Applied Ergonomics 51 (2015) 69–79

Contents lists available at ScienceDirect

Applied Ergonomics

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

Applying riding-posture optimization on bicycle frame design

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ARTICLE INFO

Article history:
Received 30 July 2012
Accepted 18 April 2015
Available online 19 May 2015

Keywords:
Riding posture optimization
Bicycle frame design
Image processing

ABSTRACT

Customization design is a trend for developing a bicycle in recent years. Thus, the comfort of riding a bike is an important factor that should be paid much attention to while developing a bicycle. From the viewpoint of ergonomics, the concept of "fitting object to the human body" is designed into the bicycle frame in this study. Firstly, the important feature points of riding posture were automatically detected by the image processing method. In the measurement process, the best riding posture was identified experimentally, thus the positions of feature points and joint angles of human body were obtained. Afterwards, according to the measurement data, three key points: the handlebar, the saddle and the crank center, were identified and applied to the frame design of various bicycle types. Lastly, this study further proposed a frame size table for common bicycle types, which is helpful for the designer to design a bicycle.

1. Introduction

With the improvement of living standards, the design orientation of bicycles has moved from its past significant role in the transportation field to its potential in today's leisure sports. Accordingly, customized design has become a trend in the development of bicycles in recent years. The comfort of riding a bike is an important factor that should given serious consideration when developing a bicycle. For example, Hsiao and Chou (2005) incorporated the degree of riding comfort into the design and development of an electric motorcycle, and also aimed at improving the comfort of riding on bicycle products by importing the design concept of "fitting an object to the human body".

Among numerous studies on riding, de Vey Mestdagh (1998) suggested that riding posture could be optimized by changing the height of the saddle. Peveler et al. (2007) pointed out that injuries caused in bicycle sports are mostly related to incorrect adjustment of the saddle height, handlebar and/or pedals. In addition, Laios and Giannatsis (2010) proposed an appropriate design method related to bicycle size that considered bicycle design in accordance with human body dimensions, and further examined assessment results ergonomically to re-design a series of bicycles for children aged between 7 and 14.

In the studies and development of bike riding posture, Delong (1974) and Sloane (1970) concluded that when riding on bikes with upward-bent handlebars, the upper body of the rider will be erect, shifting most of the body weight onto the saddle, thus compressing the intervertebral disks. If the body bends forward, a portion of the body weight can be shifted to the arms, enabling the backbone to be stretched, thus lessening the pressures on the intervertebral disks. Kolehmainen et al. (1989) argued from a different point of view, and stated that the upward-bent handlebar can help lessen the pressure on cervical vertebra. Richmond (1994) and Matheny (1992) found that if the height of the handlebar is too low, it will increase the probability of oppression on the nerves around the haunch, as well as symptoms caused by overuse, such as health problems involving women's pudenda or men's prostate areas.

On the other hand, Wu et al. (1998), when exploring the influences exerted by vertical vibration over the pressure distribution on the interface between the human body and saddle, found that for those with heavier body weights, the effective contact area on the saddle should be increased to reduce the pressure on the ischium. Christiaans and Bremner's study (1998) proposed that the saddle of a racing bicycle should not be ridden in an erect posture due to this posture creating the greatest vertical pressure, which increases the probability of saddle sores. Diefenthaeler et al. (2008) concluded that when riding, the average angle of the trunk is 38° (±5°), the average angle of the lumbar is 57° (±6°), and the spinal bent angle is 149° (±8°). Adding to this, Mellion (1991) suggested that the rider should keep a forward-bending posture, but not an over-stretched posture, over long periods of riding since in

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http://dx.doi.org/10.1016/j.apergo.2015.04.010

comparison with the bending posture, a stretching posture poses less pressure on the neck, lower back, arms, palms and shoulders. Furthermore, a stretching posture enables the extension of the thorax, enabling smoother breathing. de Vey Mestdagh (1998) also put forward a similar concept, which held that the vertebras are supported when the pelvis is bent forward, thus enhancing the riding momentum.

In addition, taking biomechanics as the starting point, Christiaans and Bremner (1998) attempted to measure and analyze the riding dimensions of the human body by using an adjustable bicycle model. Then, by measuring the bike in a dynamic way, they obtained the most suitable sizes and joint angles related to riding. In Silberman et al.'s (2005) view, most people generally accept that riding efficiency and comfort depend on the bicycle design, but having a bicycle that fits is the most important. Schwellnus and Derman (2005) pointed out that some of the most common health problems and troubles are caused by incorrect riding postures. Later, Diefenthaeler et al. (2008) performed a riding assessment study on midsagittal trunk kinematics, which has had milestone significance in the anatomy of the lowest ribs, and is now used to calculate the tilt angle of the trunk, the bent angle of the spine and tilt angle of the lumbar. Bressel et al. (2009) focused on exploring the influences of various bike saddle designs on saddle pressure and stability perception, and showed that these two factors are negatively correlated.

Human computer-aided motion capture has become a commonly used method in recent years (Thomas and Erik, 2001, Thomas et al., 2006). Due to the enhanced efficiency of computers, the acquisition of images has become very easy. In this manner, applying a hierarchical Part-based method to conduct human body pose estimation was beneficial to efficiency and accuracy of estimation (Navaratnam et al., 2005). The meaning of objectives' behaviors were able to be recognized and estimated by the acquired body actions through the set conditions, because human actions were logic related (Cristian et al., 2006). Furthermore, useful information was able to be acquired by the analysis of computer vision for the detected human actions, which enhanced the determination of each decision and analysis (Ronald, 2007). Nowadays, more complete human motions are able to be real-time captured through depth cameras (Wang et al., 2013; Aggarwal and Xia, 2014), especially for 3D information of the human skeleton. This diversified the application of the related field. Even though more complete information is able to be acquired with depth cameras, considering the accuracy of detection for points of human features, a system for detection of feature points based on 2D images was then constructed.

In this study, three common bicycle types were selected, namely, the racing bicycle, city bicycle and lady's bicycle, to discuss the frame sizes for different bicycle types and for different human body dimensions in regard to the best riding posture. Firstly, the important riding-posture feature points were automatically detected by the image processing method. In the measurement process, the best riding posture was identified experimentally; thus, the human body's feature points and joint angle positions were obtained. Afterwards, according to the measurement data, three key points, the handlebar, the saddle and the crank center, were identified and applied to the frame design of various bicycle types. Lastly, this study further proposed a frame size table for common bicycle types, which could be used as a guide in the design bicycles.

2. Study method

2.1. Definition of feature points

This study used a branch map to illustrate the rider's riding posture on a bicycle, as shown in Fig. 1. The defined feature point

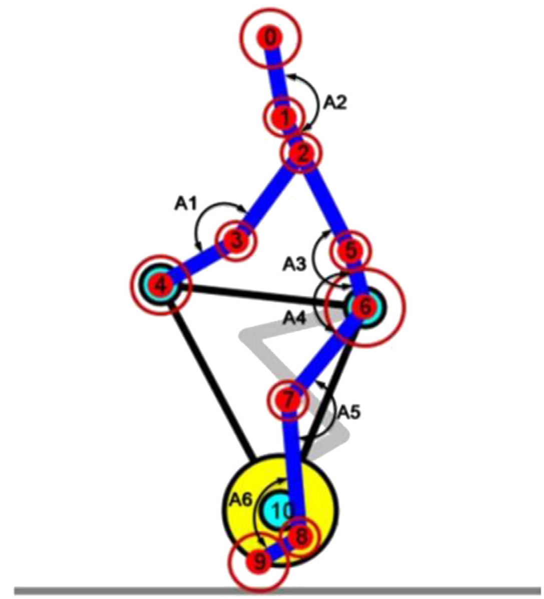

Fig. 1. Positions of feature points and their feature angles formed when riding.

positions mainly included: the head (0), neck (1), shoulders (2), elbows (3), hands (4), waist (5), inguinal region (6), knees (7), ankle bones (8), and soles (9), which are all marked with red (in the web version) points. Simultaneously, the three feature points on the bicycle frame were the handlebars (4), the saddle (6) and the crank centre (10). The design of the relative positions between the three points would determine the final frame-size design. Among all feature points, points 4, 6 and 9 are the places where the human dimension and frame size interact with each other. It is from these points that the comfortable riding-posture degree could be measured, thus yielding the frame-size design.

In addition, based on the interrelationships formed between feature points, this study defined six feature points related to the degree of comfort, to analyze and understand the relation between feature angles and degree of comfort. The definitions of the feature angles are shown in Fig. 1. A1 signifies the elbow angle formed by 2-3-4; A2 the neck angle formed by 0-1-2; A3 the waist angle formed by 2-5-6; A4 the sciatic angle formed by 5-6-7; A5 the patellar angle formed by 6-7-8; and A6 the malleolar angle formed by 7-8-9. Since this study mainly measured the relative positions of each feature point on a projection plane, the above mentioned feature angles refer to the angles formed by each feature point on the projection plane, and the value of each angle could be calculated by the vector inner-product in Formula (1).

$$\theta = \cos^{-1}\left(\overrightarrow{u}\cdot\overrightarrow{v}/|\overrightarrow{u}|\cdot|\overrightarrow{v}|\right) \quad (1)$$

where θ refers to the value of the angle formed by two vectors, $\overrightarrow{u}$ and $\overrightarrow{v}$. After further summary and analysis, the causal relationship between the factors and comfortable degree in riding could be obtained.

2.2. Definition of bicycle frame size

A schematic of bicycle frame size obtained from the riding experiment is shown in Fig. 2. Generally, the three key feature points: handlebars, the saddle and the central crank, were used as the kernel to mark the frame size. A represents the vertical distance from the saddle to the ground; B the vertical distance from the