BIOMECHANICAL PERFORMANCES OF CLOSED-CELL POLYURETHANE TIRE AND TRADITIONAL PNEUMATIC BICYCLING TIRE

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The comparison of pedaling forces of closed-cell polyurethane and traditional pneumatic bicycle road tires on a training-roller was investigated. Four amateur cyclists and one former professional cyclist who attend the University of Ottawa were tested. The force required to pedal with the two types of tire was recorded with in-shoe plantar pressure/force measurement. It was determined that the difference in total force between the pneumatic and the closed-cell polyurethane tires was not found statistically significant ($p > 0.05$) for both conditions of 10-second sprints and 20-minute endurance trials. However, the average percentage differences of the total force for sprint and endurance were 2.8% and 0.4% respectively. This displays that under these conditions the closed cell polyurethane tire did not provide a significant difference in performance when compared to pneumatic tire.

KEY WORDS: cycling, pressure sensors, closed-cell polyurethane, tire.

INTRODUCTION:

In a survey performed by Moritz (1997), it was estimated that the average bicycle commuter traveled distance is 3100 km annually. Since such a large amount of time is spent riding their bicycles, these individuals tend to look for reliability, durability and comfort when shopping for their tires. Reliability is a key asset since the current typical tire systems rely on a pneumatic bladder system that, when not protected enough or inflated properly, is prone to punctures. This renders the tire momentarily and perhaps permanently useless as well as creating an inconvenient situation. Generally, an individual needs to carry a spare tube, pump, patch kit and tire levers to repair a punctured tire. Therefore it is enticing to have an almost failsafe tire system. The only current solution appears to be a solid single unit tire that requires no bladder to give itself the necessary ride characteristics. Recently, a one piece closed-cell polyurethane foam (Flatfree™) tire was developed by Amerityre Corporation. A solid tire would have the distinct advantage over a pneumatic system by eliminating the worry of having to repair a punctured tube.

The main concerns that tire manufacturers consider when testing new tire designs are rolling resistance, wear resistance, spring constant and static friction (Gordon, Kauzrich, & Thacker, 1989). All these aspects will affect the velocity, handling and comfort level of the tires. The rolling resistance is one of the greatest concerns that are affected by the tread pattern, width, contact area, surface friction and the material of the tire. It is generally deduced that the smaller the surface contact area of the tire the lower the resultant rolling resistance (Moore, 1975). The amount of force needed to be applied to the pedals is strongly dependent on this rolling resistance. This study consisted of comparing the pedaling forces using closed-cell polyurethane foam (CCPF) road cycling tires (Amerityre Flatfree™700 C x 23mm) and traditional pneumatic clincher road (PCR) tires (Vredstein® Recorso, 700 C x 23mm).

METHODS:

Four amateur cyclists and one former professional cyclist rode on a cycling training-roller while the forces exerted onto their instrumented insoles placed in the cyclists' shoes (F-scan® Mobile system, Tekscan, USA) were recorded. The training-roller was equipped with a fork mount to increase stability and consistency as well as safety. Two main conditions were performed: an endurance test and a sprint test. The endurance testing consisted of pedaling 20 minutes, at a self-selected cadence and gear ratio but constant for both types of tires. Recordings of in-shoe plantar pressure/force measurement with the F-scan® Mobile system

(Tekscan, USA) were done every 5 minutes for 10 second intervals. The sprint testing consisted of pedalling at a sub-maximal cadence for four 10-second intervals with each tire. Again, gear ratio and cadence had to be the consistent for this test to maintain a constant speed. The tire testing order was established randomly for both tests. By recording the applied forces, comparisons could be made between the two types of tires.
The average force of the entire foot was recorded for each foot of all trials. The forces of specific foot areas, which includes the hallux (1), 1st metatarsal head (2), 2nd metatarsal head (3), 3rd and 4th metatarsal heads combined (4), 5th metatarsal head (5), midfoot (6) and condyle (7) of each foot were also calculated (Figure 1). These data were then transferred into MS Excel for statistical analysis in which the means were taken for all the trials. The difference of the total force between PCR and CCPF tires was obtained according to equation 1. A Paired Sample T-test was then performed to evaluate statistical significance of the calculated results.

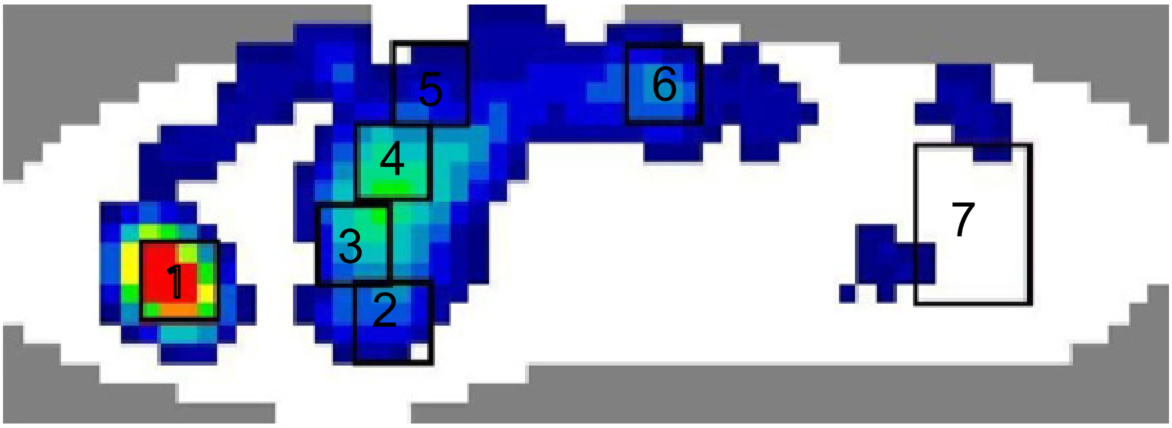

Figure 1. Location of specific foot areas where the average force was captured.

$$\Delta F\% = \left| \frac{Avg\,F_{CCPF} - Avg\,F_{PCR}}{Avg\,F_{CCPF}} \right| \cdot 100 \qquad (1)$$

RESULTS AND DISCUSSION:

The mean cadence for the endurance and sprint trials was 80.8 rpm (±1.79) and 148.8 rpm (±15.8) respectively. According to the literature, the average cadence of professional cyclists in competition ranges from 70 to 90 rpm (Lucia, Earnest, Hoyos, & Chicharro, 2003) and 130 rpm for sprints (Van Soest & CASIUS, 2000).
The difference of the average force under the entire foot between the PCR and the CCPF tires is depicted in Figure 2. The calculated differences between tires, under each condition, were 0.4% and 2.8% for the endurance and sprint trials respectively. However, these differences are not statistically significant ($p > 0.05$).

No significant differences ($p > 0.05$) were found between tires when comparing the specific foot areas in both conditions (Figure 3). This suggests that the CCPF tire has comparable rolling resistance with the PCR tire under sprints and long distance condition.
When comparing the cycling conditions (endurance and sprint), it is observed that the force is spread out over the foot more evenly during the endurance trials than in the sprint trials. This suggests that when cyclists stand for sprinting, the insole force has the tendency to be applied on the hallux and the condyle of the foot rather than spreading out more evenly over the foot.

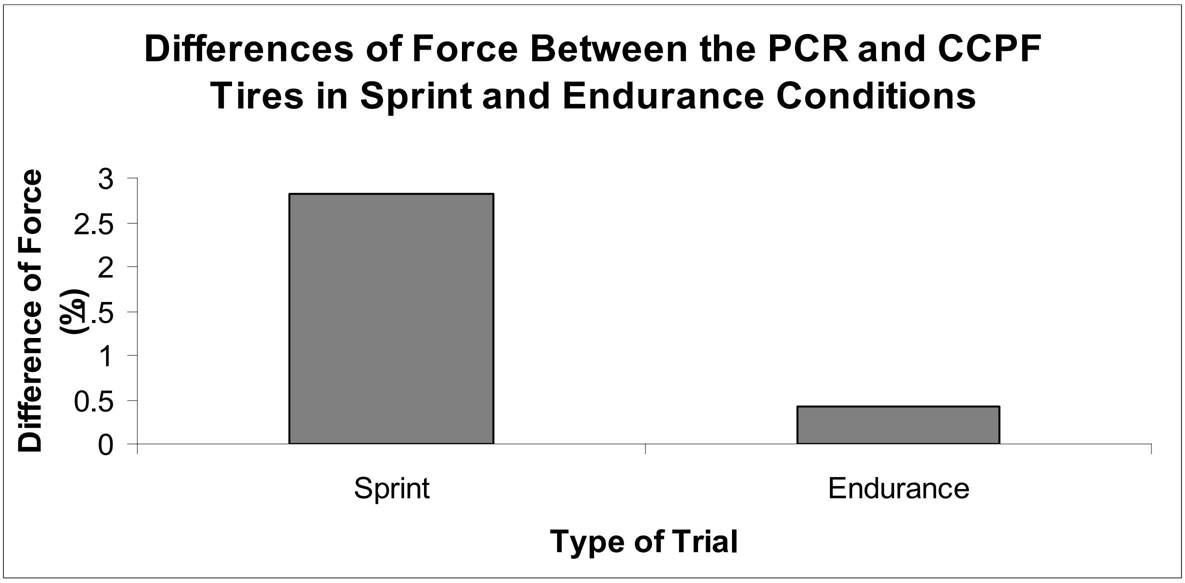

Figure 2. Differences of the total force between PCR and CCPF tires during the sprint trials (0.0283) and endurance (0.00415) trials.

This conflict with a previous cycling study performed by Hennig & Sanderson (1995) that observed the force exerted on the piezo-electric insole during cycling did not increase in the aforementioned method. It was reported that the force distribution of the foot during the pedal stroke is increased through a greater applied force in the hallux and metatarsal area of the foot (Hennig & Sanderson, 1995) instead of the hallux and condyle that was observed in this study.

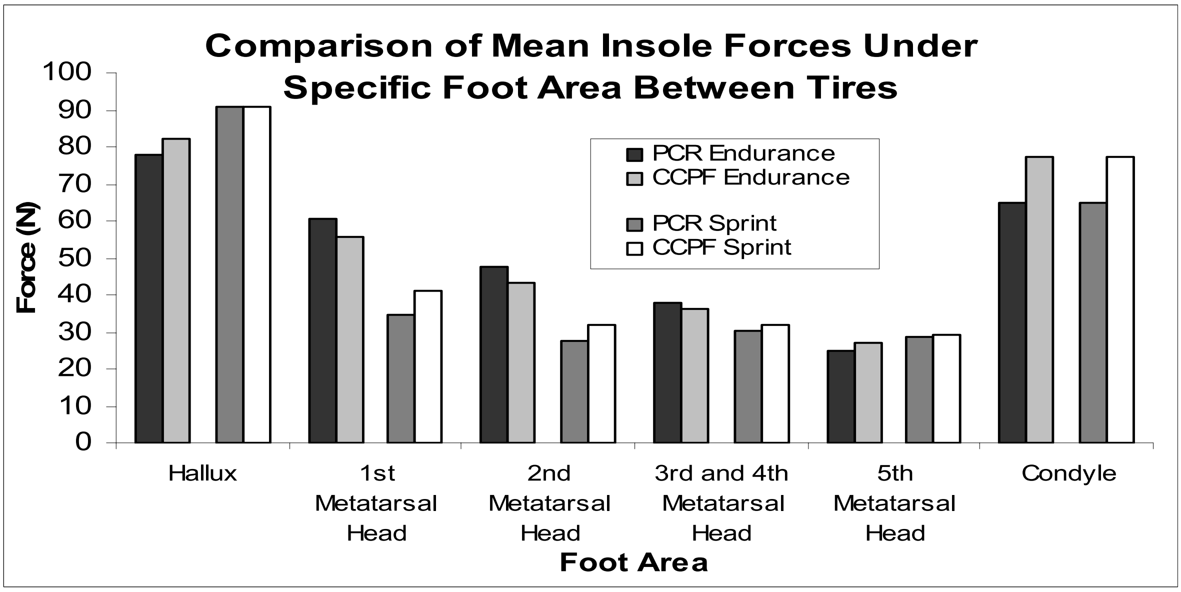

Figure 3. Mean forces, left and right foot combined, of specific foot areas of both insoles for the CPR and CCPF tires.

A potential source of error could be that between testing participant's PCR tires had to be re-inflated to a pressure of ~97 psi. This may lead to a difference between the participants relying on the accuracy of the floor pump. It is believed that a 25% decrease in rated inflation would produce an increase in rolling resistance of 10% so it is not likely that the air pressure was an enormous source of error (Gordon et al., 1989).

CONCLUSION:

In conclusion, this paper compared insole pressure/force measurements of CCPF and PCR bicycling tires. No significant of insole pressure/force were observed in between both types of tires on bicycle training-roller. This implies that the use of CCPF tires is a good alternative for commuter. The use of such tires allows the cyclist to ride without having to carry the extra weight of a pump, spare tube or repair kit. This also eliminates the risks of tire punctures and waist of time for changing the tube.

Although the CCPF tires performed admirably, it should be mentioned that the participants subjectively commented that they felt more resistance with the tire than PCR, especially while initiating the pedaling movement. Further investigations need to be performed for the tires under various other conditions.

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Acknowledgements

The authors would like to thank the participants for their participation and RPMB Inc (www.rpmb.ca) for providing the Flatfree™ tires.