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Measurement of skidding to determine the optimum ergonomic configuration of the racing wheelchair

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1. Introduction

The popularity of wheelchair athletics has grown considerably, making it one of the most popular Paralympic sports worldwide. This trend towards performance optimization has stimulated research into wheelchair ergonomics and performance criteria (Mason, van der Woude, & Goosey-Tolfrey, 2013). Thus, wheelchair performance criteria such as seat position, wheel camber angle, wheel and handrims size were studied. Performance is quantified by kinematics and kinetics propulsion parameters (Van Der Slikke, De Witte, Berger, Bregman, & Veeger, 2018) or, more recently, by measuring rolling resistance (Baldissera, Delprete, Rossi, & Zahar, 2021). In disciplines such as cycling or motor sports, coefficients of friction (static and dynamic) are additional factors considered. The recommended values depend on various parameters such as soil type and degree of slope but are generally between 0.6 and 0.9 (Rajamani, Phanomchoeng, Piyabongkarn, & Lew, 2012). However, to the best of our knowledge, no study has focused on this measurement in the context of wheelchair sports. This study aims to identify optimal skidding torques by testing different ergonomic settings of a racing wheelchair wheel. This knowledge could complement the practice of para-sport by optimizing the athlete-wheelchair pairing. We have chosen to keep mass as the explanatory factor, which leads to a study of skidding torques rather than friction coefficients.

2. Methods

2.1 Measuring tool

A skidometer has been created to measure the skidding torque of a wheel, i.e. grip loss torque and grip recovery torque. This tool proposes a system for classifying wheel grip, by measuring the torques that reflects the effect of different parameters: tubular type, pressure, camber angle and loading. To achieve this, a motor is mounted on the wheel axle and applies an increasing torque up to the point where the tubular skids on the ground surface. The grip recovery torque is determined based on the last 10 data recorded before stopping the test. The test bench is equipped with a tube for loading the system with calibrated weights, and a protractor for modifying and controlling the wheel camber angle.

2.2 Experiments

Wheel skidding torques were measured on a tartan-type ground reproducing the practice's ecological environment. Loading characterizes the athlete's mass distributed over a single wheel, on the assumption that the athlete's weight is uniformly distributed. To determine the ergonomic combinations of the wheelchair, the levels of the factors studied are listed in the table 1.

2.3 Taguchi method

Full factorial design experiments would have necessitated 192 trials ($n_{trials} = n_{tubular} \cdot n_{pressure} \cdot n_{load} \cdot n_{camber}$), that was not possible, considering an average trials time of 3 minutes

for a single tubular. Following Taguchi's method, the L16 table was chosen as the model. There are therefore 128 combinations in total ($n_{comb} = 16 \cdot 8_{tubular} = 128$) and each condition are repeated twice ($n_{tot} = 256$).

Table 1. Characteristic of the various factors studied.

(Tubular no.) Tub. type	(1) Michelin Power Cup Tubular (2) Dugast Strada 20" (3) Dugast Strada 22" (4) Vittoria Pista 19-28" (5) Vittoria Pista 23-28" (6) Tufo Elite S3 (7) Dugast Piste Latex 20"* (8) Dugast Piste Latex 22"*
Pressure [bars]	5,5 6 7
Loading [kg]	20 25 30 35
Camber	11 12

*Tubular that did not stand up to testing (not considered)

3. Results and discussion

The effect of the type of tubular on the torques obtained is shown in Figure 1. For each type of tire, torque values were averaged over three tests.

The average grip loss torque across all tubulars is 138 Nm, and the average grip recovery torque is 110 Nm. In the case of wheelchair racing, the aim is to minimize the risk of wheel skidding, and therefore to achieve a high grip loss and recovery torques. In addition, the difference between the two torques must be minimized, as it reflects the speed of regaining grip on the ground. Averaging each type of tire, the average difference between torques is 27.7 Nm. Following the principle of minimization, the tubular no. 2 is the most suitable tubular for wheelchair racing with a difference of 25.25 Nm.

Complementary results showed that there is no effect of pressure or camber on skidding torques. However, increasing load results in a linear increase in skidding torques, i.e. the heavier the load, the greater the torque generated. The lack of influence of pressure and camber parameters can be attributed to the ranges of values tested. Finally, behavior differs according to the material

and width of the tubulars used. The thicker the cross-section, the greater the torque (e.g., tubular no. 2 with a thinner cross-section and tubular no. 5 with a larger cross-section). Fortunato (2015) as incorporated new notions such as the influence of the frictional heating on skidding. When using elastic material, Coulomb's law is not respected, and it would be better to study more specifically the deformations of the material on the ground to include these characteristics in our study.

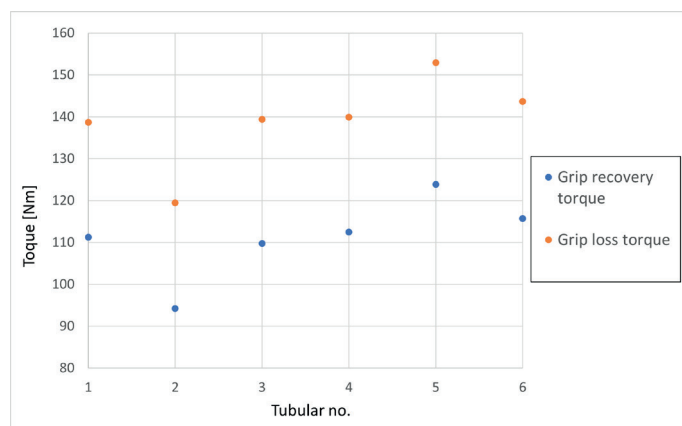


Figure 1. Torque variation according to tire type (i.e. table 1).

4. Conclusions

This study determines the ergonomic combinations for the track and field chair, based on the measurement of grip loss and recovery torques. By studying the parameters recommended by the wheelchair athletics commission, we conclude that tubular no. 5 is the most suitable, since it limits the risk of skidding. To continue the study, we would like to focus exclusively on the Vittoria Pista Speed 23-28" tubular. This would enable us to check, over a wider range of values, whether tubular pressure and camber angle affect the measured torques. It would also be relevant to analyze wheel behavior on wet tartan, as weather conditions can play a decisive role in para-athlete performance. Finally, our long-term ambition is to reproduce this experiment for all varieties of wheelchair sports.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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