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Observation of the steering torque applied by the rider on a cargo bicycle

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1. Introduction

Maintaining balance on a bicycle is a very complex problem still not well understood. Moore et al. (2011) focused on kinematics analysis to quantify the control actions used by a rider while riding on a treadmill. They found that steering actions are the most important strategies for balance control. More specifically, they highlighted the “steer into the fall” principle (steering in the direction of the turn to induce centrifugal acceleration that tends to straighten up the system) as mandatory for bicycle stability. Other studies confirmed that the steering action is the most important control action for bicycle balance by building numerical models able to reproduce rider behaviour with steering torque as the only control action (Dialynas et al. 2023). These studies highlighted the main variables used by the rider to make his control actions. For example, according to Dialynas et al. (2023), steering torque feedback is relevant but not dominant in the control actions used by the rider, which leads them to the conclusion that the rider acts against steer inertia and not wheel inertia and tyre/road interaction. Most of the studies involved riding on a treadmill or in straight line regardless of rider skills. The effect of the track curvature and the rider skills have been described in the literature, but separately, and only for model fitting. Plus, many studies focused

on straight lines were made on treadmills, which is not an ecological condition for bicycling. This study aims to use a bicycle model and data from inertial measurement units (IMU) to compute the torque applied by the rider on the handlebar, in two different situations: straight line (SL) and left turn (LT). Moreover, we propose an exploratory study on the effect of the rider skills on this torque.

2. Methods

2.1 Data Acquisition

Data used for this study came from a previous study (Ronné et al. 2023), where 30 participants rode a cargo bicycle on a track including straight lines and turns. They were not specifically accustomed to the cargo bicycle and thus considered here as novices. Additional data from an expert rider highly familiar with the cargo bicycle, collected in the same conditions, were included in this study. Three IMUs (on the frame, the front assembly and the rear wheel) were synchronised and recorded the bicycle movements at 120Hz. For each IMU, we used angular and gyroscopic data to determine the movements according to the following model. For this study, data from two sections of the track were considered: SL (43m) and LT (radius of 5m and length of 17m).

2.2 Bicycle Model

After estimating the geometrical and inertial parameters of the cargo bicycle, a Whipple model (Meijaard et al. 2007) corresponding to our experimental bicycle was made. This model includes two equations of motion, one along the roll axis (φ) and one along the steering axis (δ). It also allows computing the external efforts applied to the bicycle given its current state.

2.3 Torque Analysis

The data and the previous model were used to compute the torque applied by the human around the roll and steering axis (respectively T_φ and T_δ) for each time frame. As steering is considered the most important control action, this study is focused on the torques applied on the front assembly along the steering axis (δ). More specifically, two external torques applied on the front assembly were studied: the torque applied by the rider ($T_{\delta \text{ rider}}$) and the torque due to the roll angle of the bicycle ($T_{\delta \text{ roll}}$).

For each section (SL and LT) and each riding skill, the root mean square (RMS) and the standard deviation (STD) of $T_{\delta \text{ rider}}$ were computed. For computing these metrics (RMS and STD), we focused on the steady state of each section, so we removed the transition phase between sections. A one-way ANOVA on novice data was used to study the effect of the section.

3. Results and discussion

The results for the rider steering torque applied on the front assembly are displayed in Table 1. Figure 1

shows a representative example of the time-profile of $T_{\delta_{rider}}$ vs. $T_{\delta_{roll}}$ for one novice and one expert riders.

Table 1. Means of RMS and STD of rider torque on the handlebar in 2 sections: SL and LT, for 2 different riding skills.

Section	Nb of runs		RMS		STD	
	SL	LT	SL	LT	SL	LT
Novices	57	88	0.32	0.35	0.32*	0.25
Expert	1	1	0.22	0.29	0.21	0.11

* means SL > LT with $p < 0.05$

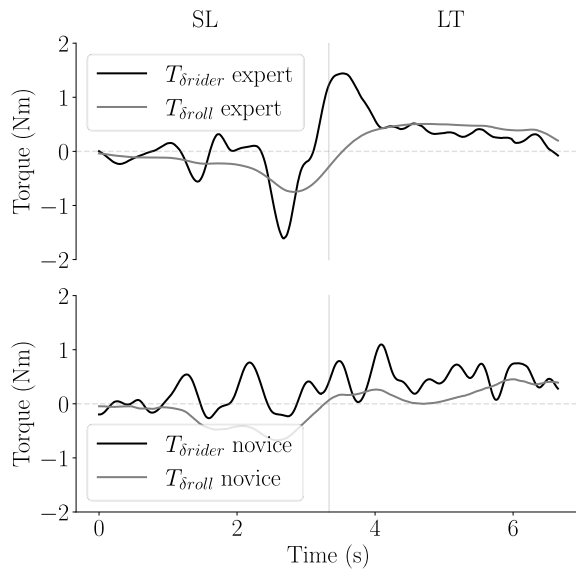


Figure 1. Comparison of different torque variables during a transition between SL and LT for 2 different skilled riders on a cargo bicycle at 3.4 m/s. Signal synchronisation was made by recognising the minimum raw angle ψ (vertical line).

First, one can observe that torque amplitudes were comparable to those obtained in previous studies in similar settings but with a more direct instrumentation (Dialynas et al. 2023). Then, we observed an effect of the section on the torque applied: RMS tends to increase between SL and LT (although the effect is not significant), while STD decreases. It highlights the fact that during a turn, the torque applied is not centred to 0, and its variations are smaller than in SL.

Results also provided a preliminary insight of the difference between control actions made by expert and novice riders. The expert seems to reduce its variations of torque on the handlebar in both sections, which is consistent with classical results on motor control expertise (Todorov 2006). In particular, the expert reached the steady-state turn faster and used much more the bicycle lean (higher roll angle) as a steering control action than the novice.

In this analysis, we focused on the torque applied by the rider directly to the handlebar, as it was described as the primary control mechanism. Yet, other control actions can be used by the rider, in particular applying torques along the roll axis by adjusting its angular momentum (e.g., while riding without touching the handlebar), should be considered in future studies.

4. Conclusions

This study presents a method for computing the torques applied by rider on a bicycle while riding under ecological conditions, using a simple and versatile instrumentation. It was used to analyse the control actions of novice riders on the handlebar, showing the impact of the track section. Preliminary results also showed that an expert driver tends to limit its steering control action compared to novice riders.

Conflict of interest statement

The authors declare no conflict of interest during this study.

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