Medical Engineering and Physics 37 (2015) 392–399

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Influence of wheel configuration on wheelchair basketball performance: Wheel stiffness, tyre type and tyre orientation

B.S. Mason [a,*], M. Lemstra [b], L.H.V. van der Woude [b], R. Vegter [b], V.L. Goosey-Tolfrey [a]

[a] Peter Harrison Centre for Disability Sport, School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, Leics, LE11 3TU, UK
[b] Centre for Human Movement Sciences, University Medical Centre Groningen, University of Groningen, Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 16 October 2014
Accepted 7 February 2015

Keywords:
Wheelchair configuration
Mobility performance
Wheelchair propulsion

ABSTRACT

The aim of the current investigation was to explore the lateral stiffness of different sports wheelchair wheels available to athletes in 'new' and 'used' conditions and to determine the effect of (a) stiffness, (b) tyre type (clincher vs. tubular) and (c) tyre orientation on the physiological and biomechanical responses to submaximal and maximal effort propulsion specific to wheelchair basketball. Eight able-bodied individuals participated in the laboratory-based testing, which took place on a wheelchair ergometer at two fixed speeds (1.1 and 2.2 m s^{-1}). Outcome measures were power output and physiological demand (oxygen uptake and heart rate). Three participants with experience of over-ground sports wheelchair propulsion also performed 2 × 20 m sprints in each wheel configuration. Results revealed that wheels differed significantly in lateral stiffness with the 'new' Spinergy wheel shown to be the stiffest (678.2 ± 102.1 N mm^{-1}). However the effects of stiffness on physiological demand were minimal compared to tyre type whereby tubular tyres significantly reduced the rolling resistance and power output in relation to clincher tyres. Therefore tyre type (and subsequently inflation pressure) remains the most important aspect of wheel specification for athletes to consider and monitor when configuring a sports wheelchair.

1. Introduction

It has been well documented over recent years how wheelchair configuration can affect performance in wheelchair sports, such as wheelchair basketball [1]. Research has typically focused on how major areas of configuration such as the size [2,3] and camber angle [4–6] of the main wheels influence athletes mobility performance. However, there are numerous other features of a sports wheel that may also affect the ergonomics of sports wheelchair propulsion. Wheels currently available to athletes differ in the number, thickness, material and orientation of the spokes, which according to the cycling literature can affect the stiffness of a wheel [7–9].

Wheel stiffness refers to a wheel's resistance to deflection under loading [7]. From the cycling literature, Minguez and Vogwell [9] revealed that a reduction in the number of spokes (from 18 to 12) reduces the radial stiffness of wheels. Alternatively, Gavin [8] suggested that increasing the thickness of the spokes (1.6–2.0 mm) increases the radial and lateral stiffness of wheels. The material of wheel spokes also differs with steel thought to provide a stronger, fatigue-resistant spoke compared to aluminium or titanium [7]. However, the introduction of composite fibre materials offers a lighter, more expensive alternative [7]. Finally, the orientation of the spokes is also thought to impact wheel stiffness [8]. Wheels can be distinguished by the number of times one spoke is crossed by others (typically 0× [radially spoked], 2×, 3× or 4×) with a greater number of crossings thought to reduce wheel stiffness [8]. Although the majority of the cycling literature has focused on the radial stiffness of the wheel, a key difference in sports wheelchairs is the 15°–24° camber angle of the main wheels [5]. Therefore a large percentage of the load placed on the wheel is not radial, suggesting that lateral stiffness would be a more appropriate measure for a sports wheelchair wheel.

Few studies have investigated different spoke configurations specific to wheelchair users [10,11]. Comparisons have been made between Spinergy wheels, which incorporate composite fibre spokes, in relation to conventional steel-spoked wheels [10,11]. However no improvement in physiological demand [10] or reduction in vibrations [11] was identified in Spinergy wheels, despite the perceived improvement in ride comfort [10]. Although no performance benefits were observed, details on the specific differences in wheel specifications, aside from spoke material, were not provided. In order to optimise performance through wheel specification, details of individual components need to be examined to establish reliable cause and effect relationships. It is also worth noting that both these studies were conducted from a daily-life perspective and as such translations to an athletic population are not possible. Another important consideration for the wheelchair user is wheelchair maintenance, since a

* Corresponding author. Tel.: +44 1509 226387.
E-mail address: b.mason@lboro.ac.uk (B.S. Mason).

http://dx.doi.org/10.1016/j.medengphy.2015.02.001
1350-4533/

poorly maintained wheelchair can increase the physical strain placed on the user [12]. Therefore it would also be of interest to quantify the impact that a reduction in spoke tension, which occurs over time in a used wheel, could have on wheel stiffness and subsequently performance.

In addition to wheel stiffness, wheels currently available to athletes also differ in tyre type and subsequent inflation pressure. Such parameters have again been investigated under conditions specific to daily-life wheelchair propulsion and have demonstrated that pneumatic tyres reduced the physiological demand compared to solid tyres [13,14]. These studies also revealed that power requirements and physiological demand both increase when tyre pressure drops to 25% [14] and 50% [13,15] of the recommended inflation pressure. Pneumatic tyres are the popular choice for athletes participating in wheelchair basketball, however the tyres themselves can differ in their construction. Clincher tyres are most common, whereby the tyre extends from both walls of the wheel rim to partially encompass an inner tube [7]. However, an increasing number of athletes are selecting tubular tyres, which do not require an inner tube as the tyre is completely enclosed and sits within the walls of the wheel rim [7]. Tubular tyres enable a higher inflation pressure and are thought to be less prone to punctures [7].

As mentioned previously, the main wheels of a sports wheelchair are cambered, which can deform the tyre and increase resistance [5]. Recently manufacturers such as Celeritas 300 (Den Haag, The Netherlands) have introduced novel developments to the wheel rim in an attempt to optimally orientate the tyre so that deformation and resistance are minimised. Yet to the authors knowledge, the impact of tyre orientation on aspects of mobility performance has not been investigated.

The aims of the current investigation were to: (1) explore the lateral stiffness of different sports wheelchair wheels commercially available to athletes in 'new' and 'used' conditions; and (2) determine the influence of (a) wheel stiffness, (b) tyre type (clincher vs. tubular) and (c) tyre orientation on the physiological and biomechanical responses to submaximal wheelchair propulsion and on maximal effort propulsion specific to wheelchair basketball. It was hypothesised that stiffer wheels would result in reduced physiological demand, since less energy would be dissipated through the wheel. Tubular tyres were hypothesised to reduce rolling resistance through their higher inflation pressure, which was expected to minimise physiological demand and improve maximal effort sprinting performance. This effect was hypothesised to improve further still when the tyres were orientated optimally by an innovative wheel rim design.

2. Methods

2.1. Participants

Eight able-bodied (AB) males (age = 30 ± 5 years; body mass = 80.5 ± 9.1 kg; height = 1.81 ± 0.06 m) with previous experience of laboratory-based modes of wheelchair propulsion participated in the laboratory testing in the current study. A further three participants (age = 28 ± 8 years; body mass = 78.0 ± 10.0 kg) with extensive experience (≥6 years) of over-ground sports wheelchair propulsion participated in the field-based testing only. The study was approved by the local ethical committee and all participants provided their written, informed consent prior to testing.

2.2. Wheels

Three pairs of wheels currently available to wheelchair basketball players [(i) Spinergy SLX, Spinergy Inc, San Diego, USA; (ii) Sun Equalisers, Sun Components, Milwaukee, USA; and (iii) Sun Classics, Sun Components, Milwaukee, USA] in both 'new' and 'used' conditions were investigated. In the used condition, spoke tensions were reduced and equated to the spoke tension of a 12 month old wheel, which were verified using a tension meter (Park Tool TM-1, Minnesota, USA). Each of these wheels was fitted with Kenda Kontender clincher tyres (Kenda, Ohio, USA), inflated to 110 psi.

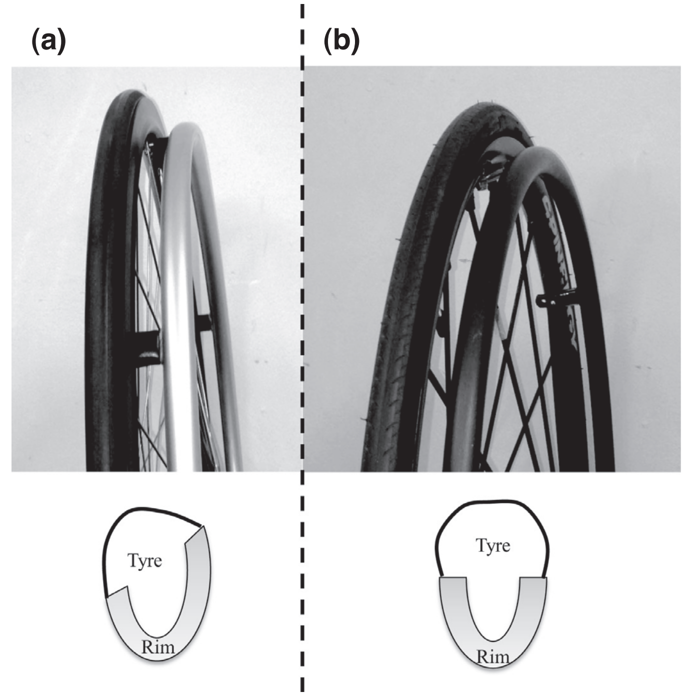

Fig. 1. Illustration of the wheel rim design in (a) the Celeritas 300 and (b) standard Spinergy wheel and the tyre orientation of both wheels.

Two further pairs of wheels (Spinergy SLX and Celeritas 300 wheel) equipped with tubular TUFO tyres (TUFO, Otrokovice, Czech Republic) were also investigated. TUFO tyres are manufactured using a silicon tread compound and do not contain an inner tube enabling a higher inflation pressure, which was controlled at 160 psi. As previously mentioned, the Celeritas 300 incorporates an innovative design at the wheel rim-tyre interface. The lateral wall of the rim is slightly higher in an attempt to orientate the tyre at an optimal position with the ground in a cambered wheelchair (Fig. 1). The same chromium hand-rims were used with each wheel configuration. Further details of each wheel are provided in Table 1.

2.3. Experimental design

2.3.1. Wheel stiffness

The lateral stiffness of each wheel was examined using a deflection test (Fig. 2). During the deflection tests the wheel was supported at three contact points on the inside of the wheel rim. Three incremental loads (5, 10 and 20 kg) were then applied to the axle of the wheel with the resulting deflection reported to the nearest 0.01 mm using a metric dial test indicator gauge (Toolzone, Devon, UK). Each wheel was tested twice with the contact points in line with the spokes and twice with the contact points in between the spokes. Lateral stiffness, expressed in N mm^{-1}, for each load and position was then averaged over 24 trials for each wheel. A higher value represents a stiffer wheel.

2.3.2. Laboratory testing

Participants performed a series of 3-min bouts on a dual-roller wheelchair ergometer (VPHandisport-25, Tecmachine, France) at two submaximal speeds (1.1 and 2.2 m s^{-1}). All testing was performed on a single roller to minimise resistance, which were equipped with two electromagnetic brakes, the sensors of which were calibrated using a