Title: Effects of differing shock types on rider performance in downhill mountain biking

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Abstract:

The research explores the effects of coil and air shocks on downhill mountain biking performance, focusing on impacts on rider comfort, energy efficiency, and controlling downhill mountain biking. According to Brunckhorst's (2018) MATLAB model and other telemetry data, suspension enhances performance by increasing traction, braking efficiency, and stability, allowing riders to achieve higher downhill speeds. Primary testing included timing, acceleration measurements, and stroke-tracing with magnetometers, which highlighted how air shocks transmitted more force during impacts, as seen with peak accelerations of 52.3 m/s^2 for air shocks versus 37.26 m/s^2 for coil shocks. This difference points to the coil shocks' effective reduction of rider fatigue on high-impact terrains. Subjective assessments showed higher perceived comfort of coil shocks compared to air shocks. On jumps, stroke tracing indicates coil shocks allow deeper travel usage, improving grip by keeping the wheel grounded, while air shocks are better suited for rapid acceleration needs on flatter sections. Mathematical modeling confirmed the air shock's progressive spring rate and the coil shock's linear spring rate. The air shock's progressive spring rate provides a faster response on smoother tracks with banked turns, as observed in its advantage on jump and smooth trail segments in timing. The coil shock's linear spring rate contributes to better traction and stability on rugged, steep terrain, enhancing rider control over rough sections and reducing physical strain due to its consistent response under impact. These findings underscore that terrain-specific shock selection can enhance performance, offering empirical insights beyond typical product marketing claims.

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Introduction:

Background:

In the sport of mountain biking riders maneuver their bikes through rugged terrain. To improve control and comfort, many mountain-bikes are designed with rear suspension. Rear suspension involves a linkage driven shock, which compresses and extends telescopically corresponding to the rotational movement of the linkage[1].

Effects of rear suspension are most prominent in downhill mountain-biking[2], a discipline where athletes descend several hundred meters vertically over rough terrain in the shortest amount of time at maximum speeds of 80 km/h. (Brunkhorst, 2018) Under these circumstances, the physical strength of the rider is pushed to the limits. An effective suspension system reduces forces transmitted to the bike and the rider, and subsequently allows them to achieve better race results. (Titlestad et al. 2003)

Suspension design not only helps athletes push the boundaries of downhill racing, but also manifests itself in the amature community. Bike and suspension companies market their products by claiming that it can improve performance regardless of skill-level.

Fig 1: Position of Shock and Linkage

Fig 2: Downhill Mountain biking

Research Question:

To what extent do different characteristics of coil and air shocks affect rider performance in downhill mountain-biking.

Justification of Research Question

My research question focuses on the effect of the shock component in the context of downhill mountain biking. The purpose of this article is to determine how much we should trust product characteristics in terms of improving our own riding. This is significant because objective feedback about a shocks effect on performance allows riders to make rational purchasing decisions when buying a new component. This gives them more awareness about whether claimed performances increase are marketing slogans, which protects consumers as a whole.

Fig 3: Rockshox SuperDeluxe Ultimate Air

Fig 4: Rockshox SuperDeluxe Ultimate Coil

Literary Research Plan:

Literary research is used to gain understanding of the research question and help me in the analysis of test results. The research is presented in a order to optimize clarity and understanding.

Order	Issue for Investigation	Justification	Strategy	Type
1	Suspension background	This familiarized myself with key terms and concept that may be used in analysis.	Read suspension design papers.	Secondary
2	Existing research done on rear shocks affects rider performance.	Helps me focus my research by determining areas that have not been explored before. Helps me identify performance indicators to use in my own test. Helps me frame my own performance tests.	Read papers investigating suspensions affect on performance from academic databases.	Secondary
3	Application of coil and air shocks in different downhill tracks	Helps me answer **to what extent** by observing professional racers sensitivity to different shock choices.	Tally the shock usage in different race events.	Primary
4	Specification for two shock model	The eye-to-eye length and stroke specifications match the requirements on the bike. Two shocks must also be comparable so the spring difference is the only independent variable.	Compare my bikes listed shock specification with all potential shocks + consult experts about suitable products to test.	Primary

Literature Review

Suspension Background

When the bicycle wheel collides with terrain features such as rocks, roots, dips, and drops, the suspension system allows it to move in the direction of the impact force while keeping the frame centered. This elongates the duration of impact, and therefore reduces peak force. The movement of suspension is called **stroke**, and the amount of stroke that is used for shock absorption is called **travel**.

Shock absorbers are composed of an **elastic** (spring) and **viscous** (damper) element. The elastic component is a steel coil or an air chamber that can be preset at different stiffnesses according to the nature of the terrain and cyclist's preference. This essay focuses solely the elastic element, and therefore aims to minimize the effect from differing viscous elements.

The spring manages the majority of the energy. Energy created from impact drives the **compression stroke**, where the piston is contracted against the spring. This stores the energy within the spring, creating opposing force to the piston. During **rebound stroke**, the opposing force exceeds the impact force, which extends the piston until all energy is released or a mechanical stop limits further expansion. This is known as **top out**. A spring's capability of energy absorption is measured by **spring rate**:

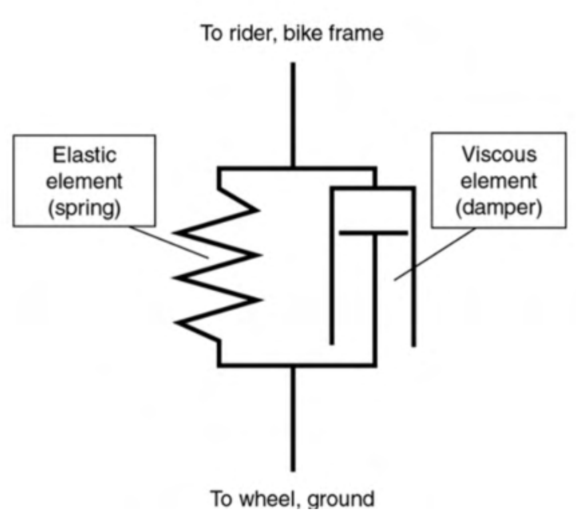


Fig 6: Elements of a shock absorber

$$Spring\ rate(C) = \frac{Applied\, force\ (pounds)}{Displacement\ (inches)}$$

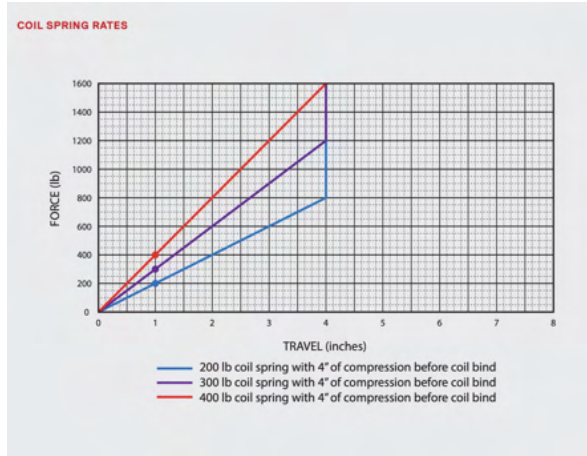


Fig 6: Coil Spring Rates

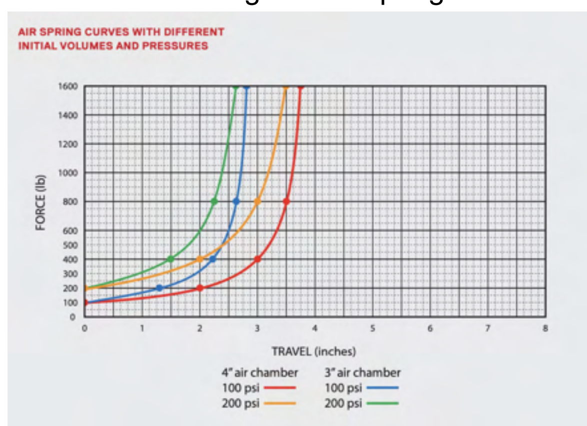


Fig7: Air Spring Rates

For coil springs this ratio remains constant throughout the entirety of **travel**. This is because energy is stored in an elastic spring, where the opposing spring force is proportional to the displacement created. This could be attributed to Hooke's Law:

$F = kx$

For air springs this ratio increases exponentially throughout the **travel**. This is because energy is stored as air pressure, which increases exponentially as the volume of the air chamber reduces. This rate of exponential growth is called **progressively**, and could be attributed to the rules of adiabatic process:

$$F = \frac{k}{v^y} \cdot A$$

When the rider steps on the bike, their weight compresses the shock absorber slightly. This is called **sag**. Sag allows the suspension to also extend over bumps to maintain traction. In coil shocks, **sag** can be adjusted by changing **spring rates** or **preloading** the spring. In air shocks, sag can be adjusted by pre-inflating the air chamber to a certain pressure.

Existing research

Research done on rear suspension's effect on performance mainly focuses on the existence , rather than the type for rear shock absorbers. Nonetheless, these research are useful for showing the extent of suspension effects on performance.

1. TitleStad, John K 2006 compared different physiological and psychological responses between twenty male participants when riding a hardtail bicycle and a full suspension bicycle. A test rig isolated performance on rear suspension, where heart rate, oxygen consumption, perceived exertion (RPE) and comfort were recorded. For full suspension bicycles, oxygen consumption, heart rate and RPE were lower on average by 8.7 ml / (kg· min), 32.1beats / min and 2.6 units, respectively. Comfort scores were higher (better) on average by 1.9 (s = 0.8) units.

2. Herrick, Jeffrey compared the metabolic and performance effects of riding hard-tail versus full suspension bicycles on a simulated cross-country race course. Seven competitive mountain bikers completed a randomized trial for each. The test showed hardtails was significantly faster than full suspension during the ascending segment of the course while Full suspension tended to be faster during the descending portion of the course.

3. Smith, Gerald 2016 Aims to quantify impact acceleration damping in three stiffness settings. Seven participants impacted a bump at 5.4 m/ s located about 2.3 m past the ramp end. Accelerometers placed on the axle and frame transmitted information to the computer at 1000 hz. Peak acceleration and the slope of impact acceleration were

extracted. All forks are similar at the axle and frame on the small bump. On larger bumps softer suspension forks significantly reduced acceleration transmitted to the rider during bump impact, while maintaining significantly higher axle acceleration. Jerk was significantly reduced at the frame compared to the axle for each suspension fork with the larger bumps. This research presented an interesting method to quantify suspension effectiveness and interpreting suspension behavior in real world context.

4. Needle & Hull (1997) used a different method to directly track suspension behavior. Data around suspension displacement was collected through the use of a linear motion potentiometer. He asserted that effective rear suspension can improve cornering, braking, line holding, and create higher downhill speeds.

5. Brunckhorst, Ben 2018 constructed a Matlab model to mathematically simulate a suspension reaction to different features before using a telemetry system to verify the effect in real life. His categorization of kinematic data encapsulates the suspension movement and its physical effects to the bike. These categories include: displacement vs time, shaft velocity vs time, spring force vs displacement, damping force vs displacement. They could be useful in setting up my experiments. I could also measure the damping coefficient of the two shocks, defined as force per velocity (Ns/v) to compare how they absorb energy.

It can be concluded that rear-suspension improves rider performance to an observable extent. Brunckhorst, Ben 2018 summarized physical and physiological reasons for this phenomenon.

First, rougher terrain need not be avoided with suspension, which improves straight-line velocity. Second, suspension improves traction by providing a more constant normal force. The normal force is proportional to the amount of friction between the tyre and ground, translating to better braking performance, cornering and predictability of the bicycle. Third, suspension creates a longer contact time which maximizes acceleration from gravity. Fourth, by absorbing energy, suspension can reduce the risk of injury due to impacts and give riders more confidence. Fifth, suspension decreases physical exertion through dampening vibrations. This improves sharpness of vision and rider strength.

Air and Coil Riding Applications

The Union Cyclist Internationale (UCI) world cup downhill series is referenced for shock usage. This competition is held around tracks of different nature. variety of tracks can exploit the performance characteristics of each type of shock. The table below features shock usage for top ten riders:

Track & Description	Picture	Coil Users	Air Users	Average Time Difference
Fort William 2.9km length, 552m elevation drop, 15.4 average gradient. Long, rocky, and physically demanding.		9	1	Coil with 3.1 Second Lead

Bielsko Bala 2.0km length, 408m elevation drop, 14.6 average gradient. Soft dirt, Smooth Berms, off-camber.		4	6	Air with 0.1 second lead
Leogang 2.1km length, 449m elevation drop, 12.2 average gradient. High(80km/h) speeds, roots, large jumps.		7	3	Coil with 2.4 second lead
Val - di - sole 2.1km length, 555m elevation drop, 40% max gradient. Technically demanding, Steep drops, tight corners, loose, dry terrain.		9	1	Air with 1.3 second Lead
Haute - Savoie 2.4km length, 553m elevation drop, 13.7% average gradient. Flat runways, slippery roots.		5	5	Air with 3.2 second lead.

Fig 8: Application of air and coil shocks on downhill course

There is a strong preference for coil shocks, especially on rougher and more physically demanding tracks, which shows a relationship between coil shocks and reduced physiological strain. In flatter, smoother, and tracks with tight turning that requires frequent acceleration, air shock usage increases. This is similar to research on how hard-tails reduce power inefficiency.

Selected Product Specification

I selected Rockshox SuperDeluxe Ultimate Coil and Rockshox SuperDeluxe Ultimate air as the two products for my comparative study. They both meet my bike's mounting specifications with an eye to eye length of 205 millimeters and stroke length of 65 millimeters. The two shocks are equipped with similar dampers to isolate spring performance. A test carried out by MacRae et al with six riders used the old version of the RockShox Deluxe rear-shock absorber. The test showed that damper performance was similar across riders of different weights, proving the products reliability in isolating spring performance.

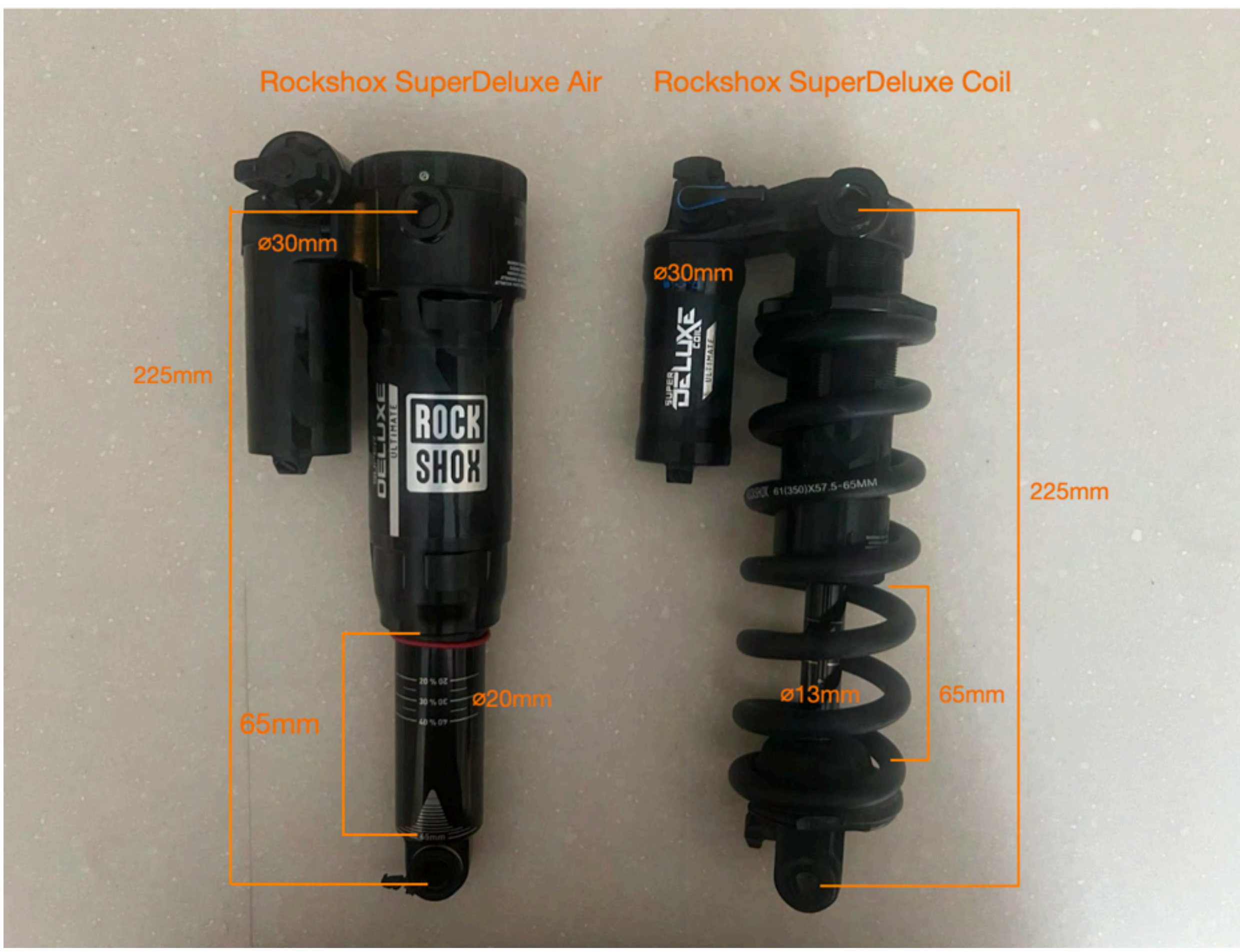


Fig 9: Measurement of air(left) and coil(right) shocks

Product	Spring	Damper	Rebound Tune	Compression Tune	Lockout Force(N)	Weight(g)	Shaft Eyelet
Air	DebonAir Linear	RC2T Hydraulic Bottom out	Linear	LC	320	458	Trunnion
Coil	57.5 Steel	RC2T	Linear	M	320	902	Standard

Fig 10: Shock Specification Table

Fig 11: Air Shock Product Page

Fig 12: Coil Shock Product Page

Testing Plan

Testing is conducted in order of importance to collect primary data.

Priority	Test Description	Dependent Variable	Type	Controls	Method of Collection
1	Timed Recording	Total timing (min & sec)	Quantitative	Track Condition Physical Condition Damper Tuning Section Start End	Field testing
		Sectional Timing (s)	Quantitative		
		Sectional Max Velocity (mph)	Quantitative		GPS
		Feature max acceleration (g)	Quantitative		Accelerometer
2	Performance review	Perceived ride quality	Qualitative	Physical Condition Damper Tuning	User Trail
		Air time(s)	Quantitative		Video Observation
3	Stroke tracing	Maximum Travel (mm)	Quantitative	Track Condition Physical Condition Damper Tuning Magnemoter Distance from shock	Linear Displacement Sensor
		Mean Stroke Position (mm)	Quantitative		Calculation
		Stroke standard deviation (mm)	Quantitative		Calculation
		Shock Movement trend	Qualitative		Displacement Graph + Recording
8	Psychological feedback	Perceived Physical Exertion(1-10)	Quantitative	Similar User Group	User Survey: Ordinal

		Perceived Comfort(1-5)	Quantitative		Data Scale
5	Single impact acceleration	Peak acceleration (m/s^2)	Quantitative	Impact Strength Damper Tuning Sensor Position	Lab Testing
		Acceleration Trend	Qualitative		
7	Single impact stroke tracing	Maximum travel use(mm)	Quantitative	Impact Strength Damper Tuning Sensor Position	Lab Testing
		Shaft speed (mm/s)	Quantitative		
		Shock Movement trend	Qualitative		

Testing setup:

Sag Setting

Ensuring a similar spring rate between the two shocks is important for isolating the spring mechanics from other factors. Here, weighted initial stroke (**Sag**) is used as a control variable and set at 20% of full travel. This process was completed by standing on the bike(Fig 13) and sliding the red o-ring(14) to top of the stroke. Air pressure and spring rates are adjusted accordingly on each shock to achieve the 20% mark.

Fig 13: Setting Sag

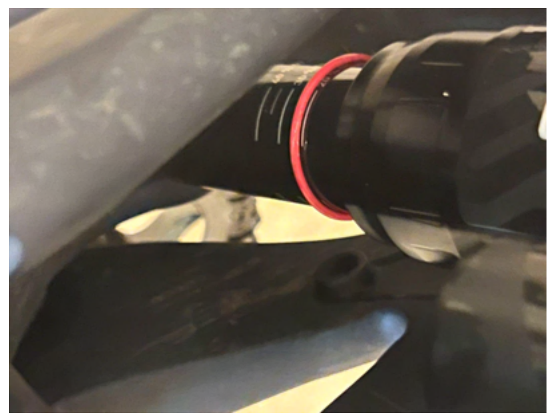


Fig 14: O-ring indicating 20% Sag

Spring Rate: 350 lbs/inch

Air Pressure: 155 psi

Damper tuning:

The two dampers are tuned similarly to isolate spring characteristic from damper performance. Since the two shocks have the same damper, I can copy the settings from coil shock to air, and vice versa. Mathematically, under the same setup the two shocks should have the same **damping coefficient**. I determined the final setup through a mix of manufacturer recommendation and personal preference.

Shock Type\Adjustment	Low Speed Compression	High Speed Compression	Rebound
Coil	⅖ clicks (softer)	0/5 clicks (softest)	5/15 clicks (faster)
Air	⅖ clicks (softer)	0/5 clicks (softest)	5/15 clicks (faster)

Fig 15: Damper tuning of the two shocks

Mounting process

The two shocks will be mounted to the test bike back and forth for each test. This method maximizes consistency in track and physical conditions by reducing the time difference. The shock is assembled through an upper shock bolt and a lower shock bolt. A modified CNC ring has to be pressed into the coil shock mount for tight fitment. Changing time is 10 minutes.

Fig 16: Disassembly of the shock bolt

Track Selection:

L2.2 and L4 showed that the test environment can significantly affect results. Therefore, **Field testing** will be conducted on two locations to measure the advantages and disadvantages of each system. Characteristics in each track vary similar to world cup tracks. This makes a good test for **product versatility**.

Fig 17: Two tracks indicated on bike park map

Race Track Information

Location: China, Chongli, Forlong Bike Park

Length: 2.39 km

Elevation Drop: 248m

Average Gradient: 10.3%

Features: Rough, Off-camber, Tight Corners, Mix of Steep and Flat Sections.

Fig 18: Race Track


Fig 19: Rugged Terrain

Jump Line Information

Length: 1.96 km

Elevation drop 186m

Average Gradient: 10.4%

Features: Smooth, Banked Corners, Large Jumps.

Fig 20: Race Track

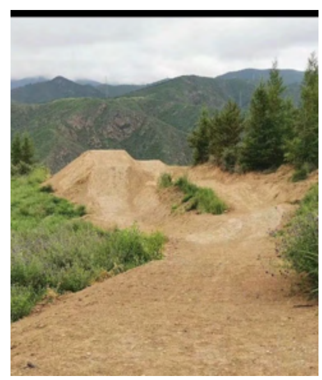


Fig 21: Large Jump

Timed Recording of coil vs air shock on two varying courses

Method

A gopro was mounted to my chest armor(Fig 22) which recorded the full run. On the first day, both shocks were tested on the race track for three trails each. On the second date, both were then tested on the jump line. For sectional comparisons, particular features on track recorded by the camera are used as benchmarks.

Fig 22: Gopro Mounted to Chest Armor

Fig 23: Race Track Recording Ending at 5:30

Fig 24: Jump Line Recording Ending at 3:41

Overall Timing

Trail\Track	Race Track(Air)	RaceTrack(Coil)	JumpLine (Air)	JumpLine (Coil)
Trail 1	5:29	5:30	3:34	3:40
Trail 2	5:45	5:32	3:32	3:39
Trail 3	5:21	5:22	3:35	3:45
Average	5:31	5:28	3:31	3:41

Fig 25: Table indicating overall timing of both shocks on both tracks

Analysis

The air shock was significantly faster than the coil shock on the jump line because it required pumping for acceleration, which prioritized the support of the air shock. On a race track, the coil shock was slightly faster than air shocks. The mix of terrain allowed each shock to perform in its area, so there were no significant differences overall. This is why sectional timing is used.

Sectional Timing

Section Description	Time Interval Air	Max Velocity Air	Time Interval Coil	Max Velocity Coil
1. Smooth Banked Corners. 	**0:00-1:10**	**21mph**	**0:00-1:13**	**21mph**
2. Rough Steep Straight 	**1:11- 1:47**	**16mph**	**1:14-1:49**	**18mph**
3. Consecutive Tight Corners 	**1:48-2:07**	**10 mph**	**1:50-2:10**	**8mph**

4. Off Camber Terrain 	**2:08 - 2:17**	**8 mph**	**2:10 - 2:17**	**11mph**
5. Mixed Jump Section 	**2:18 - 4:02**	**29 mph**	**2: 18 - 4:01**	**28mph**
6. Flat Section 	**4:03- 5:29**	**17mph**	**4:01-5:30**	**17mph**

Fig 26: Sectional Timing for Both Shocks on Race Track

Analysis (Race Track)

On rougher sections 2, 4, and 5(Fig 26), coil shock was faster than the air shock. On smoother sections 1, 3, and 6, air shock was faster. Compared to the overall timing, the sectional difference is more significant. For example, on section one which is only 70 seconds long, the air shock gained an advantage of 3 seconds, equivalent to 4% faster. This is because the air shock is able to gain more velocity in berms and pumps. On section 4, however, the coil shock gained a massive 29% difference. This is because the coil shock provided more traction, and allowed me to ride down uneven terrain smoother without washing out.

Analysis (Jump Line)

On the jump line, there is no purpose for sectional timing because it is monotonous. Instead, I compared the maximum velocity of two shocks on a straightway.

Fig 27: Gopro Screen Shot of Coil Shock

Fig 28: Gopro Screen Shot of Air Shock

The air shock achieves a higher maximum velocity (Fig 28), however, its speed also diminishes quicker. When the air shock reaches a similar position to the coil shock, its speed reduces to 26mph, while the coil shock remains consistent at 28mph (Fig 27). This can be attributed to the characteristics of suspension (Research 1.1 & 2.5) where coil shock creates a more constant normal force, allowing gravitation acceleration to have a longer effect compared to friction.

Particular Feature Acceleration

Acceleration on particular features are recorded through a built in accelerometer. A group of data was collected when the accelerometer was mounted on the frame near the shock(Fig 28), and a group of data collected when it was mounted near the seat post. The acceleration graph is cross referenced with the altitude meter to make sure that data is collected at exactly the same point.

Fig 28: Gopro Mounted Near Shock

Fig 29: Gopro Mounted Near Seatpost

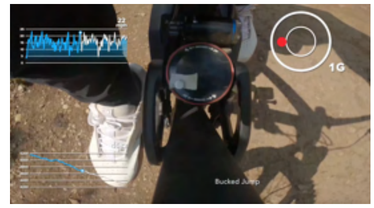


Fig 30: Shock compression recorded through frame mount on a cased jump at 1G

Fig 31: Shock compression recorded through seatpost mount on corner at 1G

	Race Track			Jump Line	
	Compression before corner (Fig 31) 	Undulation 	Cased Jump (Fig 30) 	Jump 1 	Jump 2 
Coil peak acceleration(g)	1g	1.0G	0.5 G	0.5G	0.9G
Air peak acceleration(g)	2g	1.7G	1.0G	1G	1 G

Fig 32: Maximum Acceleration Recorded on Different Features

Errors and Uncertainties

The method for overall timing, sectional timing, and maximum velocity all proved to be reliable from multiple trails. The data output is also well within expected range. However, the method for Particular acceleration is not as polished. This is because go-pro only outputs a rough acceleration graph instead of detailed data. There are some errors within the data, for example in a cornering measurement, the difference was as large as 1G, which is unrealistic.

Subjective Performance Review

Perceived Ride Quality(2.1):

When I compress a coil shock, it sinks deep into the travel. There is a minimum feeling of resistance against my compression force. During riding, when the rear wheel collides with an obstacle, the shock moves rather freely and gently lifts over the obstacle, absorbing most of the impact force. The shock allows the rear wheel to trace the terrain constantly because of how easy it is to move into the travel. This results in tremendous amounts of traction (Lit 2.5) since there is constant normal force with the ground. This is also demonstrated through the significant advantage of coil shock on the off - camber section. (Test 2.2). However, these characteristics also result in disadvantages. The shock is so easy to sink into travel, that it would often bottom out. It also has a “soggy” feeling, in which the shock gives me no support when I am trying to accelerate through pedaling, pumping, or cornering.

When I compress an air shock, it sinks shallower into travel. There is a noticeable feeling of resistance starting from the middle stroke. During riding, when the rear wheel collides with an obstacle, the shock bounces slightly over the obstacle, transmitting a pulse of acceleration to me. The shock is less sensitive to gradual terrain changes such as undulations. This can be attributed to the steep progression curve (Lit 1.2). This results in more support and less traction. The shock is able to efficiently convert my work into forward momentum, demonstrated through the significant advantage of air shock on the smooth berm section which requires me to constantly accelerate the bike (Test 2.2). However, these characteristics also result in disadvantages. The shock can be too supportive, which causes more acceleration to be transmitted to me on big impacts(Lit 1.4). When I experience this repeatedly fatigue comes and affects my physiological performance.

Air Time (2.2)

Method

A jump that is 2.5m tall and 4m from takeoff to landing is selected. The rider glides down the jump runway from 50 meters before the jump without pedaling. This creates a consistent velocity of 20mph when the rider approaches the jump. A video is recorded by another person from takeoff to landing at 60 frames per second. Then frames are counted in video analysis to determine which shock produces longer air time.

Fig 33: Air

Fig 34: Coil

Fig 35: First Person with air shock

Fig 36: First Person with coil shock

Analysis

The air shock was in the air for 72 frames, while the coil shock had 78 frames. This translates to 1.2 and 1.3 seconds of air time respectively. This difference is minimal considering the variations in technique. However, there was a massive perceived difference. I felt that the air shock “boosted” me more, and gave me significantly more air time. This can be attributed to the stiffness of the air shock. Because it is stiffer, the shock transmitted more acceleration from the jump to me. When comparing the body position in the two pictures, the coil shock puts the bike in a more leveled state, while the coil shock results in a steeper pitch. This is because the air shock supports and lifts the real wheel while the coil shock sinks the rear wheel under acceleration.

Errors and Uncertainties

The method of video analysis can record air time with high accuracy. Despite this, the results were counter-intuitive considering that the air shock is supposed to grant more air time. I can attribute this to variations in jumping technique, as a different rider input can significantly impact the jump trajectory.

Stroke Tracing (Field Test)

Method

Recording of shock movement can be done with a displacement sensor attached to two ends of the shock(Lit 2.3). For simplicity, I will use magnetometers instead. A 7mm diameter cylindrical magnet is glued onto the top of the coil shock(Fig 37). The built-in magnetometer in the iphone will function as the measuring device. The iphone is taped to the bike's downtube(Fig 38), and the distance is adjusted according to field strength(μT) to ensure that the iphone remains at a constant position.

Fig 37: iPhone magnetometer and Magnet

Fig 38: Relative position between iPhone and bike

Baseline testing is conducted with an unpressured air shock, which allows the suspension to compress and extend freely. By recording the magnetic values at topout and bottom out, a calibration spectrum could be set.

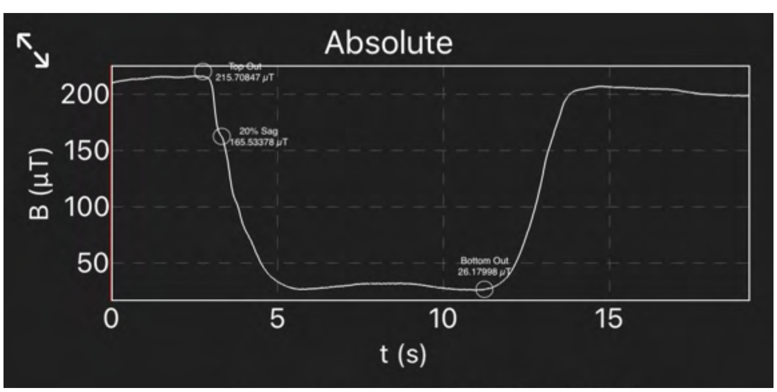


Fig 39: Magnetometer Reading on a Full Compression with Important Points Indicated

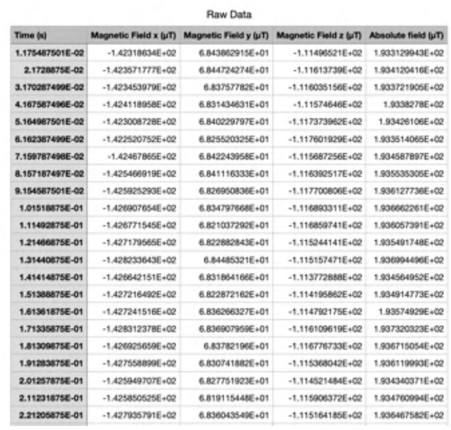
The Magnetic field is 215(μT) at 0 mm displacement and 16(μT) at 65mm displacement(Fig 39). Since Magnetic fields from a dipole source decay following an **inverse cubic law**, we can combine our data with the equation:

$$B(r) \propto \frac{1}{r3}$$

To derive a formula that transforms field strength readings to displacement readings(mm):

$$B(d) = \frac{5.5 \cdot 10^7}{(63.6 + d)^3}$$

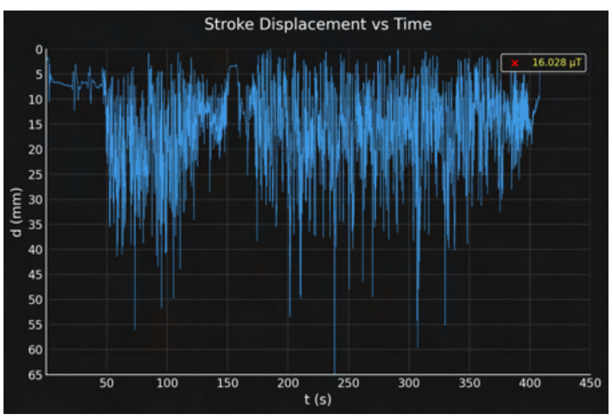
The magnetometer readings are taken at 100 Hz, and its data are outputted as a csv table(Fig 40). Then I used a data processing software to graph the charts.


Raw Data

Time (s)	Magnetic Field x (μT)	Magnetic Field y (μT)	Magnetic Field z (μT)	Absolute field (μT)
1.175487501E-02	-1.42318634E+02	6.843862915E+01	-1.11496521E+02	1.933129943E+02
2.1728875E-02	-1.423571777E+02	6.844724274E+01	-1.11613739E+02	1.934120416E+02
3.170287499E-02	-1.423453979E+02	6.83757782E+01	-1.116035156E+02	1.933721905E+02
4.167587496E-02	-1.424118958E+02	6.831434631E+01	-1.11574646E+02	1.9338278E+02
5.164987501E-02	-1.423008728E+02	6.840229797E+01	-1.117373962E+02	1.93426106E+02
6.162387499E-02	-1.422520752E+02	6.825520325E+01	-1.117601929E+02	1.933514065E+02
7.159787498E-02	-1.42467865E+02	6.842243958E+01	-1.115687256E+02	1.934587897E+02
8.157187497E-02	-1.425466919E+02	6.841116333E+01	-1.116392517E+02	1.935535305E+02
9.154587501E-02	-1.425925293E+02	6.826950836E+01	-1.117700806E+02	1.936127736E+02
1.01518875E-01	-1.426907654E+02	6.834797668E+01	-1.116893311E+02	1.936662261E+02
1.11492875E-01	-1.426771545E+02	6.821037292E+01	-1.116859741E+02	1.936057391E+02
1.21466875E-01	-1.427179565E+02	6.822882843E+01	-1.115244141E+02	1.935491748E+02
1.31440875E-01	-1.428233643E+02	6.84485321E+01	-1.115157471E+02	1.936994496E+02
1.41414875E-01	-1.426642151E+02	6.831864166E+01	-1.113772888E+02	1.934564952E+02
1.51388875E-01	-1.427216492E+02	6.822872162E+01	-1.114195862E+02	1.934914773E+02
1.61361875E-01	-1.427241516E+02	6.836266327E+01	-1.114792175E+02	1.93574929E+02
1.71335875E-01	-1.428312378E+02	6.836907959E+01	-1.116109619E+02	1.937320323E+02
1.81309875E-01	-1.426925659E+02	6.83782196E+01	-1.116776733E+02	1.936715054E+02
1.91283875E-01	-1.427558899E+02	6.830741882E+01	-1.115368042E+02	1.936119993E+02
2.01257875E-01	-1.425949707E+02	6.827751923E+01	-1.114521484E+02	1.934340371E+02
2.11231875E-01	-1.425850525E+02	6.819115448E+01	-1.115906372E+02	1.934760994E+02
2.21205875E-01	-1.427935791E+02	6.836043549E+01	-1.115164185E+02	1.936467582E+02

Fig 40: Data Table Exported from Magnetometer

Max and Min Travel



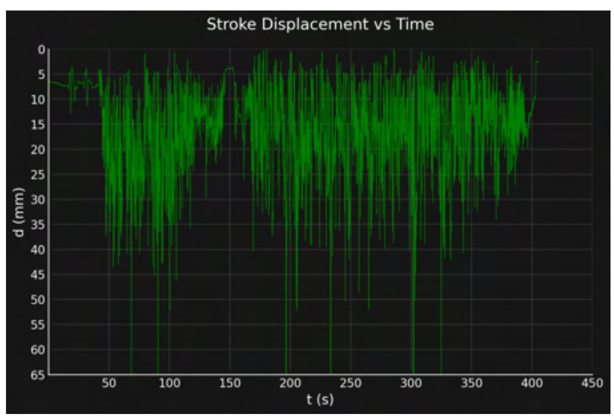


Fig 41: Displacement vs Time for Air Shock

Fig 42: Displacement vs Time for Coil Shock

	Air	Coil
Number of Bottom out	1	6
Number of Impacts over 55mm	4	6
Number of Top Out	7	5

The coil shock is much easier to bottom out(Fig 44) compared to the air shock. This can be attributed to the spring rate (Lit 1.2), where the air shock ramps up exponentially while coil remains linear.

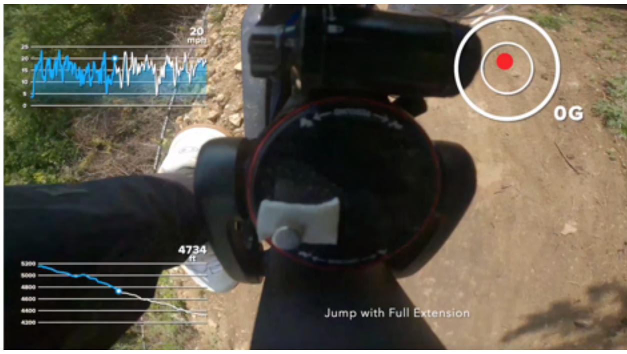


Fig 43: Shock Top-out on trail

Fig 44: Shock Bottom-out on Trail

Mean Stroke

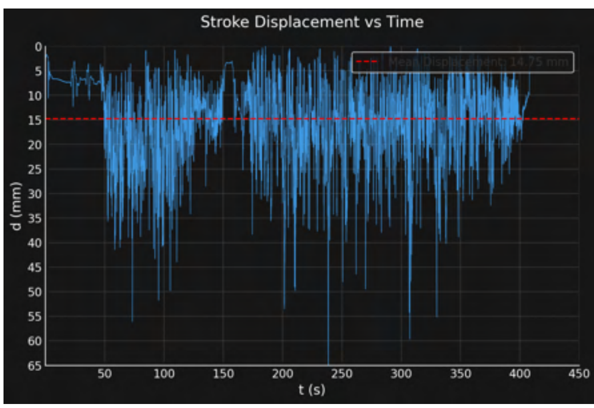


Fig 45: Mean Smoke Line indicated for air

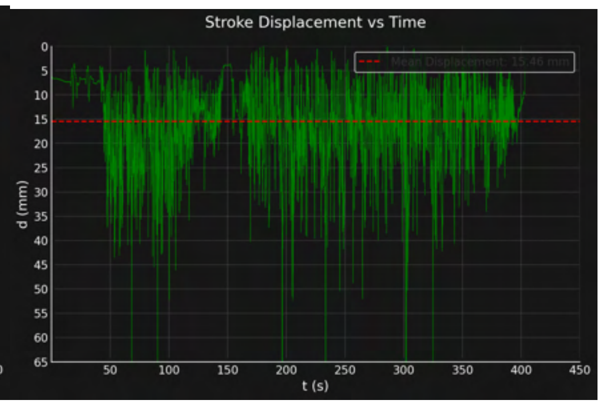


Fig 46: Mean Smoke Line indicated for coil

The coil shock has a higher mean stroke number at 15.46 mm versus the air shock at 14.75 mm. This means that the coil shock sinks deeper into the travel, which explains the feeling of sogginess mentioned in (Test 2.1) Although both shocks are set at the same sag, there is still a difference, showing the differences between the characteristics of two shocks.

Stroke SD

σ Air = 8.86 mm

σ Coil = 9.30 mm

Standard Deviation measures how much each stroke deviates from the mean stroke. This is a good measure of shock activiness. We can see that the coil shock is relatively more active than air, which explains the better traction but less support.

Shock Movement trend

When plotted against each other, the two graphs have a similar trend(Fig 47). This corresponds to the obstacles on the same trail. However, due to slight timing differences, the two graphs don't entirely overlap with each other.

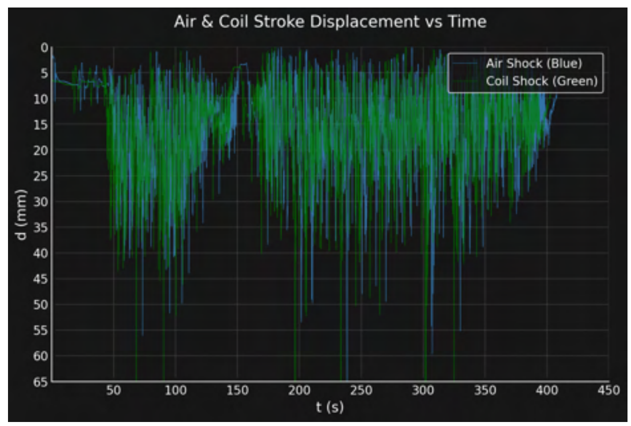


Fig 47: Comparison Graph between Air & Coil

Errors and Uncertainties

There was one error in stroke tracing of the air shock. The raw data feedback was 16.028 μT, which translated to a stroke of 87.5mm. This is unrealistic because the shock stroke only extends 65mm.

Psychological feedback: Survey

Method

Literary Research 2.1 highlighted the importance of including psychological feedback. I mimicked their experiment setup, using 1-10 ordinal scale to measure perceived physical exertion and a 1-5 scale to measure comfort for both shocks.

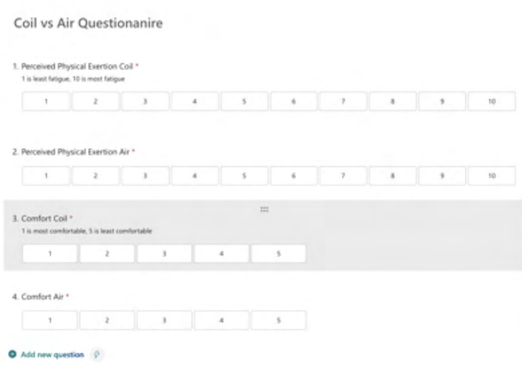


Fig 48: Survey Design

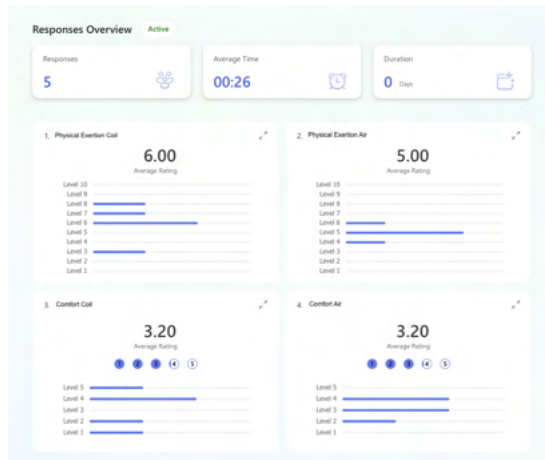


Fig 49: Survey Results

Analysis

The five participants in the survey all have experience with both coil and air shocks. The physical exertion for coil was consistently higher than that of air. This verifies my feeling of reduced support in the event of pedaling. The average comfort level is exactly the same. However, the standard deviation for coil shock results is larger than air shock results , which indicates that users have varied opinions about the coil shock, while the air shock satisfies a wider user base.

Errors and Uncertainties

There were no anomalies in the results. Only five people participated in the survey, so this may affect the reliability of the data.

Single Impact Acceleration

Method

Attributing to literary research 2.3, an iphone accelerometer was taped to the frame close to the shock. The test involves one rider dropping down a 0.5m step(Fig 50) while tracing the peak acceleration, jerk, and general trend during a cycle of suspension compression, which can be identified through video or the time interval between v(t)=max and v(t)=0.

Fig 50: Testing Process

Mathematical Prediction

Since acceleration is defined as $\frac{dv}{dt}$, we can calculate it mathematically by obtaining the two values. The impact velocity at landing can be calculated using the equation $v^2 = u^2 + 2ax$

Working this out:

$$v = \sqrt{2gh}$$

$$v = \sqrt{2 \cdot 9.81 \cdot 0.5}$$

$$v = 3.13m/s$$

The time difference can be obtained through video analysis. The landing took 12 frames in a 60 fps video, translating to 0.2 seconds. Therefor, the predicted acceleration is:

$$a = \frac{3.13}{0.2}$$

$$a = 15.65\, ms^{-2}$$

Experiment Results

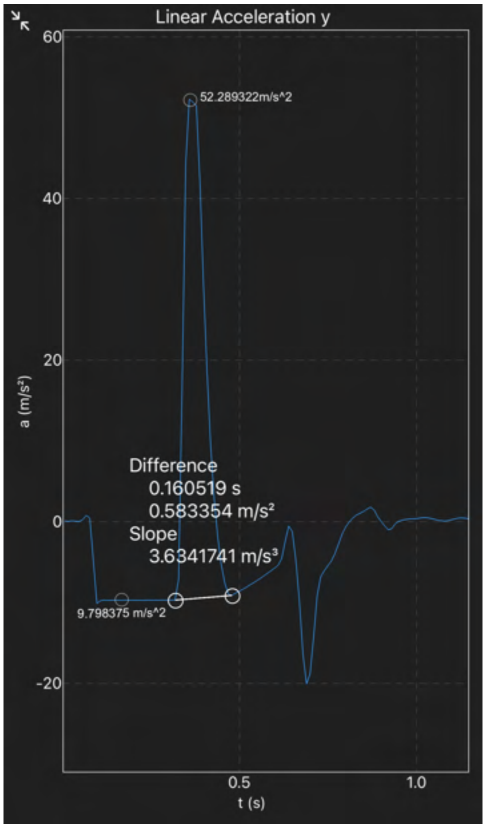


Fig 51: Air Shock Acceleration Graph

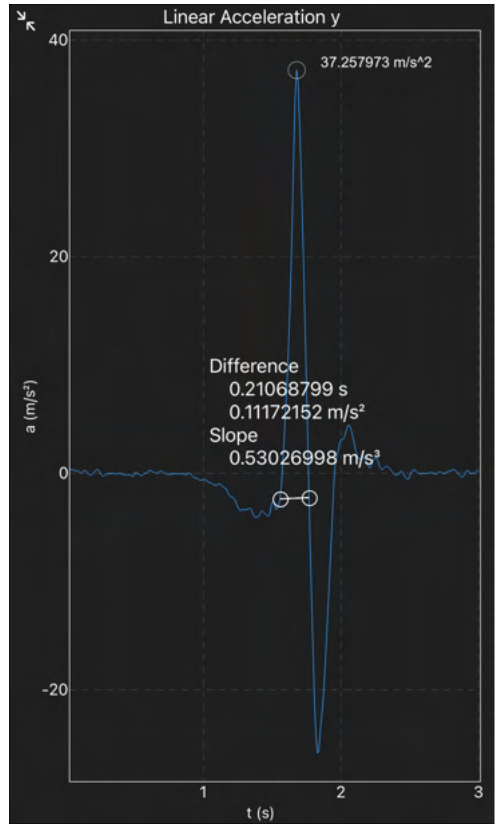


Fig 52: Coil Shock Acceleration Graph

Analysis

Interpreting the graph, we can see that the acceleration falls to roughly -9.8 m/s^2. This is gravitational acceleration experienced during free fall. After the wheel contacts the ground, acceleration rapidly increases in the positive direction, as downwards velocity approaches zero. The peak appears near full compression, as the force of the spring reaches maximum. For the air shock, the peak lies at 52.3m/s^2, while for the coil shock, the peak lies lies significantly lower at 37.26 m/s^2. This is reasonable since the time used for coil shock is longer than the air shock at 0.21 and 0.16s, respectively. A longer time dissipates the impact force better and therefor reduces acceleration. Another observable characteristic is that the air shock becomes more rounded near the peak, while the coil shock is linear throughout the acceleration change. This can be attributed to the fact that the air shock is progressive, and therefor provides more resistance as the shock compresses deeper into travel.

To verify our mathematical calculations, we can divide the velocity change, 3.13, as calculated, by the actual compression interval, which is 0.16s in the air shock. The average acceleration is then 19.6m/s^2, aligning with the graph.

Errors and Uncertainties

The acceleration collected is within expected value and fairly accurate. However I can only roughly approximate the end of the stroke, as it is difficult to determine when the velocity reaches zero using solely an acceleration graph.

Single Impact Stroke Tracing

Method

Similar to T5, an iPhone magnetometer is used instead of an linear potentiometer to measure the shock movement. The test involves one rider dropping down a 0.5m step while tracing the **stroke displacement**, **stroke velocity**, and **trend** during a cycle of suspension compression. This can be identified through video or the time interval between the start of compression stroke and start of rebound stroke.

Results

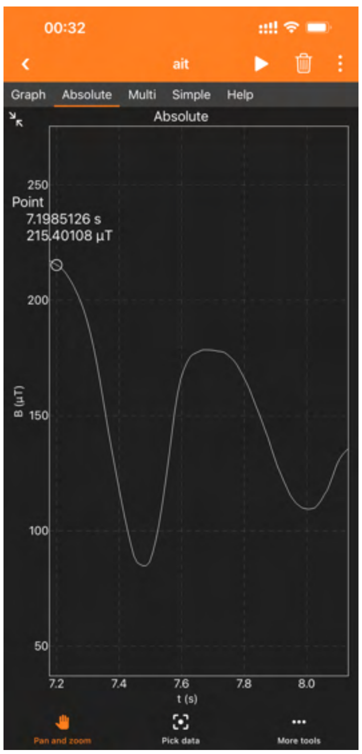


Fig 53: Air Top-out point indicted on graph

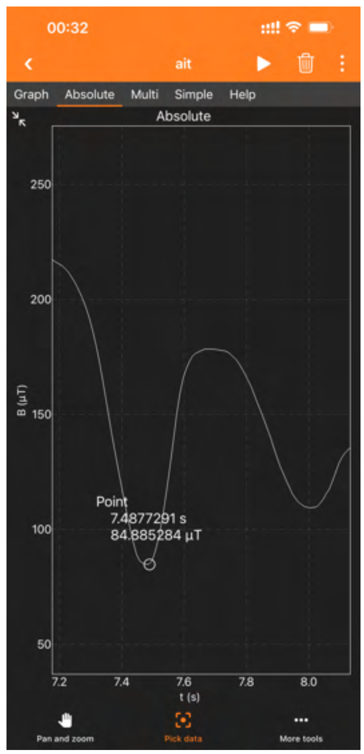


Fig 54: Air bottom-out point indicted on graph

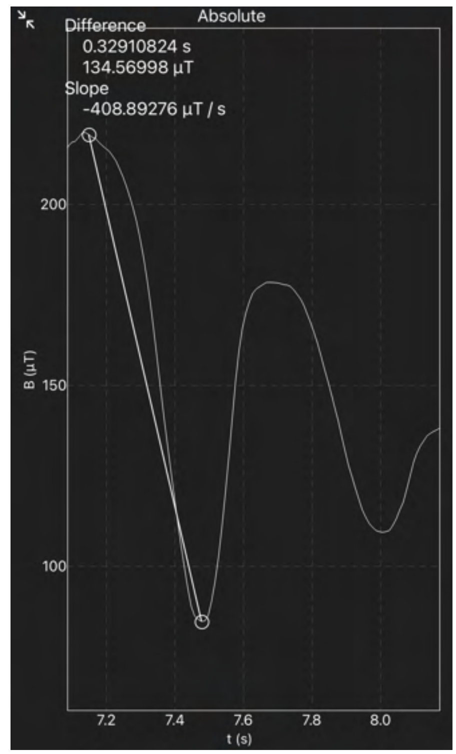


Fig 55: Air Time difference and slope indicated on graph

Analysis

At 7.2 seconds, the magnetometer reading is 215 µT(Fig 53), which translates to a fully extended, 0mm stroke(refer to T3). Here, the bike is still airborne so there is no weight compressing the shock. After this point, the bike makes contact with the ground and compresses the suspension rapidly. The compression reaches maximum at B=85 μT(Fig 54), translating to a **stroke displacement** of 23.39mm, or 36% of full travel. The time difference between these two points is 0.33s(Fig 55), and we obtain a **average shaft velocity** of 76mm/s.

Similarly, we can calculate the **stroke displacement** of the coil shock at 24.76mm, or 38% of full travel. From here we can see that the coil shock has slightly(2%) more displacement than the air shock. The time difference between two points is 0.31s, yielding a **average shaft velocity** of 80mm/s. The faster shaft velocity is likely due the coil shock providing less resistance mid stroke.

The **trend** for the coil shock(Fig x) shows that compression is slower at the start, then linearly increases throughout the travel. The trend for air shock shows that compression is faster at the start, and slows down as it approaches maximum compression.

The fact that the coil shock uses more travel to absorb the impact implies that it transmits a lower amount of acceleration to the rider. This concept can be shown through $V^2 = U^2 + 2ax$. However, this equation is not correct for our situation because the actual suspension (including tire compression, frame flex, and rear wheel movement) is different from the stroke length of 65mm.

Errors and Uncertainties

The data collected is fairly error free. However, I couldn't use the stroke information to calculate specific acceleration due to multiple sources of uncertainty. A fixed setup on a test rig that only compresses the rear shock would mitigate this situation.

Evaluation Against Specification

Area	Coil	Air
Rough Terrain Speed	Coil	
Smooth Terrain Speed		Air
Jump performance		Air
Traction Performance	Coil	
Comfort	Coil	
Support		Air
Fatigue Reduction	Better at reducing fatigue caused by vibrations	Better at reducing fatigue caused by physical exertion

Test	Strengths	Weaknesses	Improvements
Timed Recording	Accurate Fast to Setup	Can be effected by my physical conditions.	Use more trails Test no more than three trails each day to preserve physical strength
Single Feature Acceleration	Helpful in determining the shock absorbing qualities of each shock.	Go-pro accelerometer lacks precision.	Use accelerometers mounted on the front axle, rear axle, and frame instead.
Performance Review	Provides detailed information on perceived shock performance.	Input only comes from one person, therefor is highly subjective.	Use performance reviews from 2-5 people.
Stroke Tracing	Clearly indicates the movement of the shock at different times, making it easy to connect shock movement with riding performance. Displacement Measurements are relatively accurate.	Requires a lot of data processing. Measurements can be affected by external magnetic fields. Measurements can be affected by tape loosening.	Use a linear displacement sensor instead. Input the information into a professional shock tuning software
Psychological Feedback	Feedback from riders with different preferences. Data is fast to collect. Intuitive presentation of the results.	Lacks specific details on why certain psychological feedback is perceived.	Analyze this test together with performance review.
Single Impact Acceleration	Isolates all other variables on the trail, which creates a consistent testing environment for objective results.	Measurements can be affected by tape loosening.	Use accelerometers mounted on the front axle, rear axle, and frame instead.
Single Impact Stroke Tracing	Isolates all other variables on the trail, which creates a consistent testing environment for objective results.	Measurements can be affected by tape loosening.	Use a linear displacement sensor instead.

Evaluation of Testing Methodology

Conclusion

Research Question: To what extent do different characteristics between coil and air shocks affect rider performance in downhill mountain-biking.

The evidence collected shows that switching from air to coil shock can create a time difference up to 10 seconds on a 5 minute track. This is considered a significant effect as Winning runs in downhill races typically have margins less than 1 second. Most notably, the difference is created between characteristic advantages on different terrain. For example, a coil shock is suited more to rugged terrain that demands stability and traction, while an air shock is suited to smooth terrain that demands support and quick acceleration.

From a subjective rider perspective, there is a noticeable difference in ride feel(T2, T5). The coil shock gives more comfort but at the expense of having a soggy feeling. The air shock gives more support but at the expense of traction. I verified that these feelings are not placebo through attributing them to the characteristics of coil and air shocks(L1, L2, lab testing (T6, T7), and the shock movement during my field testing (T4).

The meaning of this test is to show that differences in coil and air shocks are not marketing slogans. However, it is important to select the product that is best suited to the terrain and style of riding a consumer archive. Also, Companies don’t note the specific physiological improvements in their product marketing. This piece of research quantifies the physiological difference made. From a competitive perspective, product differences can create a significant advantages, while from an experience perspective, product difference minimal improves rider skill and overall riding experience.

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