Analysis of Equipment Considerations for UCI's Para-Cycling T-Class

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Introduction

This paper analyzes the state of competition in UCI's para-cycling T-Class, concluding that the low participation relative to the H-Class, and relative to the size of the population encompassed by the classification criteria for the T-Class is due in large part to the use of upright tricycles which are inherently unsafe and unsuitable for individuals who meet the classification criteria for the T-Class. This paper goes on to discuss a superior alternative, the recumbent tricycle, theorizing that the use of recumbents would enhance safety, provide access to elite level competition and transform the level of competition within the T-Class to a more viable standard. Recumbent tricycles, as discussed below, are safer, easier to handle, less expensive, more generally available, and promise more exciting competition than upright tricycles.

Analysis of the Viability of Competition in Sport Class-T

Through August 17, 2012, 42 athletes competed in UCI events in Sport Class-T (MT1: 8; WT1: 4; MT2: 25; WT2: 13). By comparison, 140 athletes have ridden recumbent handcycles in UCI competition this year.

In the United States alone, there are 20 races for recumbent handcycles on US Handcycling's national racing calendar, whereas only one race in the US has drawn more than one upright tricycle (at the US National Championships, 4 upright trikes took part, while 42 recumbent handcycles competed). Indeed, USA Paralympics believes there are 10 UCI-compliant upright trikes in the entire country.[1] (), and only three U.S. have ever competed in UCI events on upright trikes.

[1] Steven Peace, 3; Beth Hope, 1; Alexander Mask, 1; Jay LaPointe, 1; Aaron Baker, 2; Stu Flacks, 1; and Doug Schneebeck, 1.

US Handcycling estimates more than 90% of riders in their events live with paraplegia, with most of the remainder made up of athletes with leg amputations. The T-Class, by comparison, encompasses athletes with cerebral palsy, traumatic brain injuries, strokes, and a host of other neurological diseases. Table 1 shows a comparison of the estimated prevalence of the primary conditions represented by athletes in the H Sport Class and the T Sport Class.

Diagnosis	**Estimated Prevalence**	**Source**
Paraplegia	0.7 per 1000	Foundation for Spinal Cord Injury Prevention, Care & Cure
Leg amputation	0.7 per 1000	K. Ziegler-Graham
Cerebral Palsy	2 per 1000	Surveillance of Cerebral Palsy in Europe (SCPE) network
“Severe” traumatic brain injury	0.14 per 1000	National (U.S.)Health Interview Survey
Stroke	50 per 1000 under age 50	JR Neyer, KJ Greenlund, PhD, CH Denny, PhD, NL Keenan, PhD, M Casper, PhD, DR Labarthe, MD, PhD, JB Croft, PhD, Div for Heart Disease and Stroke Prevention, National Center for Chronic Disease Prevention and Health Promotion, CDC.

Table 1 makes the incorrect assumption that all athletes with leg amputations would choose to participate in handcycling rather than in Sport Class C, likely over-stating the prevalence of disabilities within the Sport Class H criteria. Furthermore, Table 1 limits included TBI’s to those classified as “severe” by the Center, while athletes with “moderate” TBI’s may well fit within the criteria for Sport Class T. Moreover, there are numerous conditions aside from CP, TBI, and stroke that fit within the classification criteria for Sport Class T. All this is to say that the population from which the H-Class is drawn is probably smaller than indicated in the table, and the population from which the T-Class is drawn is probably larger than indicted in the table. Accordingly, a liberal estimate would be that the H-Class is drawn at a rate of 1.4 people per 1,000 in the general population; whereas the T-Class encompasses at least 52 people per 1,000 in the general population.

Even using conservative estimates as to the base population within the classification criteria for Sport Class T, using liberal estimates as to the base population within the classification criteria for Sport Class H, it appears the base population for Sport Class T is significantly larger than the base population for Sport Class H. Nonetheless, participation in UCI para-cycling events by handcyclists is 350% that of participation in Sport Class T.

The next section of this paper discusses the dangerous and difficult characteristics of upright tricycles as compared to recumbent trikes and recumbent handcycles, which probably account for the disproportionate under-representation in Sport Class T.

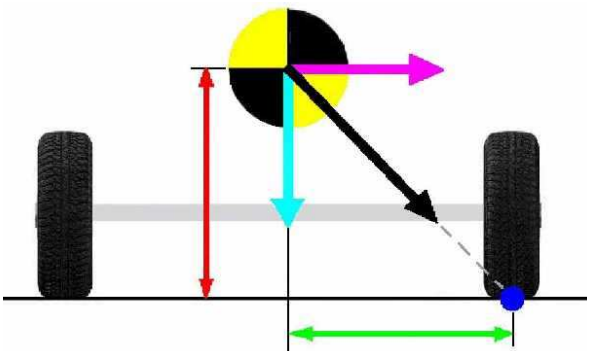
Upright Trikes are Inherently Unsafe and More Difficult to Manage Than any Machine Used in Para-Cycling.

A. **Safety.**

1. **Instability.**

At first blush, it might appear logical that a tricycle would provide more stability for a balance-impaired athlete than a bicycle. The truth, however, is that this is correct in only two situations: when the tricycle is not moving, and when the tricycle is moving in a straight line at a constant rate of speed on a perfectly flat surface. See, GSG, R., D. G., Gawade, T., Santosh, K. et al., "Parametric Study of Three - Wheeler Directional Stability using MBD Simulations," SAE Technical Paper 2010-32-0102, 2010, doi: 10.4271/2010-32-0102.

In the late 1980's, the dangerous attributes of upright three-wheeled vehicles led the United States Department of Labor, the United States Congress, and the US Consumer Products Safety Commission to take action which ultimately led to a ban on the importation or sale of three-wheeled all-terrain-vehicles in the US. See, Safety and Health Information Bulletin, SHIB 08-03-2006; 15 USC § 2089. The American Academy of Pediatrics would have gone further, favoring a mandatory recall of all existing three-wheelers. http://pediatrics.aappublications.org/content/105/6/1352.full.html



The physical principles working against the stability of an upright trike are outlined in the following discussion.[2] These terms will be used as follows:

1. Base of Support (BOS)– The footprint or the area within an outline of all ground contact points of any object. In this case the triangle of the tricycle formed by the points of contact of its three tires.
2. Stability- a condition achieved when the center of gravity is maintained within the limits of the base of support.
3. Limit of stability – the point at which the center of gravity is located at the limit of the BOS.
4. Loss of balance or loss of stability – a condition achieved when the center of gravity exceeds the limits of the base of support and the tricycle begins to roll over.

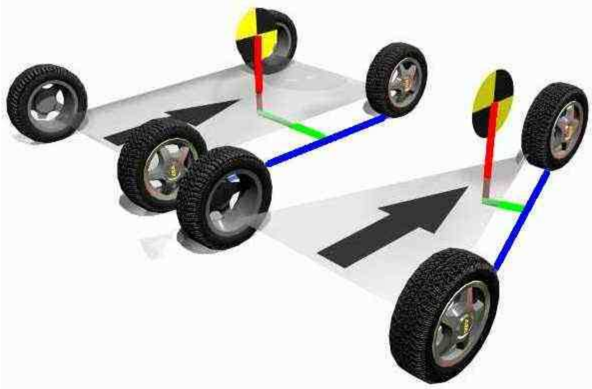
The illustration above represents A trike in a curve towards the left. A **centrifugal force (magenta color)** is exerted on the center of gravity (black and yellow circle) of the trike, while the trike's weight exerts a downward **gravitational force (cyan color)**.

Thus, the **centrifugal force (magenta)** tends to roll the trike over an **axis line (deep blue)** under the right tire, and diagonally forward to the front tire, while the **gravitational force (cyan)** holds the trike back to avoid rollover.

[2]Pierre M. Ethier, http://www.clevislauzon.qc.ca/Professeurs/Mecanique/ethierp/index_en.htm

The centrifugal force and the gravitational force combine into a **resulting force (black)** exerted on the center of gravity. The likelihood of a rollover increases with any of the following: (1) higher center of gravity; (2) lighter trike weight; 3) narrower rear axle; (4) cornering (tighter radius , faster speed, and any reverse camber will all increase the centrifugal force).

Once the combined center of gravity of the trike and rider passes outside the limits of the BOS represented by the triangle formed by the three wheels, the trike will roll over. The same factors (1) through (4) make this more likely to occur. Upright trikes are narrow, light weight, and have a high center of gravity. As if that weren't enough, there is another factor that plays directly against the stability of trikes.



The lines **(deep blue)** in the illustration represent the rollover axes of a 4-wheeler and a trike.
With the trike, the distance the center of gravity must travel (represented by the **green line)** in order to pass beyond the limits of the BOS (which will result in a rollover) is much shorter even though the center of gravity height, the length and the track of the trike are the same as those of the 4-wheeler.[3]

This problem is obviously exacerbated by moving the center of gravity forward, which happens as braking occurs . (and by moving the center of gravity laterally which is seen when hitting bumps and pot holes with one rear wheel. The impact of seemingly small bumps and holes is magnified by the lever that is the rear axle).. Obviously any combination of encountering road hazards, turning and braking can have undesirable consequences. Add to that the speed of a descent and a reverse-cambered surface, and remaining upright is a massive challenge. There were three such descending, off-camber 90 degree turns in each lap of the T-Class time trial and road race at the UCI Para-Cycling World Cup in Baie-Comeau, one of which took the reigning WT2 World Champion out of the road race.[4]

Ironically, the athletes contending with the most significant disabilities are pitted against machines with these unfortunate characteristics.

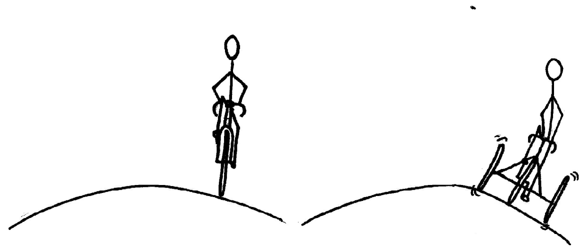
2. **Balance.**

In light of the foregoing, it is easy to understand why traversing a slope would be dangerous on an upright trike. In technical terms, the effect of crossing a slope is to move the trike's center of gravity away from its center, and downhill. Most roads have a crown and slope toward both sides to enable

[3] A humorous illustration of these concepts can be viewed at:
http://www.topgear.com/uk/videos/clarkson-tips-over-reliant-robin

[4] Recognizing the relationship between the height of the center of gravity and the width of a three-wheeler's axle, Canadian regulations were adopted in 2003 limiting the height of the center of mass for a three-wheeled vehicle to 75% of the width of the axle. While this regulation has been criticized as providing an insufficient margin for safety (See footnote 1), applying Standard 505 as written would require a rear axle with a width of approximately 1320 mm for an upright trike ridden by someone with a height of 1.8m (the maximum axle width allowable by UCI specifications is 900 mm, and the widest axle currently available in the marketplace is 800 mm).

drainage. This side slope is called “camber”. When a bicycle is ridden on a cambered roadway, the bike and the rider remain upright/vertical. Riding a trike on a cambered surface has the same effect as traversing a slope because the rear axle of the trike conforms to the degree of camber as illustrated below.



To counteract the effect of the camber, the trike rider attempts to compensate for the camber by tilting his torso (and thus the trike/rider’s center of gravity) away from the camber. This maneuver, which must be performed to one degree or another anytime the trike is ridden on a surface that is not perfectly flat, requires the rider to perform a complicated balance technique involving both upper and lower body elements which is never required of bicycle riders. The trike rider is required to separate the angle of his or her body from that of the machine, whereas a bike and its rider maintain one angle whether travelling straight or turning. In a turn, the inclination of the bicycle/rider system (which is determined by the skill of the rider and is limited only by the friction between the tires and road surface) allows this system to remain in alignment with the resulting vector and stability is maintained much as it is in static standing and straight line riding. In contrast, any inclination of the tricycle is dictated by the road surface and is independent of speed, turning radius and rider skill or intention. The only inclination available to the tricyclist is that of his/her own body. In addition to having only half of the tricycle/rider system available for alignment with the resulting vector, this inclination is restricted by the physical limits of the rider. (arm and leg length as well as strength).

The severely limited ability of the tricyclist to position the center of gravity over the BOS and to align the system with the resultant vector results in very early failure of the system to maintain stability in a turn.

Able-bodied athletes countering turning forces on bikes and a trike. While the bikers counter centrifugal forces by leaning the body and machine at a uniform angle, the trike rider can do so only by separating his body angle from that of the trike.

3. The Severity and Incidence of Crashes.

In a crash situation, a bicycle can be "laid down", which can minimize injury by bringing the rider to the road surface away from the direction of the crash. A simple example of this type of "low side" crash is when a cyclist takes a wet corner too fast, losing traction, and the bike slides out from under the rider. A low side crash is not possible on a trike because there are two wheels in the back. In the example of the wet corner, a trike that loses traction can only tip over to the "high side", which increases both the distance and the speed of the fall. Because the outward centrifugal force cannot be counteracted by the rider to produce a low side crash, all trike crashes are high side crashes.

While far from a scientific sampling, the following data was gathered from three trike races in 2012:

Event	Riders	Crashes	Incident Rate
Defi Sportif RR	6	3 high side	50%
USA National TT	4	2 high side	50%
World Cup Final RR	6	1 high side	17%

While also not scientific, the author of this paper has crashed four times in 600 miles of training on the trike, as compared to four crashes in 35,000 miles of road biking prior to switching to a trike. All of the trike crashes were high side, two of which resulted in broken helmets and rib injuries, while all of the bike crashes were low side without injuries other than abrasions.

4. Braking.

Braking an upright trike requires more grip strength than braking a bicycle. This is because technical specifications applicable to trikes require two rear brakes operated by a single brake lever. Athletes with grip strength disabilities have difficulty engaging the rear brakes because of the additional strength required to overcome the spring mechanisms in each brake unit.

5. Shifting.

This problem is prevalent among Sport Class T-1 riders. Most T-1 riders utilize mountain bike-style (flat) handlebars. Many also require electronic shifting due to the lack of finger and hand dexterity and strength. Electronic shifters, however, are not available for mountain bike bars. This requires riders to make modifications such as the one pictured below that require the rider (who, by definition, has balance impairment) to take one hand off the bars in order to execute a shift.

While the rear gears can be shifted by pressing the buttons on the left, the front gears can be changed only by pressing the tab alongside the brake lever on the right because a button unit is not available for front derailleurs. The right hand must come off the grip to accomplish this maneuver.

6. Standing.

Rising from the saddle to a standing position over the pedals creates a significant competitive advantage in acceleration, sprinting and climbing. It also enables an athlete to regain momentum to support racing in a larger gear, whereas an athlete who cannot stand must downshift and rebuild momentum with a higher pedal cadence. Mixed into all divisions of the tricycle category there are riders who can and cannot stand. This inevitably creates an inequity in competition.

7. Ergonomics.

Athletes who have compromised upper body strength can find a traditional cycling posture to be impractical. The strength necessary to hold one's head upright, grip and maintain a balanced and mechanically-efficient position over the bars is significant. A sample of adaptations used by cyclists in the tricycle categories is illustrated by the photograph below.

Neck support.

Grip assist.

A. **Practical Issues.**
   1. **Availability.**

Upright trike frames or conversion axles that comply with UCI's technical specifications are available from only two manufacturers, both located in the UK, and both requiring significant lead time (up to six months) for custom production of every frame and axle.

   2. **Cost.**

Because every upright trike is a custom product, entry-level machines with only mid-range components can easily exceed USD 6000.

For the reasons above, upright trikes present significant hazards and challenges to competitors over and above the hazards and challenges inherent in bike racing.

Recumbent Trikes Represent a Superior Equipment Choice for Riders who Meet a Classification Criteria for Sport Class T.

A. **Safety.**
   1. **Stability.**

With a center of gravity less than one foot off the surface of the road, plus the stabilizing effect of two front wheels, a recumbent trike provides stability even when cornering at high speed. Application of the Canadian Standard 505 to the traditional geometry of a recumbent trike yields a safety margin that would allow the center of gravity to be 30cm higher than it is on any racing-designed recumbent trike on the market.

2. **Balance.**

Because of the very low center of gravity, the effect of camber is also minimal (essentially the same as a recumbent hand cycle) when operating a recumbent trike.

While riding an upright trike on a track is not possible, the recumbent's low center of mass makes this possible.

3. **The Severity and Incidence of Crashes.**

Again owing to the low center of gravity, the likelihood of crashing a recumbent trike is quite low. Also, while any crashes will be high side crashes, the recumbent trike rider's head will be 1.0-1.5 meters lower when the crash begins than it will be on an upright trike. Obviously, this will reduce the likelihood of severe injuries as compared with upright trikes.

4. **Braking.**

On recumbent trikes the brake levers are mounted forward of the grips. A rider with a grip strength impairment can exert adequate power by simply curling his or her fingers around the levers and pulling backwards with the arms or torso. Also, because the brakes are independent, there is no need to operate two brakes from one lever as is required of an upright trike rider.

5. **Shifting.**

Shifters for recumbent trikes are located on the grips, which eliminates the need for a one-handed shifting maneuver as is required of many upright trike riders.

6. **Standing.**

There is no maneuver for a recumbent tricyclist that is the equivalent of standing on an upright bike or trike. For this reason, this competitive inequity is erased for recumbent trikes.

7. **Ergonomics.**

Recumbent trikes are available with head supports, and they have hand grips and steering mechanisms that can be effectively and safely controlled with even substantially limited upper body strength.

B. **Practical Issues.**
   1. **Cost.**

Recumbent trikes outfitted suitably for racing begin at about USD2500 and top out at about USD 6000.

   2. **Availability.**

Recumbent trikes are produced with telescoping booms and adjustable seats that account for rider size differences. That, plus the fact that there is a market for recumbent trikes outside the disabled community means that manufacturers produce recumbent trikes as a matter of course rather than an exclusively custom basis. As a result, there are dealers world-wide that stock recumbent trikes. Even special order machines are often available within a week. Finally, while there are only two manufacturers of upright trikes that meet the technical specifications, there are in excess of one dozen manufacturers of recumbent trikes in North America, Australia, the UK, and Europe alone, all of which produce machines that satisfy the technical specifications recommended in this paper.[5]

Proposal for Implementation of Pilot Program to Assess the Use of Recumbent Trikes in UCI Competition.

On paper, the differences between the classification criteria for T-1 and T-2 may seem subtle. In practice, however, UCI's classification personnel have done a marvelous job of implementing the criteria in a fashion that has created significant competitive distinctions between the classes. The factoring table that were used in London accurately reflect the performance differences between the classes. Superior bike handling skills are a primary factor in the competitive advantages enjoyed by the T-2 riders. Most athletes in the T-2 class set the front end of their machines in a fashion similar to a traditional road bike. In T-1, however, most athletes use mountain bike bars, which leads to a distinctly upright riding posture.

[5] Cat Trike - Orlando, Florida
Greenspeed - Australia.
Hellbent Cycles - Austin, Texas.
Inspired Cycle Engineering (ICE) - United Kingdom.
Logo Trikes - Spearwood Western Australia (Near Perth)
Sidewinder Recumbent Trikes Fillmore, California.
Stein Trikes - Germany
Tri Sled Human Powered Vehicles – Australia
HP Velotechnik of the same name.
TerraTrike (Formerly WizWheelz) - Hastings, Michigan
Windcheetah - United Kingdom.

T-1 athlete Shelley Gautier (CAN). *T-2 athlete David Stone (GBR).*

While the safety considerations discussed above apply to both classes, it is unquestionably true that the athletes in the T-2 class are better equipped to deal with the hazards – particularly instability – of the upright trikes. This might suggest a basis for an equipment differentiation between the classes. However, an unsafe machine is unsafe for everyone, so if UCI eventually decides to abandon the upright trike for safety reasons, it should do so across the entire T class.

Because of the significant safety issues presented by upright trikes, we recommend immediate implementation of a recumbent option for the entire T class for 2013 and 2014. We expect athletes will self-select the preferable option, making it easy for UCI to evaluate the effect on competition.

Factors that support this recommendation include:

- Safety, as discussed above.
- The comparative overall performance of upright and recumbent trikes is similar. If the performance is comparable, we believe athletes will choose the safer and more comfortable option.
- Making the recumbent trike an option only for Class T-1 would present a dilemma for the new athlete who, not having been previously classified, might appear for competition with a recumbent trike only to be ineligible for competition if classified as a T-2.
- While recumbent trikes tend to be slower uphill, faster downhill and cornering than upright trikes, they are compatible in a road race environment because the uprights have the safety bar between the rear wheels, and the recumbent trikes have a single rear wheel with the gap between the front wheels essentially protected by the chain ring, pedals and feet of the cyclist. Additionally, most upright trike riders have experience racing simultaneously with recumbent hand cyclists, who tend to share the pace differences of recumbent trikes.
- Creating a separate sub-class or experimental class for recumbent trikes would unnecessarily crowd already busy race schedules because trike fields are routinely small and rarely involve significant group racing. In 2012, no road races have seen two riders separated by less than

three minutes in Classes MT-1 and WT-1, and the largest trike category, MT-2, has not had more than three riders finish within 1 min. of each other.

- Fully integrating recumbent trikes with upright trikes would allow UCI to compare the recumbents with the uprights in a real-world environment rather than based upon theoretical models.
- By combining MT-1, MT-2, WT-1 and WT-2 into a single medal event for both the time trial and the road race at the Paralympic Games, the IPC has identified the competition in the trike class as the least viable within para-cycling. As discussed above, there is ample reason to believe the demographic encompassed by the trike classification criteria is drastically under-represented in competition. The authors of this paper are of the common sense opinion that this can be explained by the fact that the athletes who have the most highly compromised stability are only allowed to ride only the most inherently unstable machines in cycling.

Technical Specifications.

In recent years, the design of racing recumbent trikes has become more consistent across the industry. The five trikes pictured below are produced by different manufacturers in Australia, Germany, Great Britain and the United States.

Recommended specifications:

- General layout: two wheels linked by a single steering mechanism in front, one wheel in back.
- Aerodynamics: maximum angle of reclined seating is 68°; no fairings.
- Braking: disc brakes on both front wheels may be controlled by one or two levers.

- Wheel size: 406 mm (BMX size) is the maximum for front wheels, and the minimum for rear wheel.
- Wheelbase: 1240 mm maximum.
- Front wheel track width: 750 mm maximum.
- For the individual road race, the recumbent tricycle must have a mirror fixed either to the helmet of the athlete or at any point of the front of the bike in order to ensure rear view vision.

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