Human Movement Science 46 (2016) 184–195

Contents lists available at ScienceDirect

Human Movement Science

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

Cycling strategies of young and older cyclists

Vera E. Bulsink [a,*,1], Hielke Kiewiet [b,1], Dorien van de Belt [a], G. Maarten Bonnema [b], Bart Koopman [a]

[a] Laboratory of Biomechanical Engineering, University of Twente, Postbus 217, 7500 AE Enschede, The Netherlands
[b] Laboratory of Design, Production & Management, University of Twente, Postbus 217, 7500 AE Enschede, The Netherlands

ARTICLE INFO

Article history:
Received 18 July 2015
Revised 6 January 2016
Accepted 6 January 2016
Available online 18 January 2016

Keywords:
Aging
Bicycle balance
Control strategy
Cycling safety
Perturbation study

ABSTRACT

This study concentrates on the cycling strategies of older cyclists (54–62 year olds) in comparison to young cyclists (20–30 year olds). While cycling in a safe laboratory set-up, controlled lateral perturbations are applied to the rear of the bicycle. Three possible strategies to keep balance are analysed for a young and older aged group: steering, lateral trunk movement and outward knee movement. Older subjects appear to rely more on knee movement as a control mechanism than young subjects. Furthermore, the frequency domain analysis revealed that the older adults need more effort to counteract high frequency perturbations. Increased inter-individual variation for the older adults subject group suggests that this group can be seen as a transition group in terms of physical fitness. This explains their increased risk in single-sided bicycle accidents (i.e. accidents involving the cyclist only). Therefore, older cyclists could benefit from improving the stability of cycling at lower speeds.

1. Introduction

Bicycling is a common and popular mode of transport in the Netherlands. Dutch citizens frequently use their bicycle for both recreational and transportation purposes; a quarter of all journeys are made by bicycle (Centraal Bureau v.d. Statistiek., 2008), and there are more bicycles than residents in the Netherlands. A recent study reports an increase of single-sided bicycle accidents (i.e., accidents involving the cyclist only) for people aged over 55 (Consument en Veiligheid, 2010). This group has a higher risk of sustaining a bicycle fall as well as a sequential severe injury, compared to younger cyclists (Schepers et al., 2014). The increase in bicycle usage and the aging of the population partly explains the higher number of single-sided accidents among this group. Ormel, Klein Wolt, and den Hertog (2009) showed that half of the single-sided bicycle accidents in the Netherlands are related to cycling behaviour. Despite the increased accompanying risks, continuing cycling contributes to a healthy and improved quality of life (Pucher, Dill, & Handy, 2010). It is therefore important to improve the safety of older cyclists, to enable them to remain cycling for a longer time and thereby maintain their quality of life.

In the present study the cycling strategies of older adult cyclists are compared to those of younger adult cyclists, with the aim to gain insight into differences in control mechanisms used by older cyclists that could cause balance and control difficulties.

* Corresponding author.
E-mail addresses: Vera.Bulsink@utwente.nl (V.E. Bulsink), H.Kiewiet@utwente.nl (H. Kiewiet), D.vandeBelt@utwente.nl (D. van de Belt), G.M.Bonnema@utwente.nl (G.M. Bonnema), H.F.J.M.Koopman@utwente.nl (B. Koopman).

[1] These authors contributed equally to the work.

http://dx.doi.org/10.1016/j.humov.2016.01.005
0167-9457/

While bicycle dynamics has been studied for years (Kooijman, Meijaard, Papadopoulos, Ruina, & Schwab, 2011; Moore & Hubbard, 2008; Whipple, 1899) only few have studies focused on the control strategies of the cyclist, and even less on those of older cyclists. The cyclist plays an important role when analysing the dynamics of the total system of the bicycle, the cyclist and their interaction with the environment. The motions of the cyclist's body relative to the bicycle in combination with the cyclist's steering actions determine the behaviour of the system.

An extensive overview of the state-of-the-art of bicycle and cyclist models and validation data has been presented by Schwab and Meijaard (2013). Several authors showed that steering is the primary control input for balancing (Kooijman, Schwab, & Moore, 2009; Moore, Kooijman, Schwab, & Hubbard, 2011; Weir, 1972). However, Cain (2013) found, that upper-body lean control is the dominant control strategy for balance performance for cycling on rollers. In line with this insight, upper-body lean torque was successfully implemented in several cyclist control models (Nagai, 1983; Sharp, 2001). A third strategy was noted by Moore et al. (2011), who found that at low speeds, lateral knee movements are used as an additional control action.

Recently, van den Ouden (2011) presented some experimental data of older cyclists showing that the maximum value of the roll angle, the centripetal acceleration and the maximum steering angle velocity of older cyclists are larger compared to young cyclists (van den Ouden, 2011). Dubbeldam, Buurke, and Rietman (2014) investigated the coupling of cycling kinematics to physical and cognitive parameters for a large group of young (20–30 years, $n = 15$) and older cyclists (>65 years, $n = 33$). They found that variation in roll angle is related to age since the group of older cyclists showed more variation in the roll angle than the young group.

It is well-known that with aging, physiological changes take place in the human body, including decrease in muscle strength (Mitchell et al., 2012), decrease in joint velocities for knee extension and elbow flexion (Klitgaard et al., 1990) and increased reaction times (Collins, De Luca, Burrows, & Lipsitz, 1995). It is reasonable to assume that these factors play an important role in the increased accident risk for older cyclists. Furthermore, Vlakveld et al. (2015) suggested that the increase of accident risk observed in older cyclists on electric bicycles is the result of a relatively higher mental workload for older cyclists (65+ years) compared to a middle adulthood reference group (30–45 years) (Vlakveld et al., 2015).

The goal of this paper is to explore differences in cycling strategies, cycling kinematics and bicycle interaction forces of young and older cyclists in both time and frequency domain under unperturbed and perturbed conditions. Three balance strategies are investigated, namely steering, outward knee movement, and lateral trunk movement. To our knowledge, only one study used perturbations to assess the control mechanisms of the cyclists (Schwab, de Lange, Happee, & Moore, 2013). However, this study had a small sample size [$n = 2$] and concentrated on the steering movement only; all other body motions with respect to the bicycle were restricted.

An extensive dataset has been generated with the use of a laboratory set-up, which is described in Kiewiet, Bulsink, van de Belt, and Koopman (2014). The data were collected at a cycling speed of 4 m/s to ensure active control strategies, based on the computer simulations performed by Schwab, Meijaard, and Kooijman (2012), who found that for a passive cyclist, the system is unstable for velocities below 4.8 m/s. It is assumed that the characteristics of the instrumented bicycle used in the present study are similar to those used by Schwab et al.

Based on the facts that additional control actions are more important at low speeds (Cain, 2013; Kooijman et al., 2009) and that older adults have an increased delay of automatic balance-correcting muscular responses (Allum, Carpenter, Honegger, Adkin, & Bloem, 2002), the hypothesis in the present study is that older cyclists will more readily revert to recruiting additional balance strategies than young cyclists.

2. Methods

2.1. Experimental set-up

The cycling tests were performed on an instrumented Trek L200 city bicycle with a straight handlebar. The laboratory setup was based on the experimental setup described in Kiewiet et al. (2014). The front wheel rotated on a treadmill, preserving the tire-road contact and the ability to use steering corrections similar to cycling on a normal road. The rear wheel rotated on a roller bench, eliminating forward and backward motion of the bicycle. The roller bench was situated on a 6 DOF Stewart platform, allowing controllable perturbations for identification purposes (see Fig. 1).

The perturbation signal was a continuous multisine signal of 100 s (10 times a repetition of a signal of 10 s) sampled at 100 Hz. The power was distributed over a limited number of frequencies, namely: 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.8, 2.2, 2.6 and 3.0 Hz (see Fig. 2). Due to the multiple sinusoids, the signal was unpredictable for the cyclists, thus preventing anticipation of the perturbation. The signal had a descending power spectrum, containing more power at the low frequencies. The maximum amplitude was set to 1.75 cm for young subjects. Pilot testing revealed difficulties for the older subject group with this amplitude. Therefore, the maximum amplitude was set to 1.25 cm for the older subject group. The results were adjusted for the magnitude of the amplitude.

Two measuring systems, an NI-USB 6218 data acquisition card (DAQ) and the marker-based Vicon motion capture system, were used to monitor the dynamics of the system. The system measured the kinematics of the complete system of bicycle, subject and Stewart platform, contact forces between subject and bicycle (handlebars and saddle), rear and front wheel