2-Skate-Single-Track-Vehicle without Fork-Angle, Trail or Power: Tested for Rideability, Phase-Lag and Steady-State-Lean-Angles

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Abstract:

A 2-Skate, short for a Two-Inline-Ice-Skates-Single-Track-Vehicle, was built to show that without wheels, gyroscopic effects, fork angle, trail and power-to-the-wheels, a person could ride it. But the rider might have been a circus acrobat that can also sit backwards on his bicycle handlebar, and pedal while juggling and turning around in a circle. So this current study aimed at determining if normal persons can ride the 2-Skate with confidence, with the same phase lag between torso and vehicle leaning while slaloming, and the same torso and vehicle lean angles in steady state curves as predicted. A protocol was designed and 13 independent riders tested the 2-Skates. On their first trial, with the exception of a 79 year old, they could all ride it and go slaloming. Three did the phase lag and lean angle tests and obtained similar results, confirming the prediction of the Torso-Arms-Handlebar Steering Theory first presented by Ethier (1974), with differential non-holonomic and servomechanism system equations, and further explained on the web with access to recently revised equations. This confirmation (a) sheds light on how bicycles are steered, (b) clarifies that Countersteering is done automatically at low speeds, (c) supports and clarifies the way mountain bike steering is taught, (d) suggests a slight modification of the way motorcycle Countersteering is taught, (e) can be used to develop a different approach to 2-Wheeler simulators, (f) and can renew interest for motorcycles with seat belts and protective structure like the BMW-C1, and the closed-cabin electric motorcycles like the ultra-low drag and award winning Peraves e-Tracer.

Keywords: Bicycle, Motorcycle, 2-wheeler, Steering Theory, Tah, Torso-arms-handlebar, Dynamik23.com, Dbg, Dos-bras-guidon, Théorie Dos-bras-guidon, Théorie De Conduite, 2-roues, Vélo, Moto, Bicyclette, Motorcyclelette, 2-skate
Introduction

A human is a complex cybernetic system with his brain getting multiple proprioceptive and visual information, which allows him to control multiple muscles all over his body in order to move and steer a bicycle, motorcycle or any other Single-Track vehicle adequately. Many theories explain this phenomenon, among which the following most important ones: (1) Countersteering, (2) Body Weight Leaning, and (3) Brain Controlling Handlebar (The brain controls push-pulling the handlebar, thus no body leaning is absolutely required). But another theory exists: (4) Torso-Arms-Handlebar or TAH Theory. This fourth theory suggests that the three others might be linked through a hidden, base and always present mechanism at the interface of the rider and vehicle, helping him steer correctly: The TAH Mechanism which is part of a motorcycle-rider servomechanism steering system. Ethier (1974, page 4) disclosed this theory and servomechanism, involving a Vehicle-Torso-Arms-Handlebar error detector (In French: “L’ensemble véhicule-dos-bras-guidon forme un détecteur d’écart”). Also, Ethier (2000) published by the SAE, was titled “Motorcycle-Rider Servomechanism Steering Theory”. And this SAE publication was followed in 2000, by a first Web site, which was updated up to Ethier (2023a). The present paper supports these TAH Mechanism and Theory of Single-Track vehicle steering, by presenting tests done using a 2-Skate Single-Track vehicle without gyroscopic effect, fork-angle, trail or power. Ethier, (2023xyz) https://dynamik23.com/wp-content/uploads/2023/09/2-Skate-Pierre-M.-Ethier.-Paper-FULL-VERSION-2.0.pdf gives access to a 32 page PDF file full version (Director’s cut) of the present paper, with more extended information on each subject.

1.0 The TAH Mechanism, Theory and Servomechanism:

As detailed on web page Ethier (2023b), the rider of a single-track vehicle grips the handlebar, and thus constitutes the Torso-Arms-Handlebar or TAH mechanism. The torso leaning left of the vehicle chassis, naturally turns the handlebar to the right, due to the arms acting as links to the handlebar as on the following Figure 1 illustrating this TAH Mechanism. Note that it’s easier and more natural to lean sideways (yellow line) while leaning slightly forward and twisting slightly (cyan line) in the left aimed direction. Thus having right shoulder moving slightly forward, when the rider looks to the left where he wants to go.

Figure 1. Rider leaning to his left naturally turns the handlebar to his right, while also slightly leaning forward and twisting.

Typical sequence, staying up at slow speed: The following Figure 2 shows where stability comes from WITH hands on the handlebar: If a motorcycle goes straight as in (A), it may fall to the right as in (B). But the rider reacts not to fall and stays up along the vertical gray line as in (C). So as in (D), one arm automatically pushes and the other pulls (in the direction of the small black arrows) the handlebar towards where the 2-Wheeler falls. So the front wheel is oriented in the direction of the bigger black arrow as in (E). And this generates a centrifugal force along the red arrow, which brings the 2-Wheeler back to the vertical position as in (F). Thus, the TAH Mechanism naturally countersteers the handlebar and there is no need for gyroscopic reactions to build up with higher speed as WITHOUT hands on the handlebar. And note that the centrifugal force can also be seen as the front tire ground-contact-point going to the right, under the vehicle to hold it or bring it back up, just like the finger under a vertical broom falling to the right, and moved to the right to counteract falling.

Figure 2. TAH Mechanism bringing back up a motorcycle falling to the right.

Typical sequence of the three steps when going into a turn, as on Figure 3 below:

Step 1: If the rider’s torso suddenly leans to its right to go right, the 2-Wheeler leans to the left in reaction. So the front wheel is unconsciously oriented to the left by the TAH mechanism (short black line on the ground, showing front wheel orientation to the left). The front wheel orientation generates a centrifugal force, or the tire-ground contact patch rapidly moves to the left, so that the 2-Wheeler is leaned to its right. Note that the front wheel may also be oriented to the left by the rider pushing-pulling on the handlebar when applying the Countersteering technique. And by the gyroscopic reactions of the front wheel caused by the 2-Wheeler leaning to the left in reaction to the rider leaning to the right.
Step 2: The 2-Wheeler rapidly leans to its right due to the centrifugal force or the tire-ground contact patch’s left side movement. And when the 2-Wheeler’s lean angle is the same as the rider’s torso (as on the middle image), the front wheel is oriented straight ahead (short black line on the ground, in line with the chassis and the yellow general orientation line). So there is no centrifugal force or tire-ground contact patch side movement generated to hold up the 2-Wheeler, which keeps on falling.

Step 3: The 2-Wheeler keeps on falling to its right. But the torso lean angle to the vertical stays the same because the rider does not want to fall further. So the 2-Wheeler keeps on falling to the right further than the rider’s torso, thus Output or chassis lean angle is naturally greater than Input or torso lean angle. And this orient the front wheel towards the right through the TAH mechanism. Finally, this front wheel orientation lets the 2-Wheeler turn to its right and generates a centrifugal force that holds up the leaning rider and 2-Wheeler in a curve.

Note that not only did the equations predict and explain a result that was not expected, but numerous and unaware photographers of riders on motorcycles and mountain bikes, have unknowingly produced photographic proofs of this phenomenon. Web page Ethier (2023c, 2.4 Prediction of the lean angles in a steady state curve) shows a few of many hundreds of such examples.

And also note that at high speeds, the gyroscopic counter-reactions are strong and may flex the arms and elbows. So the rider may feel that he pulls or pushes on the handlebar according to the Countersteering technique. At such speeds, this Countersteering technique and the TAH Theory are thus quite similar. But the TAH Theory adds and explains that it is the torso lean angle that unconsciously starts and ‘cleverly’ controls the push-pull actions on the handlebar at all speeds. ‘Cleverly’ in the sense that the rider may initiate a turn by voluntarily counter steering for a fraction of a second, but this TAH Theory explains that it is the TAH Mechanism that insures a correct amount of handlebar motion to smoothly control the right amount of counter steering, all along after the first rider’s conscious action on the handlebar. The ‘magic’ of the right amount Countersteering followed by the right amount of turning in the intended direction, is all controlled by the TAH Mechanism, although for instance, our brain can certainly adjust some pushing-pulling on the handlebar to initiate earlier turning and/or add minute adjustments to reduce or increase the chassis lean angle. Except at very slow speeds, the rider does not have to jiggle with the handlebar to find the correct front wheel orientation, which is done automatically by the TAH Mechanism.

Typical Real Mechanical Servomechanism compared to the TAH Mechanism and Servomechanism: A simple hydraulic servomechanism as on Figure 4 below at left, helps understand the similar TAH steering servomechanism at right. Untrained eyes don’t see where the Error Detector is because it’s not as obvious as for electric servomechanisms using Op-Amps. Naturally, it’s the assembly of the Spool inside the Sliding Sleeve of the valve, such that the Error Signal is a difference in position between Spool and Sliding Sleeve, letting oil flow to the Cylinder. And the TAH Theory incorporating a servomechanism, considers that its Error Detector is the assembly of the torso on the bicycle, such that the Error Signal is a difference in angle between torso and chassis. And this Error Signal is transmitted through the arms linked to the handlebar, as an opposite orientation of the handlebar and front wheel. Thus the following hydraulic servomechanism schematics:

![Figure 3. Three steps going into a turn.](image)

![Figure 4. Simple hydraulic servomechanism at left, and similar bicycle-motorcycle steering servomechanism at right.](image)

2.0 Three Steering Theories compared to the TAH Theory:

Three most important Single-Track vehicle steering theories show convincing points but also contradictions:

1. **Countersteering**: It’s well known that a broom held on a finger, is like a bicycle: Move the finger or front-wheel contact point to the left, and the broom or bicycle fall to the right. A Google search rapidly brings the information that Countersteering is best used above 12 MPH (19 km/h). A Team Arizona (2013) link adds that: “To Turn a Motorcycle below roughly 12 MPH, use COUNTERWEIGHTING (or Body Weight Leaning)” The problem: Nothing explains what happens below the 19.3 km/h (12 MPH)
where Countersteering should be avoided, while mountain bikes and the 2-Skate both ride at or below this mark. Section 3.4 of Web site Ethier (2023d) tells more on the Countersteering theory’s limitations.

(2) Body Weight Leaning: YouTube video AlexCP67 (2009) shows a motorcyclist going down a long twisting mountain road, with both arms held high up, WITHOUT hands on the handlebar. So body weight steering is possible. The problem: Code (2023) solidly supports that body weight steering is NOT able to steer a 2-Wheeler rapidly and precisely, as when racing or when turning sharply.

(3) Brain Controlling Handlebar: The Moore (2011) video The science of balancing a bike, presents a bicycle with a cast rigidly mounted on the chassis, in order to immobilize the torso. Steering is still possible, thus the video supports that torso leaning is not necessary, because the brain controls adequately push-pulling on the handlebar. The problems are that:

(a) Section 3.15 of Web site Ethier (2023d) analyses this video and shows that the torso did move inside the cast. Although small, there’s a body-leaning of the torso. Not much, but in terms of servomechanism error-detector output, it’s there and enough to steer.

(b) Section 5.4 of Web page Ethier (2023f) also shows a test blocking the torso. The motorcycle tested in 1979 to 1982, is equipped with protective structure, backrest and seat Belt. It led to a New Interface Concept (NIC) or mechanism easing steering of such a motorcycle with limited torso leaning. For the purpose of the blocked-torso-test, this mechanism was itself totally deactivated to avoid interfering and false results. The poor quality images that survived show the rider sitting slightly leaned backwards against a rigid backrest, as on Figure 5 below. This arrangement permitted pushing hard with the legs to fully block the pelvis, spine, torso and shoulder blades against the backrest, leaving only the forearms, wrists and hands to act on the handlebar. This torso blockage test was not itself filmed but can certainly be repeated and filmed. Essentially, the result was that the 2-Wheeler was then only steerable by nervously jiggling the handlebar, which was difficult and certainly imprecise. Steering was like holding a broom vertically on a finger: It can certainly be done, but the broom will fall randomly so that the finger has to jiggle to hold it up. And as soon as the rider can move slightly inside the backrest, steering was easier, but still precluded rapid and ample torso leaning needed in case of an emergency swerve at slow speed. And it became as easy as on a regular motorcycle with the NIC mechanism back on:

(c) Section 5.3 of Web page Ethier (2023f) illustrates two cases of seat belt equipped motorcycles, where the pilots are limited in their torso lateral movements. In both cases these limitations make them hard to steer and they fall to the ground.

(d) Directly controlling the front wheel of a bicycle, is like controlling an integrator function: If the front wheel is oriented slightly to one side, its ground contact point keeps on moving towards that side, thus continuously increasing lean angle. So, sudden movements of the handlebar can result in rapid but imprecise leaning of the bicycle, which may be quickly thrown on the ground. The rider can only steer with jiggling and jerking motions and at slow speed, without gyroscopic counteractions limiting such movements and rapid leaning, the bicycle steering may be dangerous. Which is why the Countersteering practice of directly acting on the handlebar is not recommended at slow speeds. And which is why Brain Controlling Handlebar without torso leaning must be avoided at slow speeds. So, Moore (2011) could go along on a flat gymnasium. But a rider inside a cast will not be able to precisely and rapidly steer a mountain bike avoiding trees or a racing motorcycle.

(4) TAH Theory: This 4th theory regroups all 3 others, explaining that active counter steering is automatically done at all speeds, by the torso leaning and acting on it to turn it adequately by the right amount, through TAH Mechanism.

3.0 Causality Tests supporting the TAH Theory compared to Other Steering Theories:

The 2-Skate’s first objective: It was built around 2001 and adds up to the list of Single-Track vehicles including bicycle, motorcycle, 2-ski snow-bike, or single-ski-single-track snowmobile. It was intended to show that even without fork angle, trail or wheels with power and gyroscopic effect, it is still rideable, because the TAH Mechanism is still present for steerability, as seen on the left of following Figure 6, showing four screenshots from YouTube video https://youtu.be/6Apnt1SRB0w. Furthermore, the four screenshots on the right, from YouTube video https://youtu.be/dXg1k8K8IKo, clearly show that the vehicle falls when removing hands from the handlebar, thus removing the TAH Mechanism or what’s left to hold up the vehicle:

But well trained circus acrobats can sit on their handlebar and pedal backwards while jiggling with five balls. So perhaps the rider was such an acrobat that can ride the 2-Skate, which cannot really be rideable by ordinary cyclists. Answering the question whether the 2-Skate is rideable or not by more than just one cyclist, was then the first objective of the present study.
How to analyse a Steering Servomechanism if it does exist: The Typical Real Mechanical Servomechanism described above, make it clear that the error signals or differences between spool and valve body will be small and somewhat erratic, since dependent on exterior disturbances suddenly appearing and causing a correction. The same goes for (a) the torso leaning versus a bicycle-motorcycle chassis, or (b) the torso lateral movements inside the Moore (2011) white cast: According to the TAH Theory, they are the result coming out of an error detector and thus will also be small and erratic. So analysing their recorded data may not be the best way to identify the presence of a steering system that includes a hidden servomechanism. Oppositely, the presence of weak and erratic signals or angles between torso angle and chassis angle, may support the presence of a servomechanism, which is precisely what was reported by Kooijman Schwab Moore (2009, Town Ride Experiment, page 2): “The video material showed that there was very little upper body lean relative to the rear-frame, carried out during the whole ride.”

Furthermore, if the TAH Theory and the above servomechanism schematics exist for real, then analysis should use servomechanism techniques, namely reactions to four typical inputs: (a) Impulse Input, which is the suddenly pulling of the rope attached to the bicycle chassis, on the above cited Moore (2011) video presenting a rider’s torso inside a cast, at minute 2:20 of 3:07. (b) Step Input, which is riding along and suddenly going into a constant speed. (c) Ramp Input, which would be suddenly and progressively increasing torso lean angle. In the case of normal servomechanisms, this is often used to see if an increasing input, will keep the Output always late or lagging, or if there is a correction manner to progressively reduce this lagging, such as when using a PID correction (Proportional-Integral-Differential). But since a bicycle or motorcycle falls within 90 degrees, this input has not yet found any use. (d) Sine Wave Input, which is the rider’s torso slaloming right-left. Analysing the response of servomechanisms to Sine wave inputs, usually involves examining, for a constant amplitude Input of increasing frequency: The decreasing Output amplitude and the increasing Output lag behind the Input (or Phase Lag). But things are again different for the bicycle steering servomechanism: The rider’s Input slaloming amplitude and frequency going right-left, are far from being constant and adjustable as an electronic system. So the first observation to make is to verify whether or not there is a time lag or Phase Lag when Slaloming, between Input torso leaning and Output chassis leaning. Which is also predicted by the TAH Theory, making it another landmark of its existence… again if it is confirmed by observations. The phase lag could also be observed to see if it can be negative, or if the Input torso leaning can rather be late behind the Output chassis leaning. As it is with electrical circuits using condensers instead of inductances. With an inductance, the current lags voltage, just like the chassis lags the torso lean angle. While with a condenser, the voltage lags current or the current is forward of the voltage, which would mean the chassis could be forward of the torso lean angle. As it is suspected to be possible according to still another bicycle-motorcycle researcher, concerning chassis leaning that may or not be lagging behind torso leaning, because this would be a rider choice, possibly with his brain capable of thinking in advance.

Using servomechanism techniques: If the TAH Theory’s servomechanism really exists and permits steerability, using servomechanism techniques would require examining typical Input-Output for: (a) Step Input or Lean Angles in a Steady State Curve, and (b) Sine Wave Input or Phase Lag when Slaloming. Conversely, positive results to these tests would not necessarily imply the presence of the TAH Mechanism to have caused them. But then, what might have caused them? What else might explain the chassis leaning more than the torso and always lagging behind the torso? How can the human brain controlling flexible arms and/or torso twisting, produce observable and, most importantly, repetitive chassis leaning more than torso and always lagging?

The 2-Skate tests carried on and in what chronological order: Chronologically, the slalom tests were the first to be performed on a 100cc motorcycle in 1971 to 1974. But they are not easy on the 2-Skate and since the 2-Skate has a vertical handlebar and front wheel pivot, a rider has a first impression of the front skate being under his toes, much closer than a front bicycle wheel. So extending tests to other riders required them to first get used to it. Thus the following tests in chronological order:

First test or contact with the 2-Skate: The protocol’s first test was thus to let the rider sit on the 2-Skate, with a helmet on and 6mm (¼”) spikes under his boots. If he felt OK, he was pushed gently forward by another person while being filmed, to see if he could adapt to it and stay up, without forcing the handlebar, as he would do on a bicycle. If he still felt OK, he was pushed faster, until ready for the next step. Along with pictures and videos, personal information and weather conditions were also recorded.

Second test going through a line of four cones: The test was to see if the rider could do better and go slightly slaloming through a line of four orange cones, each distanced 2 meters apart, simply to confirm his turning and obstacle avoidance abilities.

Third test going into a large turn: The rider was to be pushed and immediately after stabilisation going straight, the rider would go into a large and constant radius turn towards another camera, and keep on turning past it, so the camera could picture him to determine the lean angle in relatively steady-state mode. Not perfectly constant nor steady-state, since the 2-Skate slowed down.

Forth test slaloming without cones: The slalom was to be done more naturally and at relatively constant frequency, trying to be consistent all along the slalom and the different trials or runs. The object of the test was to determine Input to Output Phase-Lag.

The last 2-Skate test of letting go both hands from the handlebar was only done by Ethier for safety purposes and lack of time. Also note that a bicycle going down a gentle constant slope, is easily observable. But on a 2-Skate, the rider has to go the fastest he can, and then do his best until coming to a stop. So there isn’t much time to experiment as on a bicycle coasting downhill smoothly. The 2-Skate was tested with the rider running and jumping on the 2 Skate, or being pushed by a runner sliding on ice. Instead, the runner could wear ice spikes to gain more speed. Or the rider could be pushed by an ice-skater to go even faster when starting each test.

It may be noted that testing a 2-Skate is an unusual activity. You may have to fight a civil servant guarding a public skating rink, who may think that the 2-Skate will cut ‘his’ ice. At no more than 50 kg load (100 lbs) on each skate, it’s nothing compared to an athletic 100kg (200 lbs) hockey player who may exert a 200 kg force (400 lbs) on each skate when accelerating or turning.

Flexing Arms and Wrists replaced by Wooden Arms: In order to further reduce cause factors and make sure that the elbows and wrists were not flexing, they were replaced by wooden arms. Thus, another test was performed, albeit on a bicycle because carried on long after outside winter ice skating period. The first pair were simple rectangles, but they fell too easily and were replaced by the second pair seen on Figure 7 below: (1) with supports over the handlebar and shoulders to further reduce chances of falling, as seen on the image below, and (2) with small chamfers to avoid hurting the rider’s armpits.
Rubber bands were also added at each end of the handlebar to get a representative width wrist-to-wrist, and avoid the wooden arms falling sideways too easily.

Constant slalom tests were first performed. But they could be modified by a step-function sudden side lean towards one side until stabilization. Then followed by another side lean towards the other side until stabilization, then followed by another side change… Exactly like when testing electronic circuits, continuously feeding a system with a chopped signal step function up-down-up… in order to easily see on an oscilloscope a fixed image of the superimposed Inputs and Outputs.

A fixed camera aimed at an immobilized bicycle, on which a rider leans and twists his torso, was also used to show the equivalent Torso-Lateral-Leaning producing the same Torso-Twisting effect, or same front wheel orientation. Using a camera starting with a front view and rotated to follow the rider on bicycle passing by, was used to also verify the presence of Torso-Twisting.

**4.0 Test Results:**

**4.1 Result of 1st Test or Contact with the 2-Skate**

Excluding Ethier, thirteen riders have tested the 2-Skate, among which five engineers. It was their first contact with the 2-Skate. They were curious but also dubious about its rideability except for one who simply jumped on it. All others accepted to try it only after seeing a demonstration. But they were all surprised to feel comfortable and steer the 2-Skate as easily as their mountain bike.

A 79 year old who could not ride a Fitebike a week earlier, only did the first part going straight. All others that were not acrobats but active cyclists, further did as easily as they would on their bicycle, the second test slaloming along a line of cones and the third test going into a large turn. The forth test slaloming without cones to determine phase lag was only done by two riders plus Ethier.

**4.2 Results of 2nd Test going along a Line of Cones**

YouTube video [https://youtu.be/UC2eV4obP_Q](https://youtu.be/UC2eV4obP_Q) shows rider G running and jumping on the 2-Skate, thus illustrating that:

(a) The 2-Skate pedals are high to let it lean more and turn sharply, so stepping on one with its long sideways lever quickly falls the 2-Skate on the same side. So at the beginning of the video, from seconds 1.7 to 3.2 of 15 sec., the rider can be seen having to run and jump-sit on the seat. Thus it’s safer to have someone else push the 2-Skate and rider, instead of running and jump-sitting on it.

(b) From seconds 4.1 to 7.3 of 15 sec., two cones are hit trying to go tighter along them. This suggests using, instead of light cones carried away by the wind, 125mm (5”) diameter discs (possibly painted home-made wood discs) of height 75mm (3”), sufficiently low not to be hit by the pedals but high enough to avoid the skates going over them and slide dangerously.

(c) At second 10.9 of 15 sec. and at the left of the following Figure 8, the rider can be seen with torso leaning less than the 2-Skate chassis as predicted by the TAH Theory:

![Figure 8](https://example.com/figure8)

**4.3 Results of 3rd Test going into a Large Turn**

YouTube videos [https://youtu.be/InwovObSpEA](https://youtu.be/InwovObSpEA), [https://youtu.be/3Pbu0LO_vD0](https://youtu.be/3Pbu0LO_vD0), and [https://youtu.be/eQHh8oMwXCM](https://youtu.be/eQHh8oMwXCM) also show the 2-Skate leaning more than riders K, M and N at the end of the videos, as on Figure 9 below. Left and middle images also
show that the rider doesn’t fall further and rather leans on the opposite side (red line) to avoid falling, while the 2-Skate keeps on falling (white line) further as predicted:

![Image of rider leaning]

**Figure 9.** The 2-Skate leaning more than riders K, M and N at the end of the videos.

YouTube video [https://youtu.be/YmR--2lyG0o](https://youtu.be/YmR--2lyG0o) shows the 2-Skate chassis leaning more than rider Q as predicted by the TAH Theory. The following Figure 10 shows screenshots with all images inverted left-right from the original video, to better show the three images on the left going INTO the turn, and the three on right going OUT. Both as seen from the front or the rear (3rd and 6th images from the left, and although the rider’s foot comes to the ground), the 2-Skate leans more than the rider’s torso:

![Image of rider leaning]

**Figure 10.** The 2-Skate leaning more than rider Q at end of video.

4.4 Results of 4th Test on Slalom Phase Lag with the 2-Skate

All the videos clearly show that the vehicle chassis leaning lags behind the torso leaning. In mathematics and electronics, zero reference time and degree correspond to a sine wave starting at zero degree. And phase lag angle is calculated from then on. On a Single-Track, this corresponds to the moment when the torso is leaning towards the right and passes through the vertical position. On a video, this position is not clear since the torso also leans forward and has to be seen in a frontal view, while torso twisting might also be present. An electronic device could be developed for this purpose, possibly using a detector of sternum, neck, mid-distance between shoulders, or mid-distance between shoulder blades, while also measuring torso twisting. Torso lean must also be measured from the vertical, not just from the vehicle chassis. Without such electronic equipment, the method is imprecise but can give at least some information. So for the present study using only videos, the reference time can rather be when the head-torso-chassis-handlebar-or-front-skate: (a) are at their maximum leaning angle, (b) are at their farthest physical position to the right or left (skates and wheels going farther out than the head, torso and chassis), or (c) start changing direction. Loud shouting right-left (gauche-droit in French) and sudden head direction change were also used as cues during filming. But untrained riders did not do such sudden changes and both trained and untrained riders shouted at different moments, even in a single run. So shouting could not be used, and it was only significant at the very beginning of a run when going straight and suddenly starting slaloming. As on YouTube video [https://youtu.be/RGiptWYbS10](https://youtu.be/RGiptWYbS10) further described below. Thus these four tests presented in chronological order:

2023-02-12 Rider **R** on the 2-Skate doing the Phase-Lag test as on YouTube video [https://youtu.be/CJzsvOLhWAo](https://youtu.be/CJzsvOLhWAo):

Rider **R** does small amplitude right-left movements at the beginning. And from seconds 9.6 to 17.2 of total 22.1 sec., the rider goes left-right-left three cycles giving a mean duration of 2.50 seconds corresponding to a frequency of 0.40 1/s (cycle/second, Hz). And the mean phase lag of 96 degrees is largely below the 180 maximum phase lag for a second order transfer function predicted in Ethier (1974) thesis.

2023-02-12 Rider **S** on the 2-Skate doing the Phase-Lag test as on YouTube video [https://youtu.be/Tid3eTm4BGw](https://youtu.be/Tid3eTm4BGw):

Right from the start and until the end, rider **S** does rapid and clear head and torso left-right movements, of similar amplitude. And from second 5.5 to 14.2 of 15.4 sec., the rider does seven cycles left-right-left giving a mean duration of 1.24 seconds corresponding to frequency of 0.81 1/s (cycle/second, Hz). The a mean phase lag of 131 degrees, is largely below the 180 maximum phase lag for a second order transfer function predicted in Ethier (1974) thesis.

2023-02-12 Rider **T** on the 2-Skate doing the Phase-Lag test as on YouTube video [https://youtu.be/RZIajfzuOk4](https://youtu.be/RZIajfzuOk4):

Rider **T** starts with small amplitude right-left movements at the beginning, progressively increasing amplitude but with some head movement hesitation. He goes at a relatively slow right-left frequency pace. And from second from seconds 1.5 to 6.2 of 7.1 sec., the rider goes left-right-left two cycles giving a mean duration of 2.31 seconds corresponding to a frequency of 0.43 1/s (cycle/second, Hz). And a mean phase lag of 93 degrees is largely below the 180 maximum phase lag for a second order transfer function predicted in Ethier (1974) thesis.

2023-02-12 Rider **J** on the 2-Skate doing the Phase-Lag test as on YouTube video [https://youtu.be/mPFrBF98a6s](https://youtu.be/mPFrBF98a6s):
A second test by the same rider but a week later, gave similar results: Rider J starts with short amplitude right-left movements at the beginning, and increases amplitude at a relatively fast pace until the end. And from second 5.4 to 9.7 of 10.3 sec., the rider does nearly three and a half cycles left-right giving a mean duration of 1.32 seconds corresponding to frequency of 0.76 1/s (cycle/second, Hz). The mean phase lag of 122 degrees, is again largely below the 180 maximum phase lag for a second order transfer function predicted in Ethier (1974) thesis.

Summary of the four 2-Skate Phase-Lag to Frequency tests, in chronological order:

Looking at Table 1, the 1st and 3rd tests were slower than the 2nd and 4th. And both slower tests had a lower phase lag than the faster ones, illustrating that as slaloming frequency increases, phase lag also increases, which is as expected for a servomechanism. In terms of Bode Plot expressing Output amplitude and phase lag as a function of frequency, the phase lag range of – 93 to – 131 degrees for the 2-Skate tests, corresponds to the breaking point of the Bode Amplitude-to-Frequency plot, or the natural frequency of the servomechanism. A mountain bike case described below is added as a reference.

<table>
<thead>
<tr>
<th>Test:</th>
<th>Period One cycle (sec)</th>
<th>Frequency 1/s (Hertz)</th>
<th>Phase Lag (Degrés)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023-02-12 Rider R on the 2-Skate:</td>
<td>2.50</td>
<td>0.40</td>
<td>-95.6</td>
</tr>
<tr>
<td>2023-02-12 Rider S on the 2-Skate:</td>
<td>1,237</td>
<td>0.809</td>
<td>-130.6</td>
</tr>
<tr>
<td>2023-02-21 Rider T on the 2-Skate:</td>
<td>2,323</td>
<td>0.431</td>
<td>-93.1</td>
</tr>
<tr>
<td>2023-02-21 Rider J on the 2-Skate:</td>
<td>1,323</td>
<td>0.756</td>
<td>-121.9</td>
</tr>
<tr>
<td>2019-08-12 Reference Mountain Bike</td>
<td>2,228</td>
<td>0.449</td>
<td>-69.1</td>
</tr>
</tbody>
</table>

Table 1. Summary of four 2-Skate Phase-Lag to Frequency tests.

4.5 The 2-Skate Speed and Torso-Twisting while slaloming

A 2-Skate Speed Measurement: The video from a camera installed sideways from the 2-Skate path, was used to measure time elapsed between the orange cones distanced 2 meters, in order to measure speed. Four runs, each passing along three 2 meter lengths, gave the average speed of 7.6 km/h (4.7 MPH). The 2-Skate did not go straight and rather went slaloming, thus traveling a longer distance for a slightly higher speed. And it’s a rough estimation since the 2-Skate stayed away from the cones to avoid going over them, thus introducing a parallax error from the camera view. Other means should be used to get more precision, ranging from lines painted on the ice to better see the skates crossing them, to a full electronic data acquisition system.

Torso-Twisting while slaloming: The sideways camera used above for speed measurement of a 5th run, was used with the front camera, to mount another video with the front camera video above the sideways corresponding video. Sound synchronization of the two videos is far from perfect, but the resultant YouTube video https://youtu.be/n8NQgkJhJ_U shows the rider: (a) with arms straight on the front top view, and (b) with the shoulders straight forward and not doing any obvious Arms-Flexing or Torso-Twisting, on the bottom view. Furthermore, the top part of this twin video, from the front camera view, can be seen alone on YouTube video https://youtu.be/mPFlBF99a6s. Less distraction shows more clearly the rider not doing obvious Arms-Flexing nor Torso-Twisting, to influence slaloming. Still furthermore, the following Figure 11 shows the 2-Skate chassis (orange line) kept vertical on the left image. The middle image shows Torso-Leaning to the rider’s left (yellow line), and resultant front skate oriented in opposite direction (red line). And the right image shows the equivalent Torso-Twisting (cyan line) orienting the front skate in the same direction (red line). It is thus clear that an equivalent Torso-Twisting can be seen even on a front camera view, here with the rider’s right shoulder visibly moved back.

Figure 11. Equivalent Torso-Leaning and Torso-Twisting turning the Front Skate

And the following Figure 12 shows the five left Torso-Leaning of this preceding 5th run video https://youtu.be/mPFlBF99a6s. It is clear that the rider’s right shoulder is not twisted back to increase the front skate’s orientation towards its right (red line), in order to increase the 2-Skate chassis leaning in opposite direction towards the left, as the rightmost image of previous Figure 11. In fact, the rider’s shoulder is rather moved forward, exactly as the middle image of this previous Figure 11, which reduces the effect of torso leaning. In terms of the TAH Theory, the Open Loop Transfer Function Gain (OLTF Gain) is reduced, which slows down the servomechanism and generally reduces overshoot while increasing precision. Note that the front skate’s orientation (red line) varies in direction, caused by the rider not succeeding in going right-left at a constant frequency, amplitude and orientation (as would an electro-mechanical device do):

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Thus, this Figure 12 contradicts above reference Schwab Meijaard Kooijman (2012, page 1210), which considers that: “For steering, the upper body needs to twist.” These images rather support that Torso-Twisting rather reduces steering effect. Furthermore, both middle image of Figure 11 and rightmost image of Figure 12 support above Figure 1 illustrating that on a mountain bike, it’s easier and more natural to lean sideways while slightly leaning forward and twisting shoulders towards the intended direction.

4.6 Further Analyses of Slalom Phase Lag, using a Mountain Bike for comparison

Advantage of a Mountain Bike: Both the 2-Skate and a mountain bike can travel at slow speed where rider and chassis lean angle differences are more visible. Furthermore, both have a large handlebar (importantly on a 29 inch wheel mountain bike, for better handlebar leverage). So at slow speed the rider will have to push-pull farther on either side, flexing his wrists or twisting his torso more than on a narrower usual street or road-race bicycle handlebar. For the rider, such larger push-pull actions on the handlebar can better be felt and controlled. And for outside observers, both the larger handlebar bringing larger movements and the slower speed bringing larger torso lean angles, will render torso leaning and twisting more visible. On the other hand, the 2-Skate slows down during each run, while the mountain bike has the advantage of being able to go down a long and constant slope, at more constant speed with time to stabilize and avoid involuntary push-pull actions on the handlebar. So a slaloming mountain bike coasting down a hill can be a good comparison and even a reference for the 2-Skate. Even more so since it’s easy to avoid adding a voluntary or involuntary push-pull on the handle bar, because there is no need to run or act fast before coming to a stop.

Torso leaning and twisting: Both the previous section Limits of the TAH Mechanism’s simplification that considers Rigid Arms, and the two previous Figures 11 and 12, illustrated that it’s easier and more natural to lean sideways while leaning slightly forward and twisting slightly. For a mountain bike, the following Figure 13 illustrates again the elbows-hands and torso-shoulder movements, adding image (E) showing the needed torso-twisting for an equivalent front wheel orientation: Images (A) to (D) show the torso yellow line leaning progressively and transversely towards its left while the front wheel goes in the opposite direction along the red line, also progressively. The cyan shoulder line also shows this progressive leaning, while the green line shows the shoulders’ forward orientation, mostly straight ahead of the bicycle chassis. And image (E) shows an equivalent red line front wheel opposite direction, with the needed torso-shoulder twisting in the direction of the green line, along the more or less vertical spine axis. This twisting direction green line is somewhat oriented parallel to the front wheel red line.

Figure 13. Similar equivalent Torso-Leaning and Torso-Twisting turning the Front Wheel.

YouTube video [https://youtu.be/OkNuZbqqwzc](https://youtu.be/OkNuZbqqwzc) shows that right from the start on the mountain bike, the rider V’s head and torso go to one side, while the handlebar goes to the other side, initiating the turn as according to the TAH Theory. Examining carefully this rider V on the video, NO elbow-wrist flexing and NO torso-shoulder twisting along spine axis can be seen. Thus supporting that simply leaning the torso sideways versus the chassis could act to orient the front wheel right-left.

Reference time for mountain bike Phase-Lag calculations: On this same YouTube video, Phase-Lag times are determined (a) when the head starts turning towards the side where the rider wants to go, (b) when the bicycle starts changing direction and (c) when the front wheel gets to its maximum amplitude, as a verification queue. And to better see the head starting to turn, the protocol also included the head looking toward the first intended side, followed by a sudden fairly visible head direction change. The following Figure 14 shows screenshots (A) to (F) taken from this video [https://youtu.be/OkNuZbqqwzc](https://youtu.be/OkNuZbqqwzc), when:
- In (A) the bicycle still goes straight down the slope, and the rider’s head starts looking towards his left to change direction.
- In (B) the bicycle goes right but starts changing direction to go left. The rider’s torso is near to its maximum lean angle to the chassis, clearly showing the bicycle lagging the torso, and showing that the front wheel has to go far out to its right in order to lean the bicycle to the left, exactly as observed in above reference Schwab Meijaard Kooijman (2012, page 1210), with excerpt: “Only in the last few seconds prior to a sharp corner was an upper body lean angle observed - indicating that the lean was carried out because of a sudden heading change.”
- In (C) the front wheel gets to its maximum amplitude towards its right, as a verification queue.
- In (D) the rider’s head starts looking towards his right, changing direction again.
- In (E) the bicycle starts changing direction to go right.
- In (F) the front wheel gets to its maximum amplitude towards the left, as a verification queue.

**Figure 14.** Screenshots from going straight, to front wheel maximum amplitude towards left.

The speed was not recorded precisely and was roughly estimated to be between 8 and 16 km/h. VLC Media Player (with Time v3.2 extension giving milliseconds) was used to analyse the first six full cycles left-right-left of the video. Results are a cycle period of 2.28 second or frequency of 0.44 1/s (Hertz). And the bicycle leaning lags behind torso leaning at estimated (98, 57, 64, 65 and 62 degrees) for an average of 69.1 degrees. With the longer 98 degrees lag at the beginning for the bicycle to go towards its right ‘in the wrong direction’, in order to first lean the bicycle. And with the following lags closer to each other.

Another video with different protocol involving fastest possible orientation changes:

YouTube video [https://youtu.be/RCjptWYbS10](https://youtu.be/RCjptWYbS10) follows a slightly different protocol, with a very sudden face and torso angle and orientation change towards the left at the beginning of the video. This was done the fastest possible to better show that there is no jiggling or hesitation to start turning. But the start is so fast that the rider “overshoots” to the left and has to correct himself. The video only shows three full cycles, which do not make it a constant-slaloming test, and thus make it less suitable for phase lag calculations. Also, there’s no visible Arms-Flexing or Torso-Twisting, but the torso is clearly leaned towards the left, with the handlebar and front wheel being oriented by the TAH Mechanism towards the right. This clearly shows that a Countersteering is done, but not willingly, and rather as a cause of the TAH Mechanism being present. From this same video and with the same line colors, the following Figure 15 below shows screenshots (A) to (E) when:

- In (A) the rider’s head and torso on the bicycle are still going straight, just before suddenly going or leaning to their left, in order to change direction as fast as possible.
- In (B) the rider’s head and torso are leaned, immediately after they went towards their left. The yellow torso line leans towards its left comparison to the bicycle chassis orange line, which oriented the front wheel red line towards its right due to the TAH mechanism’s typical behaviour. The contact points on the ground then go to the bicycle’s right. This screenshot clearly shows that the torso lean angle leads the bicycle lean angle, which is still nearly vertical (or the bicycle lags the torso lean angle).
- In (C) the screenshot is a front view of the bicycle, straight-square forward of the rear wheel, which shows the torso yellow line and bicycle chassis orange line in their correct leaning angles in the transverse plane. The ground contact points gone to the right have let the torso and bicycle fall to their left. And as the bicycle fell to its left farther than the torso lean angle, the servomechanism’s error detector (Torso on bicycle, as exposed further down) worked: The bicycle orange line leaning more than the rider’s torso yellow line, progressively flipped the front wheel orientation’s red line towards its left, permitting the bicycle to go left. There was no jiggling or hesitation to start the movement up to that point. Afterwards, the rider does not go right-left-right-left as fast. Furthermore, this screenshot is nearly at the moment where the rider’s torso starts to change direction to go towards its right, again leading the bicycle lean angle (or the bicycle lagging the torso lean angle).
- In (D) the screenshot shows the moment when the bicycle starts changing lean angle towards its right, again lagging behind the torso’s lean angle.
- In (E) the front wheel gets to its maximum amplitude towards the left.
4.7 Flexing Arms & Wrists replaced by Wooden Arms

The following Figure 16 shows the wooden arms intended to further reduce cause factors and make sure the elbows and wrists do not flex. Here again with the same line colors, images (A) to (E) show the torso leaning progressively towards his left, and image (F) shows the torso-shoulder twisting needed for an equivalent red line front wheel opposite orientation:

https://youtu.be/mP6M6gBZtMw shows testing of these wooden arms by rider X. The road being wide enough, another protocol is tested, with the rider staying vertical and going straight a short distance, in-between each right or left turn. This shows that the subsequent torso-leaning is the initiating action permitting or causing the bicycle to turn. And after the bicycle passes the camera, from second 22 to second 29, rider X follows the original slaloming protocol, simply going right-left without stopping until going uphill.

Furthermore and at the beginning of the video just after the rider has started, he goes right, left, right and left again. Then these eight screenshot images A to H are taken, to compose the following Figure 17:

We can clearly see on this Ethier (2023x) video, that rider X goes straight a short distance from A to B. He then leans right in C, to turn right in D. And then the rider again goes straight a short distance in E to F, and again leans left in G, to turn left in H. All this slalom is done keeping wooden arms straight, with shoulders and torso straight ahead of the bicycle, thus not using any elbow-wrist flexing or Torso-Twisting to turn the handlebar. The only means left available to turn the handlebar and go slaloming, is thus the TAH Mechanism. Which further supports that torso-leaning causes front-wheel orientation changes through the TAH Mechanism, which causes the bicycle to turn according to the TAH Theory.
5.0 Conclusion:

Not counting Ethier, 13 independent riders tested the 2-Skate and found it easily rideable, except for one who could not ride a fatbike either. Without wheels, fork angle, trail or motive power, the 2-Skate supported the TAH Mechanism still present to be the cause of steerability when leaning right-left.

As predicted by the TAH Theory, the vehicle lean angle being larger than torso lean angle in steady-state curves, was confirmed. And the slaloming showed the 2-Skate chassis lean angle lagging the rider torso lean angle. These experimental tests not usually applied to bicycles, demonstrated the 2-Skate having the same behaviour as regular bicycles.

Due to lack of time and for safety purposes, only Ethier demonstrated that removing the hands from the handlebar, would leave the front skate to continue in its last direction, thus causing an immediate fall. In terms of servomechanism wording: the feedback loop was removed, which made Output go to an extreme position like for other servomechanisms, so the 2-Skate fell immediately.

Thus this TAH theory: (a) sheds light on how bicycles are steered, and could be considered in any further Single-Track vehicle study; (b) clarifies that Countersteering is done automatically at low speeds; (c) supports and clarifies the way mountain bike steering is taught; (d) suggests a slight modification of the way motorcycle Countersteering is taught, with emphasis on throwing your head and body toward where you want to go; (e) can be used to develop a different approach to 2-Wheeler simulators; (f) and can be used to develop special steering means that could renew interest for development of motorcycles with seat belts and protective structure like the electric BMW-C1, and the closed-cabin Peraves e-Tracer.

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