The Effect of Cycling Shoes and the Shoe-Pedal Interface on Maximal Mechanical Power Output in Bicycling

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Abstract:

Cyclists and industry professionals argue that cycling shoes improve performance. However, scientific evidence has demonstrated that cycling shoes have no significant effect on metabolic cost during submaximal, steady-state cycling (50-150 W). I measured the mechanical power outputs and velocities of twelve healthy male subjects (age 26.6 +/- 4.7 years, mass 71.2 +/- 4.8 kg) during high-power sprint cycling with the null hypotheses of no differences. I tested subjects outdoors on a paved asphalt road with a steady, uphill gradient of 4.9%. After a 15-minute warm-up, each participant completed sets of three uphill, 100-meter cycling sprints in three conditions: (1) Nike Free 3.0 running shoes with flat pedals, (2) Nike Free 3.0 running shoes on classic aluminum quill pedals with toe clips and straps, and (3) Specialized S-Works 6 RD rigid-soled, cleated cycling shoes and Look Keo click-in pedals. Subjects rode towards the starting line at 20 km/hr before completing a full-effort sprint. There were five minutes of rest between trials and ten minutes of rest between conditions. I analyzed each subject's maximum and average power outputs (W) as well as maximum and average velocities achieved (km/hr). All four performance variables increased with the addition of a shoe-pedal attachment by up to 9.7% ($p < 0.02$) and further increased with a stiff shoe by up to 16.6% ($p < 0.03$). Hence, I reject both null hypotheses. Despite cycling shoes not improving metabolic cost, shoe-pedal attachment and stiff shoe soles independently and positively improve cycling performance during high-power, uphill sprints.

Introduction:

Competitive cyclists use rigid-soled cycling shoes and click-in pedals that firmly attach their shoes to the pedals. Cyclists (Bike Forums, 2004), journalists (Bicycling, 2019), and manufacturers (USJ Cycles, 2014) opine that cycling shoes improve comfort, safety, and performance. However, scientific evidence has not quantitatively shown that cycling performance is improved by using cycling shoes.

Enthusiasts claim that cycling shoes and pedals allow riders to pull up during the upstroke of the pedaling cycle and are thus more efficient. But, scientific measurements do not support that idea. For example, Mornieux et al. (2008) demonstrated that the shoe-pedal interface had no influence on pedaling mechanics, mechanical efficiency, or muscular activity during submaximal, steady-state cycling at 60% of their maximal power. Further, Korff et al. (2007) showed that when participants were instructed to intentionally pull up on the pedals during the upstroke compared to their normal, preferred pedaling condition (at 200 W), gross efficiency decreased. Most recently, Straw and Kram (2016) showed that there was no significant effect on the metabolic cost of submaximal, steady-state cycling (50-150W) when comparing cycling shoes with click-in pedals to two other shoe and pedal combinations.

Despite these studies, why do competitive cyclists still adamantly prefer to use cycling shoes and click-in pedals? Perhaps cycling shoes and click-in pedals provide relevant benefits to sprint cycling rather than submaximal, steady-state cycling. Though not directly shoe-related, Rodríguez-Marroyo et al. (2009) showed that non-circular chainring systems can improve high-power anaerobic performance in professional cyclists but not sub-maximal aerobic performances. Thus, it seems possible that although the shoe-pedal interface has no effect on the aerobic cost of sub-maximal cycling, it could improve anaerobic performance. Moreover, during sprint cycling, riders tend to pull up more strongly and use different muscles as compared to steady-state riding. Guilheim et al. (2012) demonstrated that there are dramatic changes in the relative contribution of the different muscles to the power production between low power cycling (150 W) and sprint cycling. Additionally, Samozino et al. (2007) showed that as cadence increases during cycling, muscle coordination was diminished. This resulted in peak pedal forces occurring later during the pedal cycle and propulsive force being applied during the upstroke of the pedal cycle. These changes in muscle coordination and the contribution of the upstroke to the pedaling mechanics during sprint cycling suggests the potential for cycling shoes and click-in pedals to benefit cyclists.

My primary objective was to quantify how maximal mechanical power output in cycling is affected by different shoes and shoe-pedal interfaces during uphill sprints on a road bicycle. I compared two extreme shoe types: highly flexible running shoes and cycling shoes with stiff, carbon fiber soles. I also compared three shoe-pedal interfaces: flat platform pedals (no attachment), pedals with toe clips/straps, and “click-in” pedals. Click-in pedals provide a very firm shoe pedal attachment that is achieved as the cleat bolted to the shoe sole clicks into a spring-loaded device. Although toe-clips and straps do not attach the shoe to the pedal in exactly the same way, the effect is quite similar. That is, with a toe-clip and tightened strap, the running shoe cannot move forward/backwards or medio-laterally relative to the pedal.

This experimental design allowed me to analyze two factors: the presence/lack of shoe-pedal attachment and the longitudinal bending stiffness of the shoe sole. I expected that cycling shoes with rigid soles that firmly attach to the pedals would increase: average power output, maximum power output, average velocity, and maximum velocity. However, I statistically tested the overall null hypothesis that there would be no differences between the shoes and shoe-pedal interface combinations in terms of the mechanical power outputs and velocities achieved.

Methods:

Twelve healthy, injury-free, experienced competitive/recreational adult male cyclists (age 26.6 +/- 4.7 years, mass 71.2 +/- 4.8 kg) participated after providing written informed consent as per the University of Colorado Boulder Institutional Review Board. Participants self-reported cycling a minimum of 4 hours per week and at least one year of road biking experience. Participants reported riding an average of 6.25 +/- 2.3 hrs/week. All subjects had prior experience riding on flat pedals with athletic shoes, as well as using click-in pedals with cycling shoes. However, not all riders had experience with toe clips. All participants rode the same Specialized Roubaix road bicycle (56 cm frame) equipped with a crank-based mechanical power meter (Quarq®, Spearfish, SD, USA). The cranks were 172.5 mm and tires were inflated to 100 PSI before testing.

I conducted the testing outdoors on a paved asphalt road with a steady, uphill gradient of 4.9% (2.8 degrees). I measured and marked a 100-meter segment of the road. Participants warmed-up with 15 minutes of easy cycling using flat pedals and running shoes. Prior to each trial, I recorded wind velocity using a hand-held hotwire anemometer (Extech Hot Wire Thermo-

Anemometer Model 407123: Waltham, MA, USA). Testing was paused if the wind velocity exceeded 4.5 m/sec. The greatest maximum wind velocity for an individual trial was 3.6 m/sec which is still categorized at the low end of "gentle breeze" according to the Beaufort scale (World Meteorological Organization, 1970). The maximum wind speed for each of the 12 subjects averaged only 2.0 m/sec.

After the warm-up, each participant completed sets of three uphill, 100-meter cycling sprints in three conditions. The three conditions were: (1) Nike Free 3.0 running shoes with flat pedals, (2) Nike Free 3.0 running shoes on classic aluminum quill pedals with toe clips and straps, and (3) Specialized S-Works 6 RD rigid-soled, cleated cycling shoes and Look Keo click-in pedals (Figure 1). The Nike Free 3.0 running shoes have a cushioned rubber midsole and are extremely flexible. As such, they constitute the opposite of rigid-soled cycling shoes in terms of sole stiffness, both in terms of vertical compression and longitudinal/torsional bending (Figure 2). The order of the conditions was randomly assigned and counterbalanced.

Subjects rode towards the starting line at a steady 20 km/hr (5.55 m/sec) using visual feedback of velocity from a Garmin 1000 display (Olathe, KA, USA) mounted on the handlebars. The Garmin 1000 did not display power output. I instructed the riders that when they reached the starting line, they should sprint with maximum effort for 100 meters to the finish line. Each rider used their own self-selected gear combination consistently for all nine cycling sprints.

A 5-minute active recovery period (easy riding) separated each of the three sprints within each shoe-pedal condition. Upon completing one set of three shoe-pedal condition trials, riders changed shoes as needed and the investigator changed the pedals. There were ~10 minutes of recovery in-between each of the shoe-pedal condition sets to allow for changing the shoes and pedals as well as to avoid fatigue. All nine trials were completed during a single experimental session.

I recorded each participant's mechanical power output (watts) and velocity (km/hr) throughout the duration of the sprint via the Quarq power meter. The Quarq power meter records both power and cadence and transmits those data to the Garmin 1000 for storage. The Garmin 1000 independently uses GPS to determine velocity while riding. I verified the GPS velocity data with this equation: velocity (m/sec) = (cadence (rpm) * wheel circumference (m) * gear ratio)/60. This method concurred within 1.5% of the velocity data determined by GPS. For the remainder of this thesis, the velocities are based on the GPS data. I imported the data from the Garmin 1000 using the Golden Cheetah analytic software (Version 3.4). Then, I analyzed each of the nine sprints to calculate the average and maximum power outputs and the average and maximum velocities.

I completed twelve Repeated Measures ANOVA's between the three sprints in each shoe condition and variable. I found an overall learning effect (i.e. increased performance in subsequent trials) for the running shoes with flat pedals condition for maximum power, average velocity, and maximum velocity (all $p < 0.05$). There was also an overall learning effect for running shoes with aluminum quill pedals, toe clips, and straps for average velocity ($p = 0.0233$). However, there were no significant differences between trials 2 and 3 for any shoe condition for any of the power or velocity variables (all $p > 0.063$), indicating that the learning effect had stabilized. Thus, I chose to compare only sprint trial 3 between the different shoe-pedal conditions in all subsequent comparisons.

Using R software (www.rstudio.com), I performed four Repeated Measures ANOVAs to detect any main effects for the four variables tested (average/maximum power and average/maximum velocity). If I detected a main effect, I performed paired t-tests. I set statistical significance at $p < 0.05$ for the Repeated Measures ANOVAs. For the follow-up paired t-tests, statistical significant was $p < 0.025$ due to the Bonferroni correction (two comparisons were made, so alpha = 0.05/2). All values are means +/- SD.

Figure 1. Test pedals used in the study. Left: flat plastic pedal. Middle: classic aluminum quill pedal with toe clip and strap. Right: Look Keo “click-in” pedal.

Figure 2. Shoes used in the study. Left: Nike Free 3.0 running shoes. Right: Specialized S-Works 6 RD.

Results:

Overall, all four performance variables were enhanced with the addition of a shoe-pedal attachment and with the stiffer soled shoes. Each of these factors had an independent, positive effect on performance. There was a significant main effect across shoe pedal condition for all four performance variables: average power (p=2.50E-04), maximum power (p=9.17E-09), average velocity (p=1.99E-07), and maximum velocity (p=6.47E-05) (Table 1).

When using the running shoes, the toe clip attachment increased average power by 9.0 +/- 8.0% (p=4.2E-03) and increased maximum power by 9.7 +/- 8.7% (p=1.7E-03). When comparing the running shoe and toe clip versus cycling shoe and click-in pedal conditions, the greater longitudinal bending stiffness of the cycling shoes further enhanced maximum power by 16.6 +/- 10.2% (p=3.25E-06). Average power was numerically 7.6 +/- 10.3% greater, but not statistically significant after the Bonferroni adjustment (p=0.03) (Figure 3).

When using the running shoes, the toe clip attachment increased average velocity by 4.3 +/- 2.2% (p=1.00E-05) and increased maximum velocity by 3.3 +/- 3.4% (p=0.02). When comparing the running shoe and toe clip versus cycling shoe and click-in pedal conditions, the greater longitudinal bending stiffness of the cycling shoes further enhanced average velocity by 4.5 +/- 3.7% (p=1.9E-03) and maximum velocity by 4.7 +/- 4.4% (p= 9.5E-03) (Figure 4).

	Running Shoes and Flat Pedals	Running Shoes and Toe Clips	Cycling Shoes and Click-in Pedals
Average Power (W) +/- SD	671.3 +/- 116.3	726.9 +/- 111.4 *	777.3 +/- 113.8 *
Maximum Power (W) +/- SD	787.3 +/- 133.4	855.8 +/- 109.1 *	996.2 +/- 144.3 **
Average Power (W/kg) +/- SD	9.44 +/- 1.29	10.23 +/- 1.24 *	10.96 +/- 1.33 *
Maximum Power (W/kg) +/- SD	11.09 +/- 1.56	12.07 +/- 1.23 *	14.07 +/- 1.81 **
Average Velocity (km/hr) +/- SD	30.2 +/- 2.0	31.4 +/- 1.6 *	32.9 +/- 2.3 **
Maximum Velocity (km/hr) +/- SD	34.9 +/- 2.8	36.0 +/- 2.2 *	37.7 +/- 2.9 **

Table 1. Average power (watts), maximum power (watts), average velocity (km/hr), and maximum velocity (km/hr). There were significant main effects for all four of these performance

variables across shoe condition (all $p<0.05$). The addition of shoe-pedal attachment and a stiffer shoe sole independently and positively improved performance (* and **). Single asterisk (*) indicates significantly greater than the running shoe and flat pedal condition. Two asterisks (**) indicates significantly greater than both the running shoe and flat pedal condition as well as running shoe and toe clip condition.

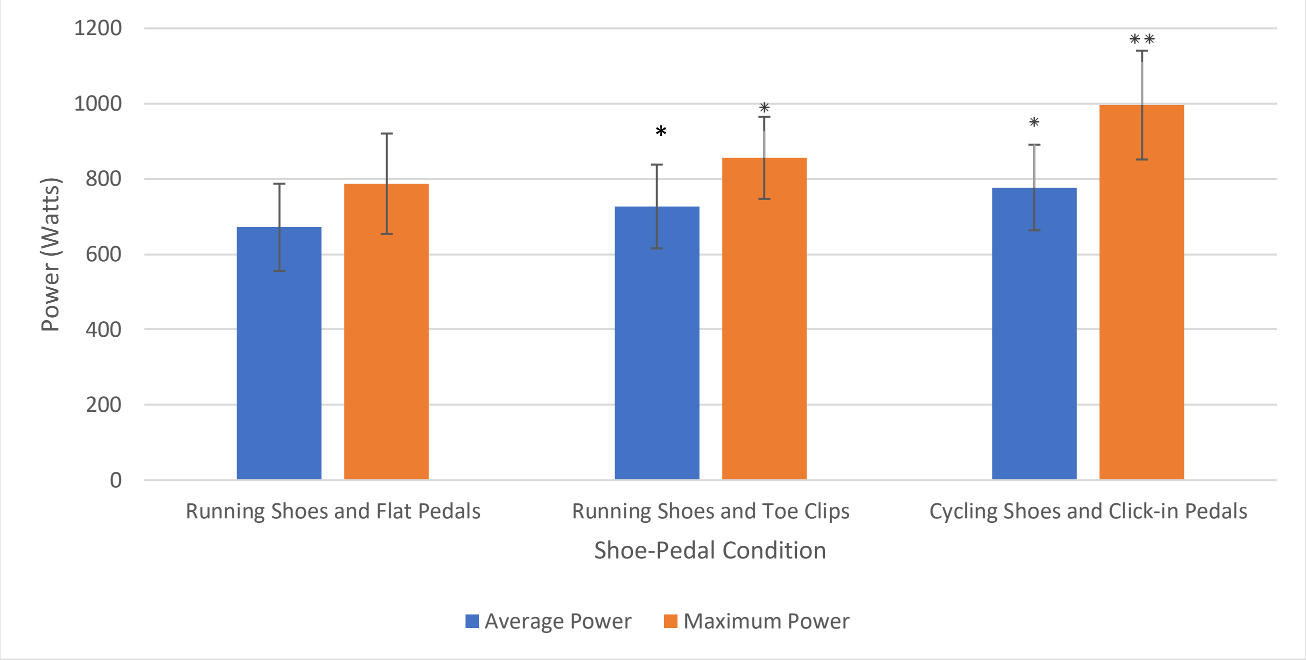

Figure 3. Average power (watts) maximum power (watts) for the three shoe pedal conditions. The addition of shoe-pedal attachment positively improved average and maximum power output (*) and a stiffer shoe sole further improved both average and maximum power output (**). Single asterisk (*) indicates significantly greater than the running shoe and flat pedal condition. Two asterisks (**) indicates significantly greater than both the running shoe and flat pedal condition as well as running shoe and toe clip condition.

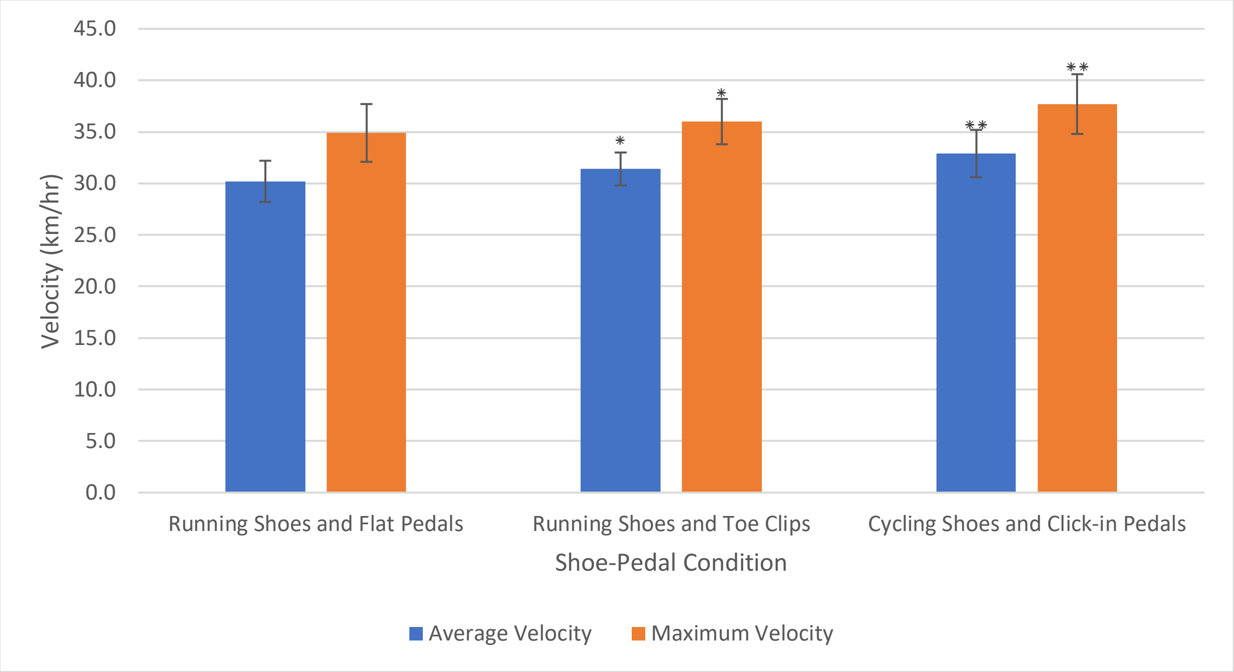

Figure 4. Average velocity (km/hr) maximum velocity (km/hr) for the three shoe pedal conditions. The addition of shoe-pedal attachment positively improved average and maximum velocity (*) and a stiffer shoe sole further improved both average and maximum velocity (**). Single asterisk (*) indicates significantly greater than the running shoe and flat pedal condition. Two asterisks (**) indicates significantly greater than both the running shoe and flat pedal condition as well as running shoe and toe clip condition.

Discussion:

I determined that when cyclists sprint uphill, the addition of a shoe-pedal attachment improved average and maximum power output as well as the average and maximum velocities achieved. Therefore, I reject my first null hypothesis of no differences. Additionally, I determined that cycling shoes with stiff soles further improved the four performance variables. Hence, I reject my second null hypothesis of no differences. The experimental design allowed me to conclude that both the shoe-pedal attachment and longitudinal bending stiffness of the shoe sole have independent, positive effects on sprint cycling performance.

In contrast to the previous study by Straw and Kram (2016), I have determined that cycling shoes are beneficial during high-power, anaerobic conditions even though there is no metabolic cost benefit when riding at submaximal, steady-state cycling at low mechanical powers (50-150W). My conclusion that cycling shoes benefit cyclists during high-power anaerobic conditions rather than steady-state aerobic conditions is in agreement with the research conducted by Rodríguez-Marroyo et al. (2009) on non-circular chainrings. Furthermore, Dorel et al. (2008) has shown that sprint cyclists apply substantial propulsive torque during the upstroke. I suspect that a shoe-pedal attachment and stiff soles allow riders to increase the propulsive torque applied to the cranks during the upstroke during maximum power conditions.

Of course, all scientific studies have limitations. One limitation of my study is that I only tested riders when they sprinted up a 100-meter paved asphalt road with a steady, uphill gradient of 4.9% (2.8 degrees). When sprinting on flat ground or a steeper road, performance variables might be affected differently. Additionally, all 12 subjects were males. While I do not anticipate different results for female subjects, it is possible. Moreover, elite athletes might have greater benefit with the use of cycling shoes as compared to their recreational and competitive counterparts. Because elite athletes tend to generally produce greater power outputs and ride at faster velocities, the effects might be amplified. Unfortunately, the crank-based mechanical power meter (Quarq®, Spearfish, SD, USA) I used does not resolve where in the pedal cycle additional forces are applied to improve power outputs and velocity. I would hypothesize that most of the differences in the pedal cycle occur during the upstroke. Another limitation of this study was the presence of a learning effect across trials using the same shoe-pedal condition.

Because this is one of the first studies of cycling shoes and sprint performance, there are many directions for future research. It would be interesting to test both female and male riders on different road gradients and on flat ground with no incline. Testing elite athletes might provide further insight in the importance of cycling shoes during competitive sprints. It would also be helpful to determine where in the pedal cycle the addition of a shoe-pedal attachment and stiffer shoe soles enhance power output. Such information could benefit shoe manufacturers in determining how to improve the design of cycling shoes to better enhance performance. A further study could analyze the effects of different closure systems of cycling shoes (e.g. buckles, laces, straps) on power outputs and velocities. Finally, while I chose to conduct three trials to minimize rider fatigue, a future study might include a preliminary day that includes multiple trials with each condition before a subsequent day for data collection.

To conclude, a firm shoe-pedal attachment and a stiff shoe sole independently and positively improved cycling performance during high-power, uphill sprints. The combination of the shoe-pedal attachment with stiffer shoe soles enhanced sprint cycling performance variables by up to 27.6%.

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