Measuring the Coefficient of Friction Between Snowboard Bases and Terrain-Park Rails Under Dry, Water-Lubricated, and Wax-Lubricated Conditions

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Abstract

This study investigated the friction between a snowboard and a metal park rail under different surface conditions. While snowboard–snow friction has been widely studied, friction between snowboards and rails has received little attention. The mechanism of friction reduction likely to happen is water-lubrication. Waxing can also help by reducing the plowing effect. The experiment is conducted on static dry snow and consists of a snowboarder performing repeated rail slides on a dry rail, a rail sprayed with water, and a rail coated with wax. Motion was recorded on video, and acceleration along the rail was calculated to determine the coefficient of friction. The dry rail had the highest friction, the water-sprayed rail had lower friction, and the waxed rail had the lowest friction. The specific values are provided but are subject to the same number of systematic errors, so they are not emphasized. These results suggest that adding water or wax reduces friction between the snowboard and the rail, with wax having the greatest effect under the tested conditions.

Keywords

Friction, Rail, Snowboard, Tribology

Introduction

Snowboard and ski speed on a sliding surface is primarily governed by gravity, aerodynamic drag, and kinetic friction at the interface between the base and the surface ((F. Wolfsperger, F. Meyer, M. Gilgien. The snow-friction of freestyle skis and snowboards predicted from snow physical quantities. *Frontiers in Mechanical Engineering*. Vol. **7**, 2021 https://doi.org/10.3389/fmech.2021.728722)) . On snow, one friction-reduction mechanism is the formation of a quasi-liquid layer at the ice interface, which shears easily and can behave like a lubricant ((A. Almqvist, K. Kalliorinne, M. Supej, M. Sjödahl, H.-C. Holmberg. A tribological perspective on friction and performance in olympic snow and ice sports. *Sport Sciences for Health*. Vol. **21**, pg. 3229–3241, 2025 https://doi.org/10.1007/s11332-025-01533-4)). While ski/snowboard friction on snow has been studied extensively e.g. Buhl et al. ((D. Buhl, M. Fauve, H. Rhyner. The kinetic friction of polyethylen on snow: the influence of the snow temperature and the load. *Cold Regions Science and Technology*. Vol. **33**, pg. 133–140, 2001 https://doi.org/10.1016/S0165-232X(01)00034-9)), friction between polyethylene snowboard bases and metal terrain-park rails has received far less attention. It is important to understand the frictional behavior of rails because they are widely used in freestyle terrain parks and plays an important role in slopestyle skiing/snowboarding.

Freestyle rail riding is associated with elevated injury risk in terrain parks ((C. Goulet, D. Hamel, B. Hagel, G. Légaré. Risk factors associated with serious ski patrol-reported injuries sustained by skiers and snowboarders in snow-parks and on other slopes. *Canadian Journal of Public Health*. Vol. **98**, pg. 402–406, 2007 https://doi.org/10.1007/BF03405428))' ((J. A. McNeil, M. Hubbard, A. D. Swedberg. Designing tomorrow's snow park jump. *Sports Engineering*. Vol. **15**, pg. 1–20, 2012 https://doi.org/10.1007/s12283-012-0083-x)). Because rail sliding depends strongly on how the base interacts with the rail surface, riders often describe performance differences between "fast" (low-friction) and "sticky" (high-friction) rails. Understanding how rail surface conditions affect friction could support safer, more consistent park setup and maintenance.

One of the most important factors influencing a rider's experience is rail condition, particularly the coefficient of friction between the snowboard base and the rail. High friction can make the slide feel "sticky," increasing the likelihood of balance loss, falls, and injury.

The snowboard base and the rail can be considered as a tribological system, which includes (1) the two interacting surfaces (snowboard base and rail), (2) the interfacial layer (e.g., water, wax, contaminants), and (3) the surrounding environment (temperature, humidity) ((T. Mang. *Lubricants and their Market*. John Wiley & Sons, Ltd, 2006 https://doi.org/10.1002/9783527610341.ch1)) . In this paper, the effect of the surroundings and the interface will be primarily discussed, while some suggestions involving the other elements will be made in the discussion section. The objective for this investigation is to quantify how interface condition (dry/clean rail, water-wetted rail, wax-coated rail) affects the effective coefficient of friction between a snowboard base and a metal rail under field conditions and propose practical recommendations for park maintenance and for riders to reduce friction and wear.

Metal-on-polymer friction is sensitive to surface films (water, contaminants, wax), whereas polymer friction is often less sensitive to thin contamination layers than metal-on-metal contact. Prior work shows water can reduce friction in some polymer/metal pairs by sharing load and altering interfacial shear, with effects that can increase with speed ((J. K. Lancaster. A review of the influence of environmental humidity and water on friction, lubrication and wear. *Tribology International*. Vol. **23**, pg. 371–389, 1990 https://doi.org/10.1016/0301-679X(90)90053-R)). However, the amount of water transferred from the snowboard to the rail during a typical slide may be limited, motivating controlled tests where the rail is intentionally wetted. As such, a group of experiment will be designed to add additional water to the rail before and between the tests to simulate an abundance of water, while the control group (where the rail is kept dry) only contains water that is brought by the board itself.

When a polymer slide against a metal surface, the asperities of the metal will plow into the polymer, introducing friction as well as wear to the polymer. The polymer that is plowed by the metal then forms a thin layer due to weak bonds forming caused by high contact pressure ((S. V. Panin, J. Luo, D. G. Buslovich, V. O. Alexenko, F. Berto, L. A. Kornienko. Effect of transfer film on tribological properties of anti-friction pei- and pi-based composites at elevated temperatures. *Polymers*. Vol. **14**, pg. 1215, 2022 https://doi.org/10.3390/polym14061215)). This process is a one-way process, meaning that only the material with low cohesive energy will be plowed away and form the layer ((S. Bahadur. The development of transfer layers and their role in polymer tribology. *Wear*. Vol. **245**, pg. 92–99, 2000 https://doi.org/10.1016/S0043-1648(00)00469-5)). Once the film is formed, it will shield the main polymer chunk from the metal and reduce its wear and friction. However, when the temperature is cold (-3 °C), the plowing might result in more material transfer and larger slabs (0.5 to 5 μm thick), increasing the friction and wear ((K. R. Makinson, D. Tabor. The friction and transfer of polytetrafluoroethylene. *Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences*. Vol. **281**, pg. 49–61, 1964 https://doi.org/10.1098/rspa.1964.0168)) . Due to the temperature of the environment, this mechanism might not apply to the snowboard-rail interface. This mechanism is regarded as the main one that causes friction between the snowboard-rail interface.

From this background knowledge, the research question: "How will different common surface conditions on rails used for freestyle snowboarding affect the coefficient of friction when a snowboard slide on the rail?" is asked, a null hypothesis "different surface conditions on the rail does not affect the dynamic coefficient of friction of the snowboard-rail interface" and an alternative hypothesis "different surface conditions on the rail has different coefficients of friction, with waxed group being the lowest, the water group being higher, and the control group being the highest" is developed. Several predictions are made from the hypothesis.

It is predicted that a thin water film reduces friction relative to a dry rail by reducing direct solid–solid contact. Another prediction is wax yields the lowest friction by forming a low-shear boundary layer on the rail. Because direct liquid-water-content measurements were not available, snow was classified qualitatively (dry vs. wet and low water content vs. high water content), based on measured snow temperature and observed conditions." Where snow is categorized into wet and dry based on the temperature, and the volumetric Liquid Water Content (LWC).

The effective coefficient of friction will be estimated from measured acceleration along the rail during the board–rail contact interval, with formulas as follows:

$$a = \frac{dv}{dt}$$

And the coefficient of friction is calculated as:

$$\mu = \frac{gsin\theta - a - \frac{F_{drag}}{m}}{gcos\theta}$$

Where F_f is the frictional force, which is calculated using the resultant force minus the air resistance. F_n is the normal contact force, which can be derived using the mass of the tester and the tilting angle of the rail. Due to the limitations of the methods and tools, LWC will not be quantified in the experiment, and the snow category will be presented based on weather conditions. Snow density will be presented in the paper.

Waxing is an effective way for snowboarders to decrease friction while sliding on snow surfaces, and its benefit also includes reducing wear and oxidation. Common snow waxes mainly consist of alkanes and fluorocarbons ((S. Rohm, S. H. Unterberger, M. Hasler, M. Gufler, J. van Putten, R. Lackner, W. Nachbauer. Wear of ski waxes: effect of temperature, molecule chain length and position on the ski base. *Wear*. Vol. **384–385**, pg. 43–49, 2017 https://doi.org/10.1016/j.wear.2017.05.004)). While waxes are commonly used on snowboards and skis, applying wax to the rail directly has been a method to also reduce friction between snowboards or skis and rails. In this paper, waxing will also be tested to compare its usefulness in reducing friction.

Methodology

variables	Unit	types
Environmental temperature	°C	external (assumed to be controlled)
Snow density	kg m^-3	external (assumed to be controlled)
Relative humidity	RH%	external (assumed to be controlled)
Snow temperature	°C	external (assumed to be controlled)
control/water/wax group	-	independent
Coefficient of friction	-	dependent

The environmental temperature (air) and humidity are measured using a Humidity-temp meter (Delixi Electric humidity & temp. meter THM-01) and its readings are collected when it is exposed outside for enough time (5 minute). The snow density is measured by cutting a rectangular chunk of snow near the surface of the snow track, weight it on an electric scale and using a ruler to measure its side lengths. The temperature of the snow is measured by sticking a digital thermometer into the snow, and waiting until its temperature stops decreasing. The independent variable is controlled by cleaning the rail and add the corresponding substances (snow for water group, wax for waxed group and nothing for control group) onto the rail. The details are mentioned in the experimental setup. The coefficient of friction is measured by taking a video from the side view of the rail and analyze the video using the Tracker ((Tracker video analysis and modeling tool for physics education. https://opensourcephysics.github.io/tracker-website/)) video analyze software to record its position frame-by-frame and therefore can calculate the velocity for each 2-frame interval, acceleration and coefficient of friction. The details of measurement and calculation is in later sections.

Although the snow permittivity can be directly measured using a dielectric sensor, this study was not able to gather funds to purchase a dielectric sensor. As a result, the snow permittivity cannot be quantified, and is assumed to be positively related to the environmental temperature and the snow density when it is above 0°C.

Participant and equipment: One experienced rider (the author) performed repeated 50–50 rail slides using the same snowboard and clothing throughout testing. The mass with equipment of the rider is 62 ± 1 kg, board model used by the rider is Nitro T1 2026-2027 edition, the length of the board is 155cm, and the stance of the rider is regular (left foot at the front).

This paper acknowledges that the experiment test subject being the author can cause bias to the experiment and take this weakness as a limitation due to the lack of qualified volunteers. However, since the test subject cannot alter the experiment result in any meaningful way (cannot perform any tricks to make the rider slide smoother or rougher based on his or her will beside from the independent variable) because of the lack of total control on the rail, and the measurement method of the dependent variable being objective rather than subjective (asking the test subject about how he/she feels), it is assumed that the author being the test subject will not largely affect the result to the extent that it is not valuable or significant.

Site and dates: Nanshan Ski Resort (Miyun District, Beijing), Feb–Mar 2026.

A test day consists of a measure of snow density, the environmental temperature and the snow temperature. After that, test runs where the snowboarder slides down the rail from a fixed starting point (to make sure the initial speed on the rail is approximately constant and weakens the possibility of speed affecting the coefficient of friction of the rail) is performed multiple times to gather test videos. The speed is kept constant because of the lubrication effect will increase with speed ((J. K. Lancaster. A review of the influence of environmental humidity and water on friction, lubrication and wear. *Tribology International*. Vol. **23**, pg. 371–389, 1990 https://doi.org/10.1016/0301-679X(90)90053-R)) and introduce additional uncertainty if not controlled. The snowboarder will use the same outfit and snowboard throughout the experiment. The snowboard is a brand-new Nitro T1 155cm length snowboard. The postures of the snowboarder will be kept consistent (arms pressed against the side of the body, knees bent, and head looking at the end of the rail) throughout the experiment to keep the air resistance constant. The air resistance will be measured by taking a standing photo of the tester in its sliding position from the sliding direction of the tester and using a photo analyzing tool to get the surface area facing the wind. Using this and the speed of the tester during a test run can derive the air resistance during the run.

Experimental Setup

The experimental day and time will be chosen when there are few people playing the same rail when the tests are run and when there is little wind around. There will be a video camera setup on the left side of the rail with a tripod as the support. The camera will be kept horizontal and capture the whole rail with 1/6 margin space. After the snow conditions are measured and the camera is set up, test runs in which the rider slid onto the rail in a 50–50 (board parallel to the rail), using an ollie to jump on to the rail from the left side of the takeoff will be conducted and recorded multiple times. the rail was wiped between runs to remove visible moisture (only for the control group).

The material of the rail is steel. The length of the rail is measured using photo analysis tools and the length of the snowboard as a calibration, it is 4.24 ± 0.02 m. The diameter of the rail is 0.31 ± 0.02 m. The uncertainty of the measurement is caused by the resolution of the photo (1 pixel represents a 1 cm $\times$ 1 cm square). The surface condition of the rail is rough, with no wax and no rust. The roughness of the rail is measured by the control group.

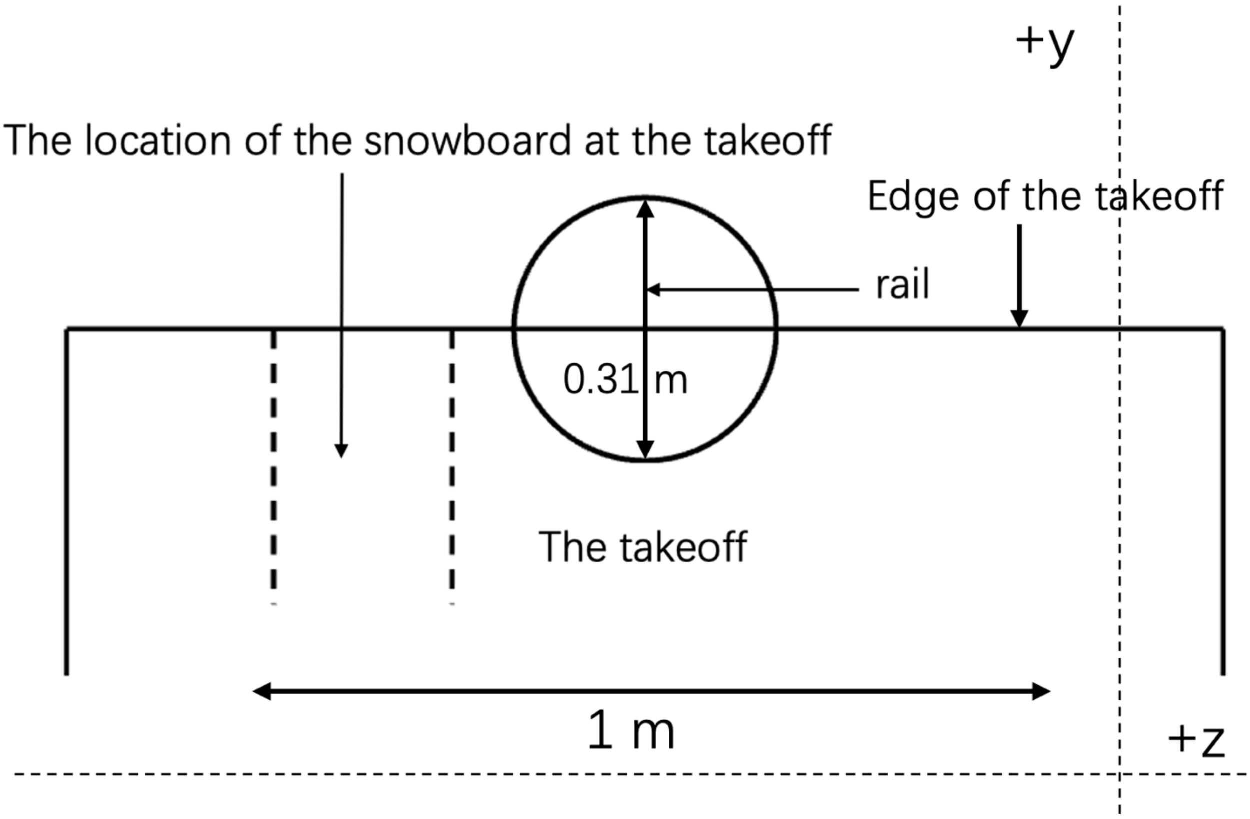

Figure 1: Schematic of the rail feature and takeoff region (back view)

The snow ramp that leads to the rail is very similar to the terrain park jump, containing the start, which is a flat area made for the snowboarders and skiers to prepare themselves, the approach, which provides a drop in height for riders to accelerate, the transition, which is a flat part to connect the approach and the takeoff, and the takeoff part, which is a upward slope that launch the rider toward the rail. After the takeoff, the rider will land on the rail, and slide on it ((J. A. McNeil, M. Hubbard, A. D. Swedberg. Designing tomorrow's snow park jump. *Sports Engineering*. Vol. **15**, pg. 1–20, 2012 https://doi.org/10.1007/s12283-012-0083-x)).

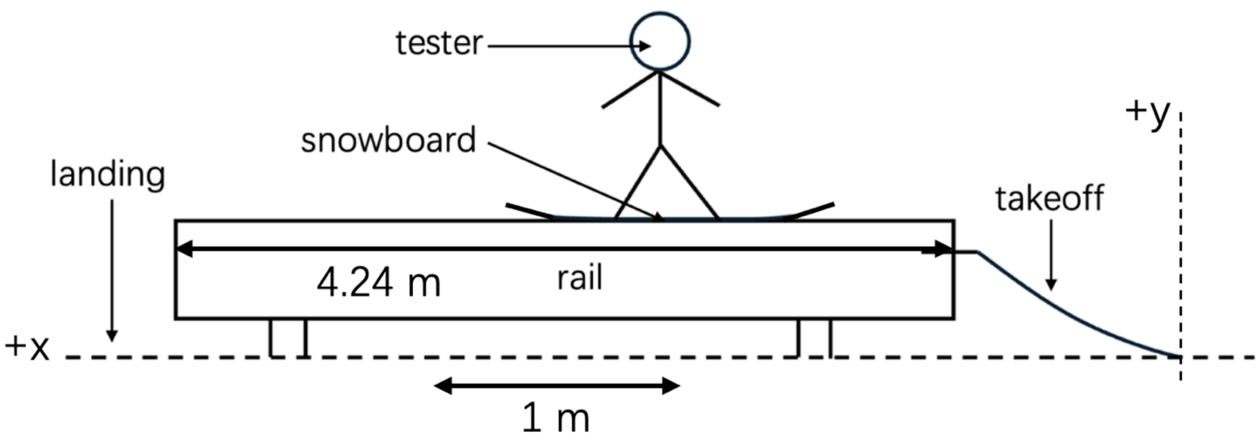

Figure 2: A figure of a rider sliding on the rail from a sideways angle (which is also the camera angle). The field of view of the camera is shown by this figure.

The tester will slide from the right side of the rail where the takeoff (represented by the curve on the right) is located at, to the left of the figure. The curve under the feet of the figure is representing a snowboard, and the rectangle under the snowboard is representing a cylindrical rail. The speed of the tester on the rail will be roughly kept constant by taking off at the same height (or distance) from the rail, since speed can potentially affect the coefficient of friction on the snow ((F. Wolfsperger, F. Meyer, M. Gilgien. The snow-friction of freestyle skis and snowboards predicted from snow physical quantities. *Frontiers in Mechanical Engineering*. Vol. **7**, 2021 https://doi.org/10.3389/fmech.2021.728722)), and potentially change the amount of water brought by the board onto the rail (which is relevant in the control group), so it is safer to keep it in a small range.

Air resistance also plays a role in the deceleration of the rider. This drag force is estimated by:

$$F_d \approx \frac{1}{2}\rho A C_d v^2$$

Where ρ is the density of air, which is $1.3kgm^{-3}$ at 0°C; A is the area of the rider facing the wind, which is estimated to be $0.3m \times 1.7m$; C_d is the drag coefficient of the rider, which is estimated to be 1.2. Additionally, $5ms^{-1}$ is taken as the velocity of the rider. It totals to about 10N of air resistance, which is significant, so this amount is deducted from the resultant force to derive the coefficient of friction.

The three groups of experiments are shown below:

(1) Dry/clean rail: rail wiped between runs to remove visible moisture.

(2) Water-wetted rail: rail sprayed with snow immediately before each run to create visible wetting. The volume of snow is fixed by filling a 5 cm x 5xm x 5cm container and using all the snow inside to spray onto the rail. Since the snow is melting during the trial, the temperature is regarded to be 0°C.

(3) Waxed rail: rail coated with snowboard wax prior to the run set. The method of applying wax is to do a clean swipe with constant force pressed against the wax to make sure that its thickness is constant. Due to the lack of equipment, the specific thickness of the wax cannot be measured in experiment condition. Due to the wax wearing off, it is re-applied using the same method every 3 runs to decrease the effect of it wearing off. The type of wax is kept constant, but the brand of it is unknown because of the waxing process is done by a park staff (who unfortunately, does not know the type of wax).

Experiment condition (1) and (2) is performed alternately for 8 times to reduce time-of-day bias. After these 2 groups are finished, the rail is then cleaned back to its controlled state. Wax is then applied to the surface of the rail, and between each trial of the 3rd group, the rail is wiped to get rid of the residual water brought by the board to ensure the consistency of the condition. Between every 3 trials, the wax is then re-applied to assure an abundance of it (here it is assumed that a slight change in thickness of the wax does not affect the coefficient of friction). Because of waxing the rail can irreversibly change the interface, and the test subject does not have access to 2 identical rials, the waxing group is conducted after condition (1) and (2). The potential systematic error caused by the change in temperature and humidity is taken as a limitation for the experiment. Group (3) is also conducted 8 times in total.

Waxing the rail is common practice in freestyle snowboarding. The waxing process is approved and performed by a park staff to avoid contaminating the rail or negatively affect other riders. Figure 3: A picture of the test rail with snow sprayed that will soon melt into water.

Figure 3: A picture of the test rail with snow sprayed that will soon melt into water.

Figure 4: A picture of the test rail being waxed

Experiment data and Graphs

The measured snow and environmental conditions on the test day are summarized in Table 1. The category of snow is dry and static, meaning no significant temperature gradient between the snow layers.

	snow temperature	air temperature	snow density	relative humidity
initial	-5.1±0.5 °C	-1.5±0.3 °C	430±30 kg/m^3	29.3
final	-4.4±0.5 °C	-0.4±0.3 °C	430±30 kg/m^3	29.3

Table i: The environmental conditions of the test day

The air temperature is very close to 0 °C, which coupled with the fact that the weather is sunny, and the upper rail surface is metal-colored, the temperature of the upper surface must be significantly above 0 °C. This hypothesis is proved by observations that the snow will melt on the rail after about 20 seconds when it is sprayed. In addition, after each trial, the water on the rail remains in its liquid state before being wiped, which proves that the rail does not change the snow into ice, and the lubricant is indeed water.

Below are the velocity-time graphs for some of the test runs. Using video tracking to extract position vs. time of a fixed marker on the board during the rail-contact interval, the velocity of each frame can be deduced and plotted in a v-t graph, then, the acceleration can be estimated from a linear fit of the graph. Video tracking was used to record marker position x(t) frame-by-frame. Velocity v(t) was computed by finite differences, and acceleration a was estimated from a linear fit to v(t) during the rail-contact interval. The position of a bright spot on the board is the reference point where the position of the rider is marked. After marking the position of the rider in the span of the slide, the data is then processed by subtracting the current position with the previous position, divided by the time elapsed (time between 2 frames) to derive the velocity. The velocity is then graphed against time, and the slope of the best-fit line of the graph is the acceleration. From the equation in the previous section, the coefficient of friction of the rail under different conditions can be derived.

The raw data from one representative trial are presented below. The t is representing the time in the video, t' is the modified time where the first frame the snowboard touches the rail is set to be zero. x is the position of the mark on the board, where the start of the rail is set to be 0 and the left (which is the slide direction of the snowboard) direction is defined to be positive. v is the velocity of the snowboard.

t (s)	t' (s)	x (m)	v (ms^{-1})
1.08E+01	0.00E+00	6.20E-01	
1.09E+01	3.33E-02	7.80E-01	4.81E+00
1.09E+01	6.67E-02	9.69E-01	5.66E+00
1.09E+01	1.00E-01	1.17E+00	6.01E+00
1.10E+01	1.33E-01	1.36E+00	5.73E+00
1.10E+01	1.67E-01	1.55E+00	5.73E+00
1.10E+01	2.00E-01	1.74E+00	5.59E+00
1.11E+01	2.33E-01	1.92E+00	5.37E+00
1.11E+01	2.67E-01	2.09E+00	5.23E+00
1.11E+01	3.00E-01	2.27E+00	5.23E+00
1.12E+01	3.33E-01	2.44E+00	5.37E+00
1.12E+01	3.67E-01	2.62E+00	5.30E+00
1.12E+01	4.00E-01	2.79E+00	4.95E+00
1.13E+01	4.33E-01	2.96E+00	5.16E+00
1.13E+01	4.67E-01	3.13E+00	5.09E+00
1.13E+01	5.00E-01	3.30E+00	5.02E+00
1.14E+01	5.35E-01	3.47E+00	4.92E+00
1.14E+01	5.68E-01	3.63E+00	4.81E+00
1.14E+01	6.02E-01	3.79E+00	5.02E+00
1.15E+01	6.35E-01	3.95E+00	4.74E+00
1.15E+01	6.68E-01	4.12E+00	5.09E+00

1.15E+01	7.02E-01	4.29E+00	4.95E+00
1.16E+01	7.35E-01	4.45E+00	4.95E+00

Table ii: The data for a test run containing time, horizontal position and the velocity.

The way of marking the position and only take the horizontal position of the board neglect the angle of the rail to the horizontal. In the video, the angle of the rail to the horizontal is measured at about 2.2 degrees, which is a small enough angle to be neglected. In the data analysis, only the horizontal component of the change in distance is considered and recorded, because cos (2.2°) ≈ 0.999, using horizontal distance introduces <0.1% error in displacement; however, the slope still affects the friction model through sinθ and cosθ (see coefficient of friction μ equation).

With the velocity and the time, the acceleration of the board can be derived by plotting the velocity and the time on a graph and draw a best-fit line. As shown below: (Take the direction of motion as positive).

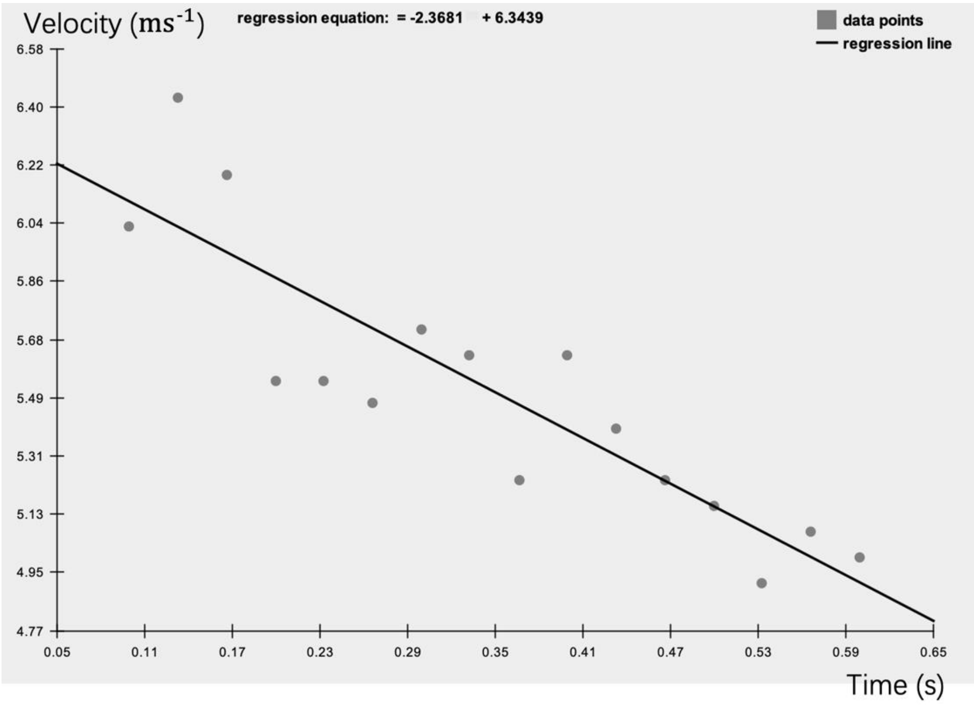

Figure 5: Graph of a trial in the first group (clean rail)

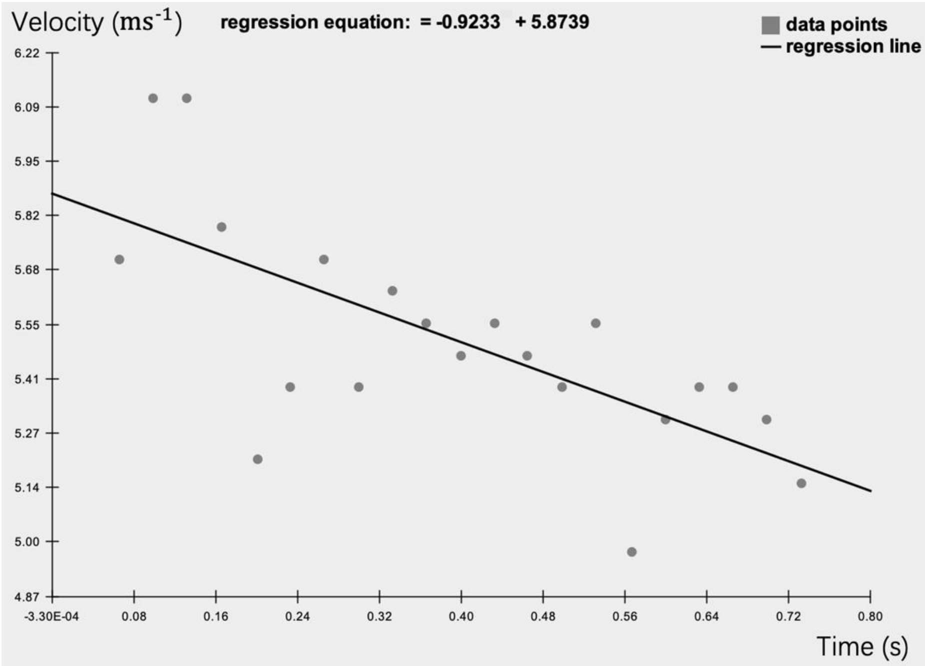

Figure 6: Graph of a trial in the second group (water on the rail)

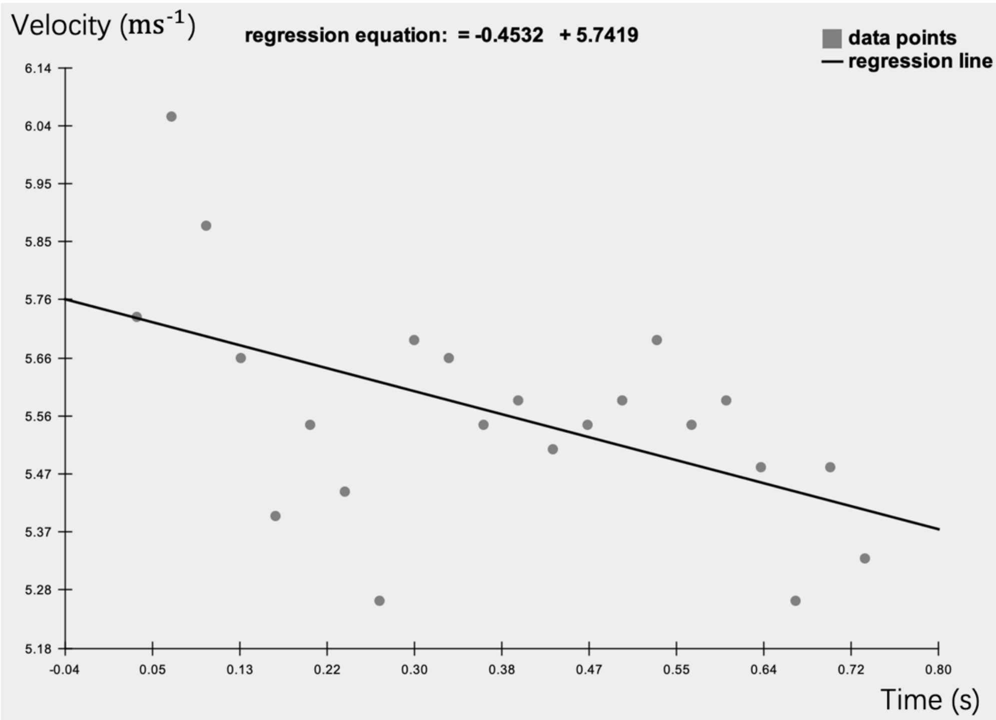

Figure 7: Graph of a trial in the second group (water on the rail)

The gradient of the graph is the resultant acceleration. By analyzing every video and averaging the acceleration of each group, the final acceleration is obtained in the table below, where the last 2 columns are variance and standard deviations of the acceleration data.

Horizontal acceleration (ms^{-2})	trial 1	trial 2	trial 3	trial 4	trial 5	trial 6	trial 7	average	S.D	p-value
group 1 (control)	2.0	1.5	1.8	2.4	1.5	1.8	1.7	1.8	0.3	0.376
group 2 (water)	1.0	1.0	1.5	0.8	1.7			1.2	0.3	0.197
group 3 (wax)	0.7	0.5	1.4	0.2	0.1	0.4		0.6	0.4	0.188

Table iii: The resultant acceleration of the trials (individual, average, standard deviation and t-value)

The coefficient of friction is then calculated using:

$$a = g\sin\theta - \mu g\cos\theta - \frac{F_{drag}}{m}$$

Where a is the acceleration above (assuming that the horizontal acceleration is very similar to the acceleration along the rail axis), and g is the acceleration due to gravity. As a result, the coefficient of friction of the 3 groups are 0.13$\pm$0.03, 0.07$\pm$0.03 and 0.01$\pm$0.04.

The p-value is tested to ensure that there is no correlation between the coefficient of friction and the environmental temperature and humidity, since the experiment is conducted in the spam of hours for each group. Take $p = 0.05$ as the benchmark for a correlation, all 3 groups have a value larger than it, so it is regarded that there is no correlation between the temperature and humidity change and the coefficient of friction in the span of time when a single group is tested.

To test whether the difference in the coefficient of friction between groups are statistically significant, the one-way ANOVA test is conducted. The variance within all 3 groups is calculated (0.098, 0.145 and 0.219) and compared with the variance across the average value between groups (0.36). Because the variance across groups is much larger than the variance within all 3 groups, so it is regarded that the difference between the average values in different groups is statistically significant.

Some trials are considered failures and discarded from the original 8 because of the inconsistency of the postures, the rider visibly falling to one side of the rail, or the snowboard is not strictly parallel to the rail. As a result, the final data only contains 5-7 trials for each group.

Conclusion

As can be seen from the data, the coefficient of friction on the rail is the lowest while there is wax on the rail, about 0.01. When there is water on the rail, the coefficient of friction is 0.07, and the control group has the highest friction, about 0.13. Under the tested field conditions, the waxed rail produced the lowest measured friction, followed by the water-wetted rail, with the dry rail highest. These observations are consistent with wax providing a low-shear boundary layer and water providing partial lubrication on a polymer/metal interface. However, because this is a field study with a single rider and a single rail geometry, the results should be interpreted as preliminary; future work should test additional rails, speeds, temperatures, and independent replication. The initial speed is controlled to 5 to $6ms^{-1}$ to limit the effect of speed to the coefficient of friction ((F. Wolfsperger, F. Meyer, M. Gilgien. The snow-friction of freestyle skis and snowboards predicted from snow physical quantities. *Frontiers in Mechanical Engineering*. Vol. **7**, 2021 https://doi.org/10.3389/fmech.2021.728722)).

According to technical specifications provided by Plastics International, the coefficient of friction of metal–polyethylene interface when not lubricated is 0.12, which matches well with the data in the control group (0.13) ((Plastics international. *Plastics International* https://www.plasticsintl.com/)). According to ((A. V. Maksimkin, S. G. Nematulloev, D. I. Chukov, V. D. Danilov, F. S. Senatov. Bulk oriented uhmwpe/fmwcnt films for tribological applications. *Polymers*. Vol. **9**, pg. 629, 2017 https://doi.org/10.3390/polym9110629)) The coefficient of friction of metal–polyethylene interface with water lubrication is 0.04 – 0.09, with the experimental data (0.07) in this research falling in the range of the external result. No reference can be found with the waxed interface. Overall, the result can be considered as accurate but not precise. From screenshots in videos, the consistency of the postures can be evaluated.

Figure 8: 1 screenshot of experiment trials for each group of experiment

As can be seen from a limited sample of 1 screenshot randomly chosen for each test group, aside from the position of the right hand (which has a small influence on drag), the body posture is very similar. As a result, it is regarded that the uncertainty from changing postures between runs as small. Notably, the main goal of this research is not to figure out exactly what is the coefficient of these 3 groups, since because of the difference of environmental conditions, rail conditions, snowboard conditions and rider conditions can largely affect the final value, so I believe that these three numbers can be better interpreted in terms of their relation. Because aside from the limitations of this experiment, some of the major systematic errors (simplify the velocity in the drag force term as a constant, the estimation of frontal area and drag coefficient might not be accurate) are consistent throughout the 3 groups of experiment, with only the temperature and humidity changing between group (3) and the rest. As such, even though the final value for the coefficient of friction might be subject to significant number of systematic errors, these errors will not likely to let the relation between these values change, that is, the waxing group is most effective in reducing friction, the water group is better than the control group in terms of reducing friction but is worse than the wax group, and the control group being the worst. The value of this relationship is what will ultimately answer the research question and provide a clear implication to snowboarder who wants a better experience on rail sliding.

Practical implication: waxing rails (where permitted by resort policy) may reduce friction; alternatively, wetting the rail can reduce friction relative to dry conditions.

Uncertainty analysis and evaluation

This single-rail, single-rider field study limits generalizability. Results may vary with rail material, surface finish, temperature, and rider speed; therefore, replication across features is needed. Different rails might have different behaviors in reaction to the presence of water or wax, the coefficient of friction will decrease, just to a different extent. There is also another type of obstacle in the park called "boxes", which is a rectangular box with its top surface made of polymers. As a result, the conclusion here might not be applicable to this. In this experiment, the temperature on the rail surface is higher than 0 degrees Celsius due to radiation from the sun, so when the snow is sprayed on the rail, it will melt into water quickly. In the case where there is no sunlight, or the environmental temperature is lower, the snow might not melt into water, and the lubrication effect might change. Furthermore, due to the length of the rail being relatively short, faster speeds are not tested to ensure that the lubrication effect works on all speed levels.

Although the LWC of the snow is not explicitly measured, it can be deduced by the environmental temperature and snow temperature. In the case of the experiment, because both is below 0°C, the LWC of the snow should be low, and therefore qualifies as dry snow. The snow conditions stayed roughly constant during the process of the experiment, so the amount of water that the board carries onto the rail is fixed.

As can be seen, the velocity-time graphs (fig. 5,6,7) are poorly fitted, with the coefficient of determination below 0.5. This is due to the limitations of the software used to process the video into data. The position of the rider is marked at each frame (the marking place is a bright-colored spot marked on the bindings of the snowboard), so as a result, a small fluctuation on the marking (usually a few pixels of inconsistencies) can cause a big difference on the velocity output by the software. The error caused by the resolution will not stack in 1 direction because the mark is traveling at the real acceleration, and the uncertainty due to the resolution can only deviate from the mark for 1 or 2 pixels at all times, which is saying that the result from the fit is imprecise, but it can be accurate. Since only one value is obtained for the acceleration for each trial, this kind of error will not make a big difference on the result of coefficient of friction.

Furthermore, due to the difficulty of the rail, the rider must balance their body to prevent sliding down early, which involves slightly changing the position of the center of mass of the rider that might not be visible to the camera. This can also cause the variations of the velocity between frames. From the video analysis, the position of the rider does not significantly change, suggesting that it does not affect the drag on the rider that much, but a shift in the center of mass can easily affect the velocity on each frame, making the acceleration fluctuate around the mean value. To solve this issue, future experiments can use a weight instead of a rider to stay on the board and change the experiment setup accordingly to eliminate the error caused by the rider.

To ensure the systematic error to be minimized, the coefficient of friction must be calculated using the acceleration along the axis of the rail. However, this approach requires accurate marking of the rider's position of a fixed point for both the x-axis and the y-axis in the vertical axis of the video. As such, it will introduce another degree of freedom for marking, and therefore worse fitted result in the velocity-time graphs and more uncertainty for the acceleration. Therefore, this paper allows some of systematic errors to occur to eliminate a source of random error. Future research can be improved by constructing a horizontal rail to make the horizontal axis and the rail axis identical.

Parallax error is also considered as a potential source for systematic error. However, because the distance between the rail and the camera is large (6 m) compared to the section where data is collected, its effect might not be significant.

It is taken to account that the trials per group is only 5-7, which might not be enough to draw a robust result. This is due to the limitation of time and availability of exclusive use of the rail. To increase the test runs, the experiment conductor can ask for permission for a closed rail on several days with similar weather conditions to exclusively use.

To minimize these errors and uncertainties mentioned above and to ensure the experiment being reproducible, future experiments can use procedures like ((L. Bäurle. Sliding friction of polyethylene on snow and ice. https://www.research-collection.ethz.ch/entities/publication/1b5fd7bb-fb03-4d41-9b48-f5a7e2b6bc3a 2006)), where instead of conducting real experiments of snowboard sliding on metal, using a piece of UHMWPE (material that makes up the bottom of the snowboard) and an steel ring that resembles a pin on a rotating disc could ensure the environmental conditions as well as the movement of the snowboard material constant, therefore eliminating most of the uncertainties.

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