

Effect of Cyclist Formation Size on Wind Speed and Direction

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Abstract

Purpose: To examine how different cyclist formation sizes influence wind speed and direction. **Methods:** A female national-level cyclist (24 years; 159 cm; 51 kg) rode on a 100-m indoor track at 20 ± 1 km/h. Wind speed and direction were measured at the lead and last riders using a custom three-hole Pitot tube with an anemometer (1 Hz). Four straight-line single-file formations (2–5 riders) with 1-m inter-rider spacing were tested, each repeated twice. **Results:** Increasing formation size progressively reduced wind speed for the last rider: ~30% for 2 riders, ~38% for 3 riders, and ~41% for 4–5 riders. Wind direction angles also shifted with formation size (1–8°). The four-rider formation offered the best aerodynamic balance. **Conclusions:** Formation size significantly affects the aerodynamic conditions for trailing cyclists, with four-rider formations providing optimal drafting benefits.

Keywords

drafting; aerodynamic advantage; wind speed; wind direction

1 Introduction

In competitive cycling, drafting allows trailing riders to exploit the wake of the lead rider, reducing drag and conserving energy (Barry et al., 2014; 2015). Benefits depend on factors such as speed, inter-rider distance, crosswind, and formation arrangement (Li et al., 2025). Relative position in the formation is particularly critical, as it alters flow structures,

wake development, and pressure distribution, directly influencing aerodynamic load. Systematic measurements are needed to quantify these effects.

This study investigates how formation size affects wind speed and direction for the last rider, providing empirical insights for optimizing team tactics, energy management, and overall race performance.



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2 Material and Methods

2.1 Participants

The study involved a female cyclist, formerly a member of the national cycling team, with a complete competitive training background and stable riding technique (24 years; 159 cm; 51 kg). Prior to the experiment, anthropometric measurements and bicycle adjustments were performed, including saddle height and handlebar position optimization, to maintain her habitual racing posture and minimize posture-related variability in wind measurements. The study adhered to the ethical principles of the Declaration of Helsinki.

2.2 Experimental Equipment

Anemometer: Wind speed and direction were measured using an anemometer combined with a custom three-hole Pitot tube at a sampling frequency of 1 Hz. The Pitot tube design followed principles proposed by Barry et al. (2014), Chue (1975), and Díaz et al. (2009), featuring a teardrop-shaped probe capable of capturing the wind conditions commonly experienced during cycling. Wind tunnel tests demonstrated that the custom Pitot tube provided accurate measurements within the 5–20 m/s wind speed range, with wind direction error below $\pm 1^\circ$ and overall error below 3%, ensuring reliable instantaneous wind speed and direction data.

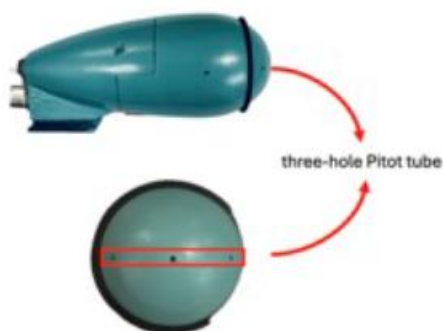


Figure 1. Custom three-hole Pitot tube integrated with an anemometer used for wind speed and direction measurements in the study.

2.3 Experimental Protocol

Four straight-line single-file formation conditions were tested: (1) two riders, (2) three riders, (3) four riders, and (4) five riders. In all conditions, riders were aligned in a straight line with a fixed inter-rider spacing of 1 m to ensure consistency of drafting conditions. Each formation was ridden at 20 ± 1 km/h over a 100-m distance per trial, with each condition repeated twice. Data collection commenced once the target speed was stabilized to ensure measurements reflected steady-state riding conditions.

2.4 Data Analysis

To assess the impact of rider position on the aerodynamic environment, wind speed and direction were compared between the lead and last riders. The standardized difference was calculated as:

$$\text{Standardized difference (\%)} = \left(\frac{\text{Rear rider wind speed} - \text{Lead rider wind speed}}{\text{Lead rider wind speed}} \right) \times 100$$

This metric effectively quantifies the effect of different formation sizes on the aerodynamic conditions experienced by the trailing rider. Descriptive statistics were used to analyze wind speed and direction differences between the first and last riders across all formation conditions.

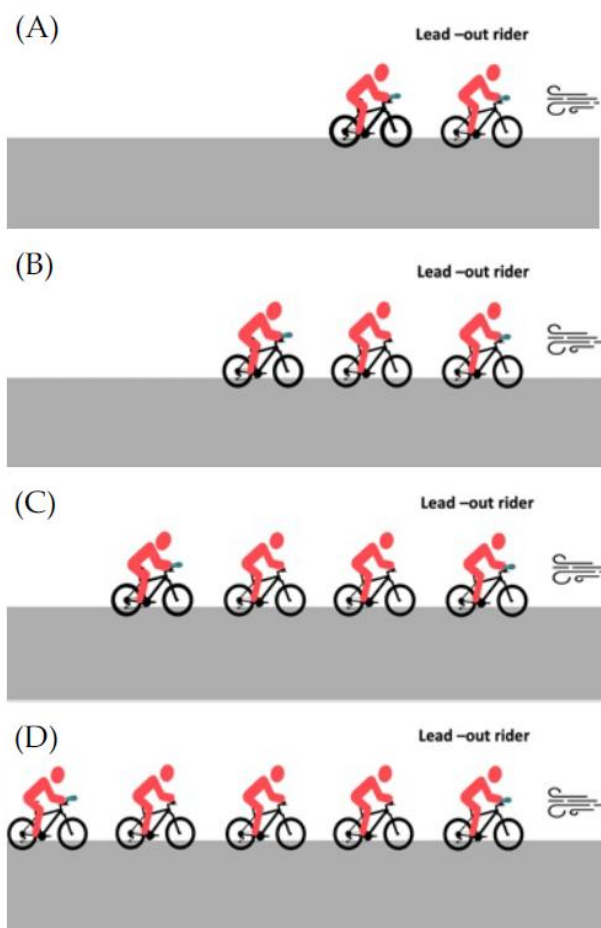


Figure 2. Schematic of the four straight-line single-file formation conditions tested: (A) two riders, (B) three riders, (C) four riders, and (D) five riders, with a fixed 1-m inter-rider spacing.

3 Results

The results showed that wind speed experienced by the last rider decreased progressively as formation size increased. In the two-rider formation, wind speed was reduced by approximately 30%; in the three-rider formation, by ~38%; and in both the four- and five-rider formations, by ~41%.

Wind direction angles also varied with formation size. The mean wind direction deviation was 1.05° for the two-rider formation, 4.94° for the three-rider formation, 3.44° for the four-rider formation, and 8.36° for the five-rider formation.

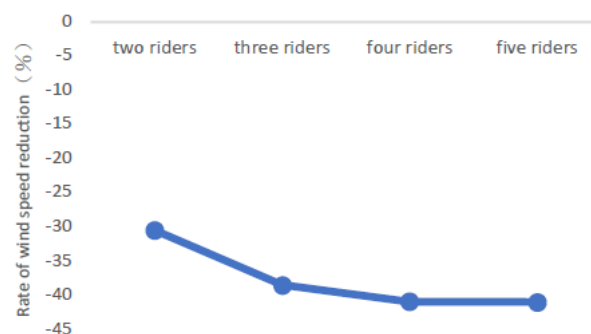


Figure 3. Mean wind speed experienced by the last rider across different straight-line single-file formations.

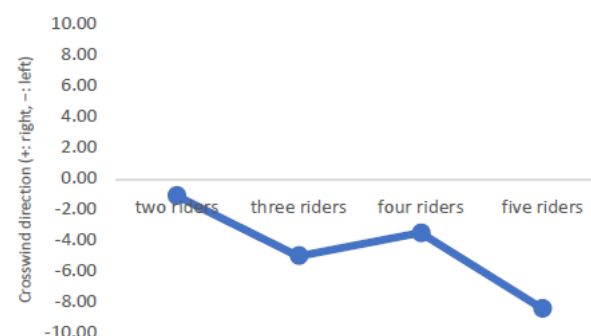


Figure 4. Mean wind direction deviation for the last rider in different formations.

4 Discussion

Wind speed for the last rider decreased progressively with increasing formation size, by approximately 30–41%, consistent with trends observed in previous wind tunnel studies (Barry et al., 2014), confirming that rider position affects aerodynamic drag. Differences in magnitude likely result from lower riding speed (20 ± 1 km/h) and indoor track conditions.

Larger formations also increased lateral wind components. The four-rider formation provided the best balance between wind speed reduction and flow stability, while the five-rider formation, despite similar wind speed reduction, showed greater wind direction fluctuations, suggesting increased wake turbulence.

Limitations include a single participant and measurements limited to wind speed and direction. Future studies should include more riders and integrate power output and

drag coefficient analysis to better assess wake structure, energy savings, and drafting efficiency under varied speeds and wind conditions.

5 Practical Applications

Increasing formation size reduces wind speed for trailing riders, enhancing aerodynamic efficiency. The four-rider formation provides the best balance between wind speed reduction and stability, offering a practical guideline for team positioning and drafting strategies in training and competition.

6 Conclusions

Field measurements confirmed that increasing formation size significantly reduces wind speed for the last rider, with reductions of approximately 30–41%. Among the tested formations, the four-rider setup provided the best balance between wind speed reduction and flow stability,

suggesting it is an optimal configuration for maximizing aerodynamic efficiency while maintaining formation consistency.

Conflicts of Interest: The authors declare no conflict of interest.

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