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# Experimental methodology of young rider bicycle handling quality measurement in ecological conditions

J. Ronné<sup>a</sup>, L. Dubuis<sup>a</sup>, J. Peng<sup>b</sup> and T. Robert<sup>a</sup>

<sup>a</sup>Univ Lyon, Univ Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR\_T 9406, Lyon, France; <sup>b</sup>Décathlon SportsLab, Morphologie Sciences Department, Lille, France

## 1. Introduction

Riding a bike is a very common activity for children. Learning to ride a bike is an important step during childhood where integrating some counterintuitive bike behaviors can be challenging. Despite extensive research these last years, theoretical approaches to quantify the bicycle handling quality (the ease a bike can be controlled) still have strong limitations and lack of validity (Schwab and Meijaard 2013). An experimental approach appears necessary. However, questionnaires are not really convenient, especially for kids who have difficulties to provide accurate feedbacks on their riding experience. Moreover, laboratory-based measurements requiring riding on treadmills or rollers are non-suitable for kids. Thus, an experimental methodology to quantify bicycle handling quality in an ecological environment is needed. Previous study with ambulatory measurement has focused on rider skill without considering design effect (Cain et al. 2012). This study proposes and evaluates a methodology focused on bicycle handling quality, based on inertial measurement units (IMU), on young children

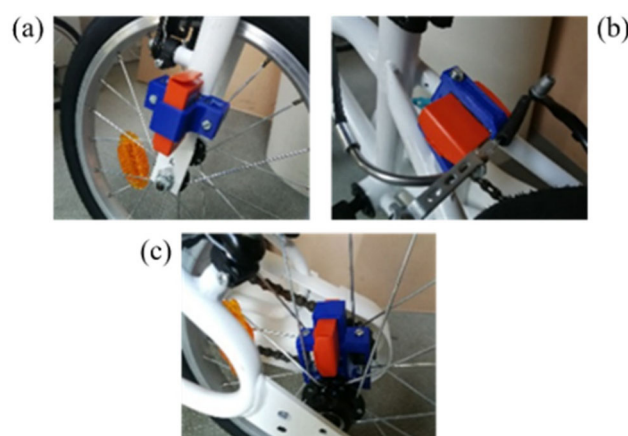
## 2. Methods

### 2.1. Subjects and procedure

Sixteen children between 3 and 7 years old were asked to ride two specifically designed experimental bikes on a 1.1 m wide and 54 m long (approximately) track, consisting of two turns, a light slalom and two straight lines. Involved participants exhibit a minimum skill level (starting, braking, turning, riding straight). Each participant rode at 3 different speeds (slow, free, fast), with two different bikes (see below) presented in a randomized order. They completed between 1 and 3 laps for each speed.

### 2.2. Design of the bikes

The experimental bikes were designed to provide significant difference in dynamic behavior based on



**Figure 1.** Location of the 3 IMUs placed on the bikes: fork (a), frame (b), rear wheel hub (c).

literature stability analysis (Zhang and Tak 2020). Head angle (about horizontal) have been modified (bike 1: 70°, bike 2: 80°), while keeping wheelbase and trail identical (only the caster offsets have been altered).

Special attention has been paid to standardize the posture of children on the experimental bikes. For that purpose, bikes have been equipped of adjustable stem (rise and reach), which has been adjusted for each participant based on their stature (Grainger et al. 2017). Yet, these recommendations, obtained on ergometers, had to be adapted (85% of reach and rise have been taken) to provide comfortable and feasible postures on real bikes.

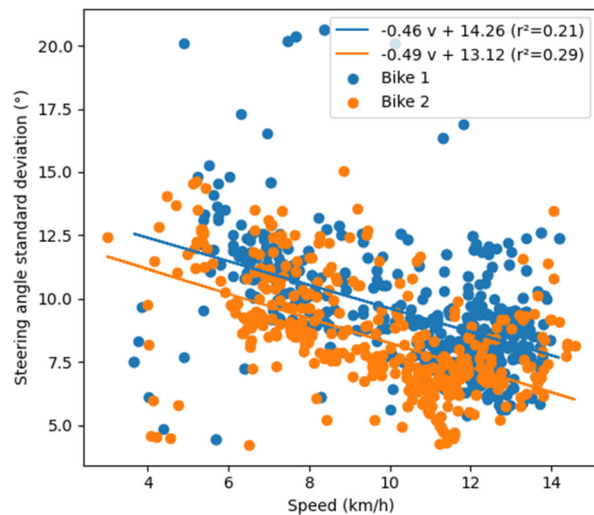
Bikes characteristics respect safety requirements of ISO 8098 norm.

### 2.3. Measurements

The bikes were equipped with 3 (XSens<sup>®</sup>) IMUs such as in (Cain et al. 2012). IMUs have been set on rear wheel hub, frame and fork (see Figure 1) to measure the rear wheel rotation speed, and the roll and steering angles, respectively. Angles were obtained using the XSens<sup>®</sup> fusion algorithm. Data were sampled at 75 Hz.

### 2.4. Data analysis

Standard deviation of steering angle is aimed to measure the bicycle handling quality (difficulty to control the bicycle). It has been hypothesized that a young rider, as a human controller, tends to minimize its control intervention (based on the minimal action principle (Todorov 2004)), and that bike control is mainly performed by steering. Thus, it has been assumed that the larger the standard deviation of steering angle, the larger the amount of control



**Figure 2.** The amount of control actions quantified by steering angle standard deviation decreases as average speed increases.

actions required to control the bike, and thus the lower the handling quality.

Steering angle has been calculated using the data from frame and fork IMUs: XSens fusion algorithm compute frame and fork rotations in a unique global fixed axis coordinate system. Then rotation matrix has been expressed in the coordinate system of the fork which is different between bike 1 and bike 2 because of different head angles. Finally, steering angle is calculated as the angle between frame and fork longitudinal axis projected in the plan normal to steering axis. A high-pass filter (order 5,  $10^{-2}$  Hz cut frequency) has been used to correct IMUs drift on calculated angles.

For each trial (between one and 5 laps), steering angle standard deviation and average speed have been calculated on time windows whose duration was equivalent to one lap and which overlapped by an 80% ratio.

The effect of speed and bike design on the standard deviation of the steering angle has been studied, respectively, with linear regression and a generalized Wilcoxon Test (non-parametric hypothesis test).

### 3. Results and discussion

The amount of control actions strongly depends on the average speed of the lap (Figure 2). Linear regressions point out that the amount of control actions of both bikes have the same speed dependency (bike 1 has a slope of  $-0.46^{\circ} \cdot \text{h} \cdot \text{km}^{-1}$ ,  $r^2=0.21$ ,  $p < 0.05$  and bike 2 has a slope of  $-0.49^{\circ} \cdot \text{h} \cdot \text{km}^{-1}$ ,  $r^2=0.29$ ,  $p < 0.05$ ). This result indicates that children use more control actions at low speeds ( $\sim 6$  km/h) than at medium speeds ( $\sim 13$  km/h). It suggests that bikes are more difficult to control at low speed than at medium

speed, which is consistent with the extensive theoretical stability studies available in the literature, and with the experimental results from (Cain et al. 2016) about rider's skill performed on rollers.

Linear regressions also exhibit an approximately  $1^{\circ}$  offset (bike 2 shows in mean about 10% less variations in steering angle) suggesting that bike 1 is less controllable than bike 2. Generalized Wilcoxon test confirms this result showing a significant difference ( $p < 0.05$ ) in the amount of requested control action between the two bike configurations. It shows that bike configuration, notably the head angle, has an influence on the handling quality which is consistent with (Zhang and Tak 2020) as far as this parameter also modify uncontrolled bicycle stability properties. However, the direct link between stability properties and handling quality remains unknown.

Despite these significant effects, data show high variability that could be explained by inter-individual variability and eventually by learning process of the kids.

### 4. Conclusions

These results assess for the first time the feasibility of this experimental methodology on young children in ecological conditions. Future works will focus on data analysis in order to compare theoretical control indexes and experimental measurements. These results also open the door for larger ambulatory quantitative evaluations of bicycle handling quality.

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### Disclosure statement

No potential conflict of interest was reported by the authors.

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**KEYWORDS** Handling quality; children bicycle; bicycle; ecological conditions

 [laura.dubuis@univ-lyon1.fr](mailto:laura.dubuis@univ-lyon1.fr)