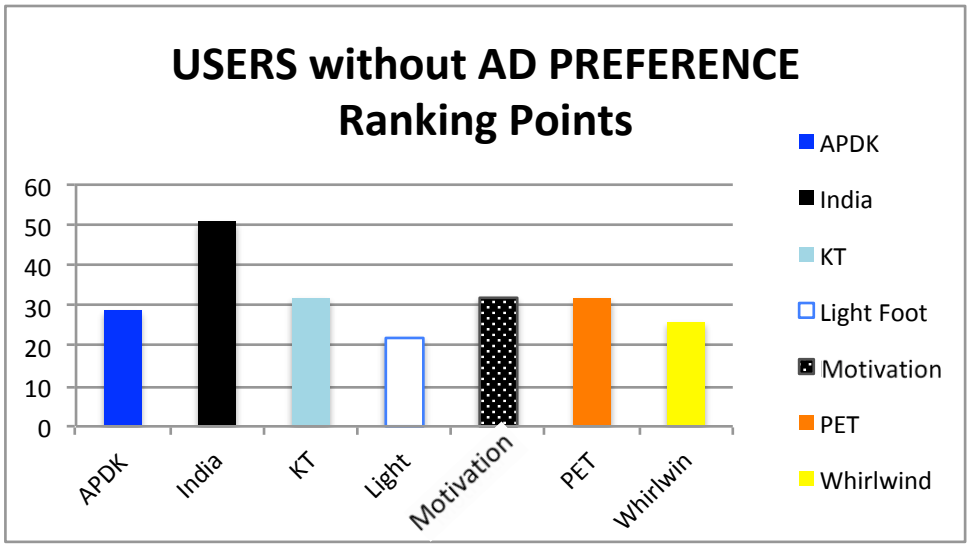


Figure 72: Test 5.8, Preference of eight users who do not use Assistive Devices. Ranking points. Highest points indicate the least preferred tricycle.

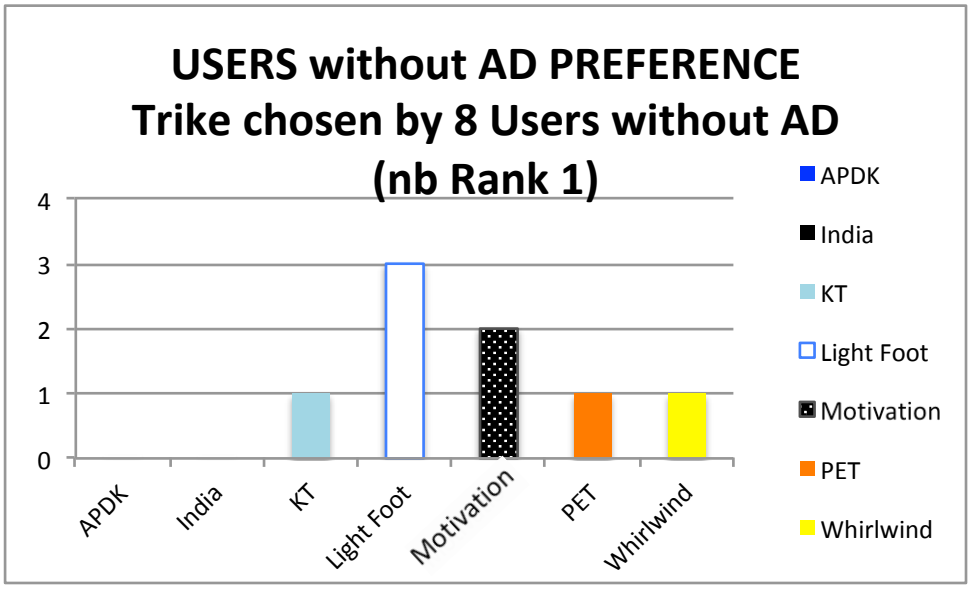


Figure 73: Test 5.8, Most preferred tricycles among users (n = 8) without an AD. Highest points show the tricycle most commonly ranked first.

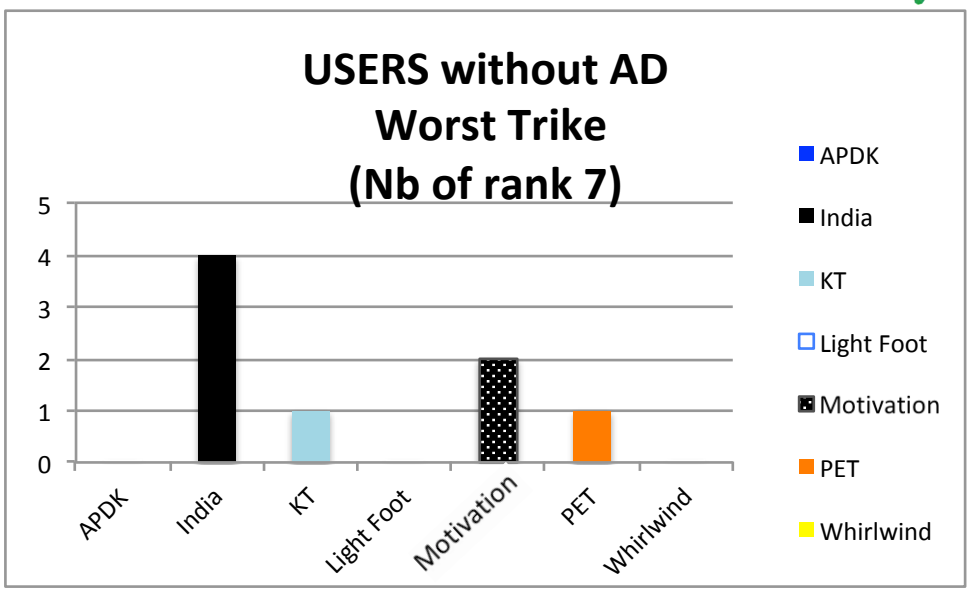


Figure 74: Test 5.8, Least preferred tricycles amongst users (n = 8) who do not use assistive devices. Highest points indicate the tricycle most commonly ranked worst.

Test (5.9) Crutch users

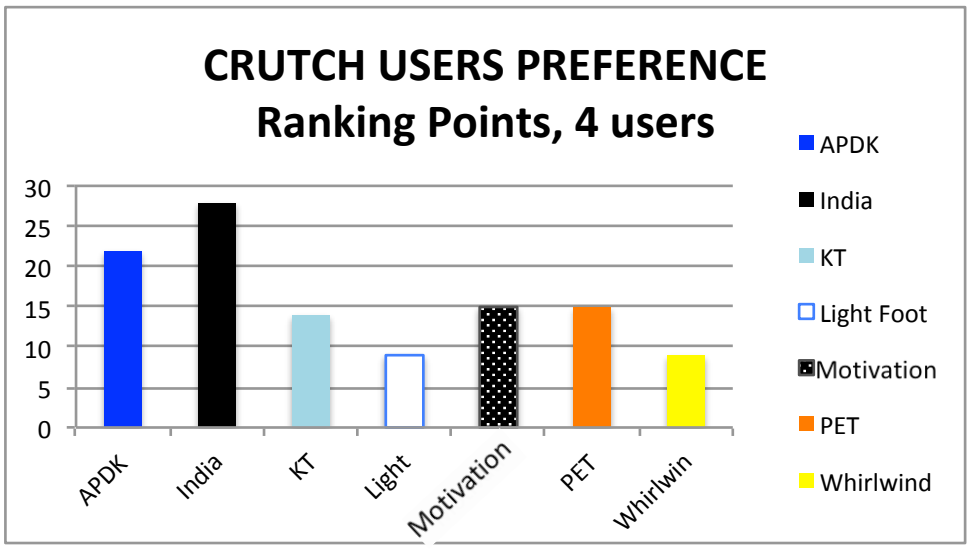


Figure 75: Test 5.9, Preference of four crutches users. Ranking points. Higher points indicate less preferred tricycle.

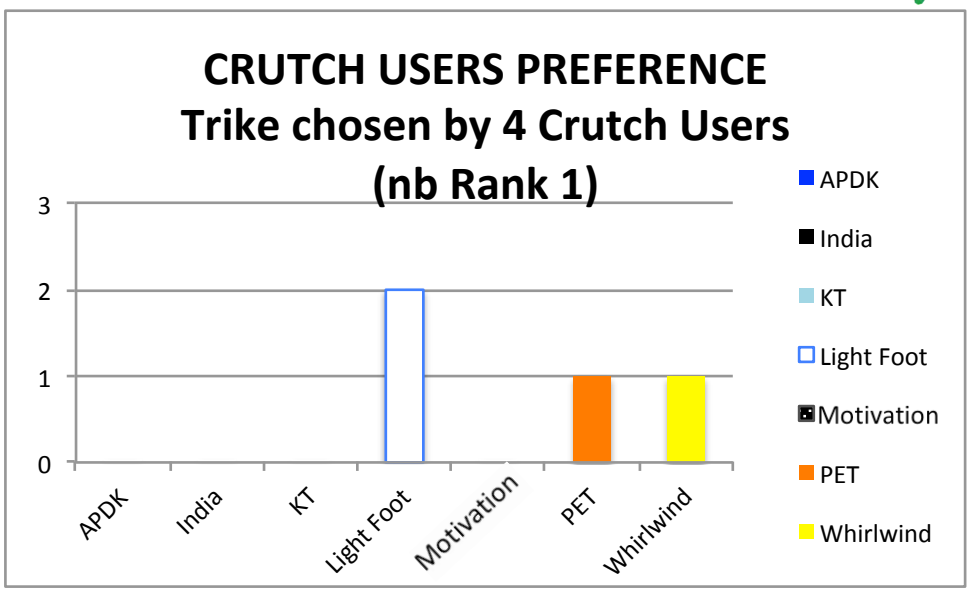


Figure 76: Test 5.9, Preference of four crutches users. Highest points indicate the tricycle most commonly ranked first.

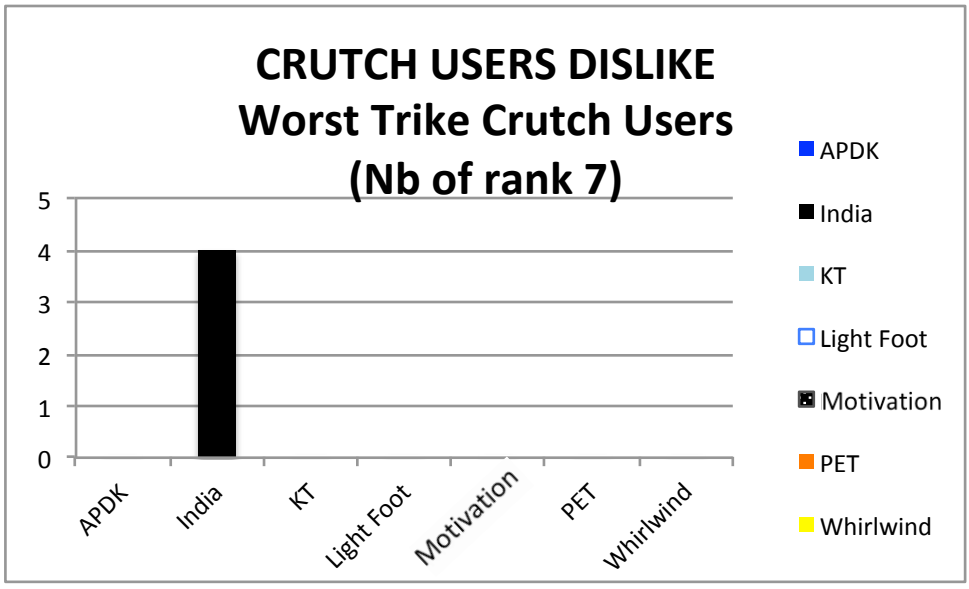


Figure 77: Test 5.9, Least preferred tricycle for four crutch users. Highest points show the tricycle most commonly ranked worst.

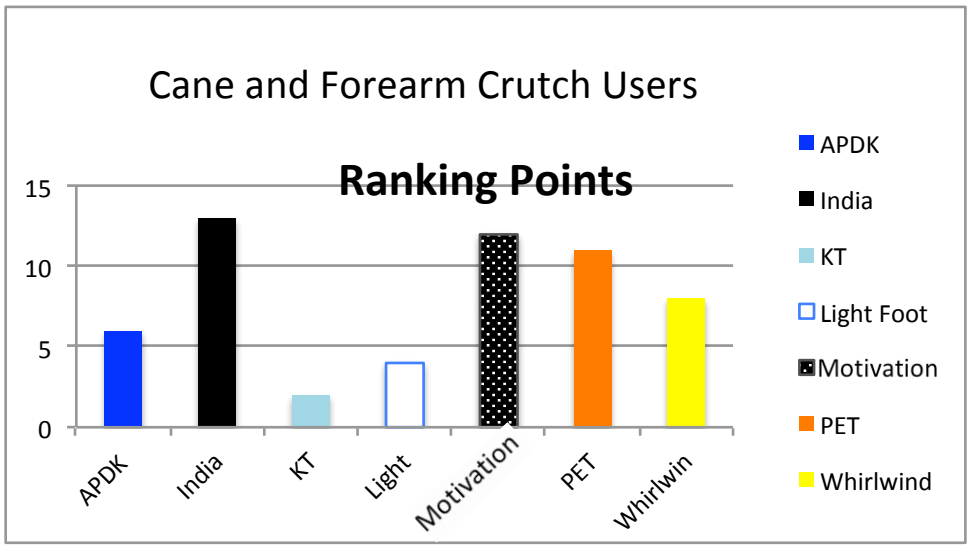


Figure 78: Test 5.10, Preference of two cane & forearm crutch users. Ranking points. Higher points indicate less preferred.

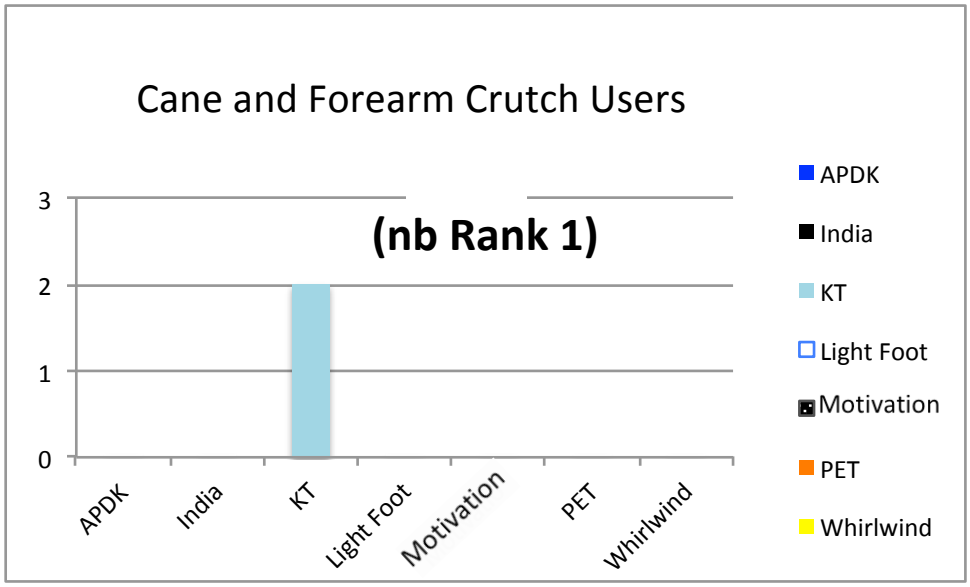


Figure 79: Test 5.10, Preference of two cane and forearm crutch users. Highest points show the tricycle most commonly ranked first.

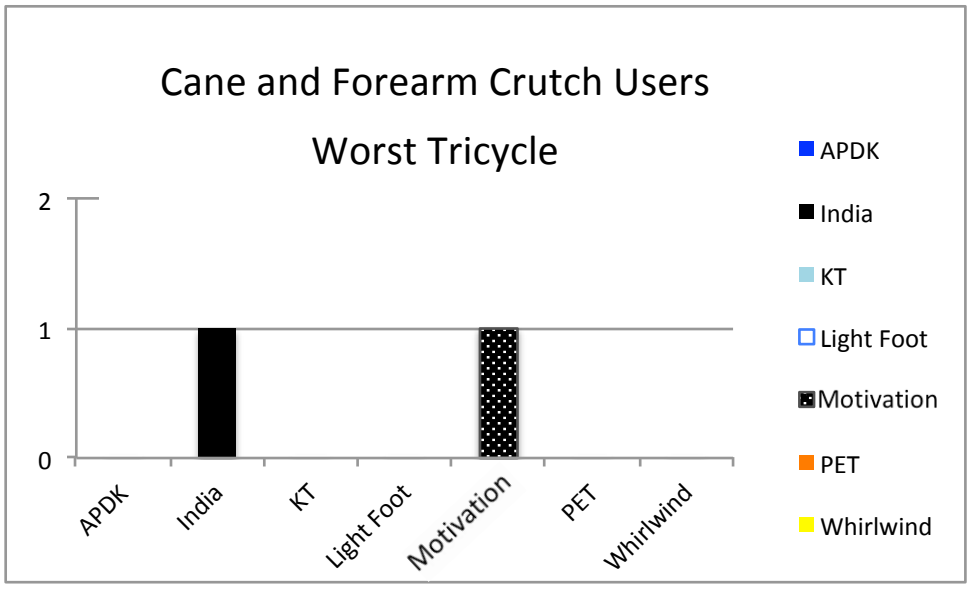


Figure 80: Test 5.10, Last preference of two cane & forearm crutch users. Highest points show tricycle most commonly ranked worst.

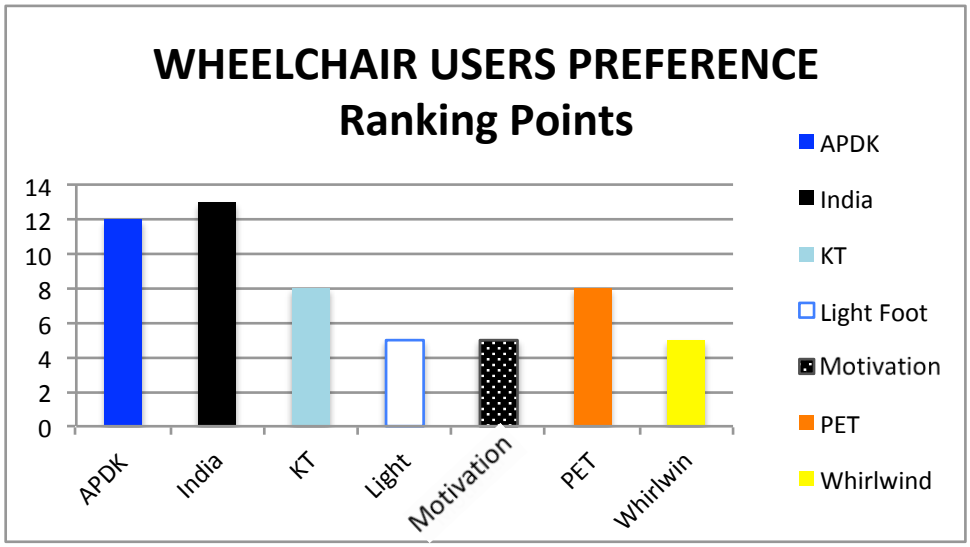


Figure 81: Test 5.11, Preference of two wheelchair users. Ranking points. Higher points indicate less preferred.

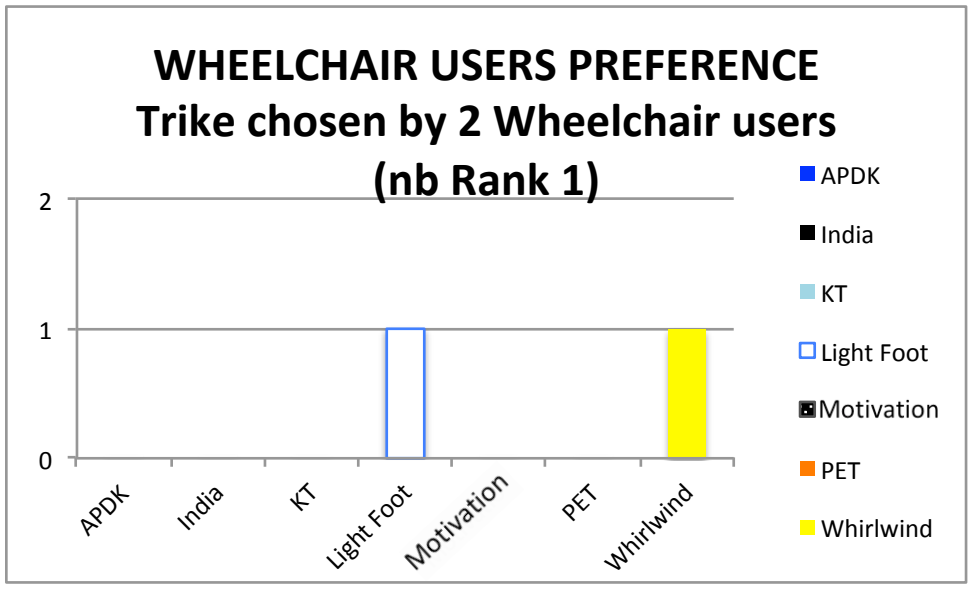


Figure 82: Test 5.11, Preference of two wheelchair users. Higher points indicate the tricycle most commonly ranked first.

Test (5.12) Knee Ankle Foot Orthotic user

The tricycle preference for a Knee Ankle Foot Orthotic user is

1) Light Foot,
2) Whirlwind,
3) APDK.

12 Focus Group Results

12.1 Principle of the Focus Group

The final test of the evaluation was a focus group interview, within three groups of five to seven users. Users were asked to report the advantages and disadvantages of each tricycle and to describe the recommended use. Users were also asked about their expectations of a tricycle.

12.2 General Outcomes on Manual Tricycle

The general conclusion on the use of a manual tricycle is:

- The tricycle is considered to reduce time of travel (compared to other orthopedic devices),
- Tricycle is convenient mode of travel in the villages and the neighborhood,
- Tricycle is not convenient for travel on a hilly road,
- Users plan to travel distances of 0 to 5 km,
- Above 5 km, users would rather use a motorized vehicle, preferably a motorcycle.

The appropriate features and accessories users would like to possess on a tricycle are:

- Push rim,
- Bell,
- Fluorescent mark for night travel.

Advantage						
APDK	**Indian Standard**	**Kien Tuong**	**Light Foot**	**Motivation**	**PET**	**Whirlwind**
Features appreciated: + Pedal + Cargo box + Bell	+ Braking system (for few users)	+ Hand Brake, + Roof, +Adjustable seat,	+ Large wide cargo box + Adjustable gear + Strong chassis,	+ Handle pedal & pedal brake, + Brake system (stop & parking), + Push rim, + Turn lock on steering wheel, + Chassis adjustment	+ Large cargo box, large load capacity, + Maneuverability Forward / backward,	+ Adjustable seat is comfortable, + Large footrest is comfortable, + Push rims,
Recommended use: => For paved, straight road, flat road, => For polio, amputee, => For selling small snacks, => For social activities,	=> Flat paved road Only	=> For Polio and amputee, => For flat road, => For rain, => For going to a casual place, => "Can only sell phone credit"	=> For Polio, Amputee, Light CP, => Can carry children, => For selling goods, => Flat road, small hill, bumpy road, => Social activities,	=> For Polio and amputee Light CP, => Wheelchair user, => Flat road, => Good for social activities,	=> For children, => For polio, amputee, CP, => Flat road, small uphill, => Interesting appearance for children => Can transport children, => Social activities, => Selling goods,	=> For polio, amputee, => Wheelchair user, => For flat road, => Social activities, => Children can ride on foot rest, => Can sell daily needs items but not food.

Disadvantage						
APDK	**Indian Standard**	**Kien Tuong**	**Light Foot**	**Motivation**	**PET**	**Whirlwind**
_ Direction unstable _ No sprocket cover to protect hands _ Small cargo area _ Brake is not ergonomic ≠ Hill, off road, sharp turn ≠ Not for CP, paraplegia, hemiplegia.	_ Hard to power _ Frame is too large _ Pedal hits leg _ No sprocket cover _ Hard to enter _ No Parking brake ≠ Need help to enter ≠ Cannot be used to sell goods,	_ Large turning radius, _ Combination of handle & moving propulsion lever, _ Difficult to pedal when starting & turning, _ No cargo capacity, _ No place for crutches, ≠ Not for paraplegia ≠ Hill, narrow place	_ Wood box[14] not durable in rain, _ Footrest not strong, _ Brake system; _Gear shift by itself, _ Too light, ≠ Not for hemiplegia, paraplegia, ≠ Not for sharp turn, ≠ Not for rough uphill. Not for down hill.	- Front wheel slips, - No cargo capacity, - No place for crutch, - Seat cushion absorbs water, ≠ Not for paraplegia, ≠ Not for hill, not for gravel road, ≠ Not for selling goods	_ Pedal move fast at high speed, _ Gear ratio limits to slow speed, _ Brake system not efficient, _ Color for kids, not for adults, _ Wood material not durable in rain, ≠ Not for paraplegia ≠ Not for long distance, ≠ Not for hill;	_ Brake confusing, _ T Style pedals were not appreciated, _ Difficult to pedal when starting, _ Limited cargo area[15], _ Front wheel slips, ≠ Paraplegia, hemiplegia, ≠ Not for uphill, gravel road, ≠ Not for selling food

[14] The wood box of Light Foot was purchased and installed in Indonesia following the manufacturer's specifications,

[15] The Whirlwind tricycle tested was a prototype. The prototype used only the under seat cargo area; the front platform was not tested.

13 Recommendations to the Tricycle Builders

13.1 APDK

Positive Features

+ Three sizes of this tricycle are available for the users,

+ Device has good maneuverability on a slow slalom and during a U-turn,

+ Device has good performance on uneven road and on a soft uneven road,

+ Device has a small cargo box.

Recommendations

=> Improve the front wheel geometry to make the front wheel more stabile,

=> Add a cover on the sprocket to protect the user's hands.

Suggestion

=> Study the implementation of brakes on other devices

13.2 Indian Standard

Positive Features

+ Industry has a long history of implementing national standard since 1976,

+ Device has good static stability of this tricycle, both rearward and sideways,

+ Device has good rolling resistance.

Recommendations

=> In design, consider ergonomic and biomechanical criteria,

=> Consider the variation of user's body sizes and the need for size adjustability,

=> Improve the ease of transfer by removing obstacles,

=> Add a cushion (based on technical requirements of Indian Standards),

=> Check the mechanical resistance of the brake (based on technical requirements of Indian Standards)

13.3 Kien Tuong

Positive Features

+ Good overall architecture, appearance, and finish,

+ Good ergonomics of the steering handle combined with the propelling lever,

+ Brakes system includes both a stop brake at the steering wheel and an effective parking brake on the rear wheels,

+ Roof feature is appreciated by users for protection from sun and rain.

Recommendation

- Improve the set up of the drum brake at the front wheel.

Suggestions

- Installation of a push rim on the rear wheels to make maneuvering and staring easier for users,
- Improve the cargo capacity with a closed box to transport goods.

13.4 Light Foot

Positive Features

+ The device has good overall performance, for all kind of roads, small spaces, and with a variety of users,

+ The device has good performance on various kinds of surfaces,

+ Users appreciated the cargo box capacity and the box's architecture,

+ The footrest has good range of adjustment,

+ The gear change function allows the user to select the most appropriate gear ratio for the current terrain,

+ The device has ample and unobstructed access to the seat while transferring,

+ The test users preferred the tricycle,

+ The tricycle has good rearward static stability (without cargo load),

+ The tricycle has good rolling resistance.

Recommendations

- Improve the lateral stability (track width, position of the center of gravity),
- Assess the strength of the seat according to ISO 7176-8:1998,
- For the seat and cargo feature, specify materials that are water resistant,
- Improve the seat fitting range,
- Improve the finishing and appearance to enhance the user's perceived value of the device,

- Choose a durable material for the sides of the cargo box.

13.5 Motivation

Positive Features

+ The tricycle has an excellent and robust overall design and appearance,

+ The tricycle has a good range of fitting, seat adjustability range, and postural support,

+ The tricycle includes a well-designed cushion,

+ The footrest has good range of adjustment,

+ The combination of the steering handle, pedal and brake lever offers good ergonomics,

+ The push rim is accessible to the user for propelling on a rough road or hill,

+ This tricycle product (based on a wheelchair) is CE marked. The manufacturer states that the tricycle conforms to the standards ISO 7176, ISO 13485 and ISO 9001 (not verified),

+ The tricycle has good static sideway stability,

+ The tricycle has good turning capacity in a limited space,

+ The tricycle has good rolling resistance,

+ The front wheel has a lock function.

Suggestion

=> Consider including a cargo box, which is preferred by users.

13.6 PET

Positive Features

+ The tricycle has cargo capacity,

+ Turning radius is small and allows use in tight spaces,

+ The tricycle can be used indoors or in a workshop to carry goods,

+ The tricycle has reflectors that help with nighttime safety.

Recommendations

=> Consider multiple sizes to fit a wider range of users (small, medium, large),

=> Implement a free wheel to improve safer for the user,

=> Investigate the availability of spare wheels in the destination countries. Possibly, a different wheel will improve rolling resistance performance and repair-ability,

=> Consider different frame material to decrease weight.

Suggestions

=> Consider the appropriateness of the current range of colors for the cultural preferences in the destination countries,

=> Check the water resistance of the wood paint.

13.7 Whirlwind

Positive Features

+ The device has excellent sideways static stability,

+ The device has good range of fitting: Seat adjustability range, and postural support,

+ The device includes a cushion,

+ The device includes a push rim feature,

+ The device has good rolling resistance,

+ The device has good braking capacity of both rear wheels,

+ The device has good overall appearance,

+ The device has good performance over longer distances (cruising speed).

Recommendation

=> Improve rearward stability.

Suggestions

=> Investigate implementation of a front brake and front brake lever,

=> For the cargo area, users prefer a box with walls to hold cargo in place.

14 Conclusion of the Tricycle Test

Table 8: Summary of the tricycle test

Test	Criteria	APDK	Indian Std.	Kien Tuong	Light Foot	Motivation	PET	Whirlwind
								
BT-a	*Roll. Resist.*	6th paved 5th sand	3rd paved 2nd sand	5th paved 6th sand	1st paved 4th sand	2nd paved 3rd sand	7th 7th	4th paved 1st sand
2e-B	*Brake pref.*	7th	4th	3rd	2nd	1st	6th	5th
2e-C	*Brake dist.*	1st	Not Classified	5th park; 8th stop	2nd	6th stop; 7th park	4th	3rd
1	*Performance*							
1a	*Paved Road*	3rd	4th	5th tied	1st	5th tied	7th	2nd
1b	*Uneven*	1st tied	5th	4th	3rd	6th	7th	1st tied
1c	*Soft uneven*	2nd	7th	4th tied	1st	3rd	6th	4th tied
1d	*Hill*	4th	7th	2nd	1st	5th	6th	3rd
2	*Maneuver*							
2a	*"Swerve"*	3rd	7th	5th	1st	4th	6th	2nd
2b	*"Market"*	2nd	6th	7th	4th	3rd	1st	5th
2c	*Forw. U-turn*	4th	5th	7th	3rd	1st	2nd	6th
2d	*Back. U-turn*	N/A	N/A	5th	3rd	2nd	1st	4th
2z	*Preference*	6th	7th	5th	3rd tied	1st	3rd tied	2nd
3	*Cargo*	Basket	No Cargo	Small platform	Cargo Box	No Cargo	Cargo box	Rack platform
31b	*Cargo Firm*	2nd	N/A	N/A	1st	N/A	4th	3rd
31c	*Cargo Soft*	4th	N/A	N/A	1st	N/A	3rd	2nd
4	*User choice*							

Test	Criteria	APDK	Indian Std.	Kien Tuong	Light Foot	Motivation	PET	Whirlwind
								
4.9	*Preference*	5th	7th	3rd	1st	4th	6th	2nd
	Appropriate use	Market place	Flat paved road	Flat straight street	Straight, flat, uneven, long or sand roads. Market	Users who need more postural support. Small spaces Long roads	Children Indoors Workshops Market place	Users who need more postural support. Long roads
	Advantage	+ 3 size available	+ History + Stability	+ Appearance + Finish + Steering wheel + Roof	+ High scoring on multiple tests + Gear change + Footrest range	+ Handle steering & brake + Range of fitting + Posture support + Steering lock + Push rims + Turn. capacity + Appearance + Finish	+ Easy transfer + Turn. capacity	+ Range of fitting Posture support + Push rims + Sideway stability + Appearance + Finish
	Limits	- Steering unstable - No sprocket cover	- Ergonomics - Poor fit - No cushion - Hard to power	- Hard to maneuver - Large turning radius	- Sideway stability	- Front wheel slide on uneven road	- Limited speed -No fitting - Heavy	- Front wheel slide on uneven road - Rearward stability
	Note				Wood panel locally purchased			Prototype subject to technical change

Reference Documents

Reference	*Title*	*Author*
UCPRUK/RD/2013/001	Yogyakarta Tricycle Trial Protocol	Matt McCambridge
UCPRUK/RD/2014/013	Tricycle Test, results of test 2: Slalom and Maneuverability	Julien Pasquier
UCPRUK/RD/2014/027	Test BT(a) Tricycle Bench Test Results, Rolling Resistance	Julien Pasquier
UCPRUK/RD/2014/029	Tricycle Results test 2e-B; Brake questionnaire User comments	Julien Pasquier
UCPRUK/RD/2014/030	Test 2e Tricycle brake test results (Rev B)	Julien Pasquier
UCPRUK/RD/2014/032	Test 1 Road tricycle test Results	Julien Pasquier
UCPRUK/RD/2014/036	Focus Group Interview results	Julien Pasquier
UCPRUK/RD/2014/042	Protocol implementation of the tricycle user field test at Yogyakarta	Julien Pasquier
UCPRUK/RD/2014/054	Tricycle Bench Test Measurement & Data processing	Julien Pasquier
UCPRUK/RD/2014/055	Static Stability Test protocol for Tricycle	Julien Pasquier
UCPRUK/RD/2014/058	Results report of the static stability test of tricycles	Julien Pasquier
UCPRUK/RD/2014/059	Data on Disability, UCP January 2014	Sri Lestari & Julien Pasquier
UCPRUK/RD/2014/062	Report on the fitting of users on tricycles	Julien Pasquier
UCPRUK/RD/2014/069	Tricycle Test, results of test 4: Interview (Rev. B)	Julien Pasquier

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