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Ergonomic evaluation and redesign of children bicycles based on anthropometric data

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ABSTRACT

Proper bicycle fit is very important for cycling performance, efficiency, comfort and injury prevention. This is especially true in the case of children cyclists that do not have the necessary cycling experience, balance and the fully developed musculoskeletal system of the adults. Bicycle fit depends on both the design and dimensions of the bicycle as well as on the anthropometric dimensions of the cyclist. In the present paper a case study concerning the ergonomic evaluation and redesign of a series of bicycles for children and teenagers 7–14 years old is presented. The study has been commissioned by a major Greek bicycle manufacturer who wanted to gain competitive advantage by introducing new anthropometrically-designed bicycles. Employing virtual modelling techniques and the method of Principal Component Analysis, bicycle affordance for selected representative cases and various bicycle sizes has been examined. Based on the results of the study redesign recommendations that improved bicycle fit for specific groups were proposed and a formal bicycle size selection method has been defined. The redesigned bicycles are now in full production and distribution is underway in many commercial outlets in Greece.

1. Introduction

Bicycles are the most common and widely used human powered vehicle around the world. Cycling is nowadays considered not only an efficient and healthy means of transportation but also a popular recreational and sport activity. The expansion of cycling over the last 50 years led to various bicycle designs, like sport/road bicycles, mountain bicycles, BMX bicycles, standard 'utility' (commuter) bicycles and more recently the hybrid bicycle (Wilson, 2004). All of the above mentioned bicycle types are specialized variants of the basic diamond frame bicycle, each one designed to meet the specific needs posed by the intended use of the bicycle. These needs and constraints are usually associated with cycling efficiency, power, safety and comfort and their relative importance for the intended bicycle application.

It is widely accepted that cycling efficiency and comfort depend not only on bicycle design but also on bicycle fit (Silberman et al., 2005; De Vey Mestdagh, 1998). Bicycle fit involves the selection of the appropriate frame size and subsequently the adjustment of various dimensions, like the seat height or fore-aft position according to the anthropometric dimensions the cyclist, so that the best posture for the intended bicycle application can be obtained. Bicycle size is defined mostly by the size of the frame and it is usually referred by the corresponding wheel size or the seat tube length, depending on the manufacturer.

Absolute bicycle fit is also very important for injury prevention (Baker, 2000). Some of the most common health problems and annoyances associated with cycling can be attributed to poor bicycle fit and wrong cycling posture (Mellion, 1991; Schwellnus and Derman, 2005). These problems are usually observed at three areas of the human body, namely the neck, the lower back and the lower limbs and most often the knee (De Vey Mestdagh, 1998). Different handlebar positions, for example, affect spinal curvature as well as the load imposed on the back/neck area and can, therefore, be associated with annoyances in these areas (Kolehmainen et al., 1989). In the case of bicycles for children, proper bicycle fit is of highest importance for both safety and injury prevention (Nemours Foundation, 2006). Safety is extremely important for relatively young children that do not have the cycling experience and are therefore prone to accidents. Furthermore, children of all ages do not have a fully developed musculoskeletal system which implies that cycling discomfort can be more apparent and cycling injuries may have more severe and possibly permanent consequences. Besides safety and injury prevention, cycling comfort should also be a major issue in the design of children bicycles not only because they represent a significant market segment but also

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because of their future potential as customers of the bicycle industry. It can be reasonably argued that the feeling of discomfort during cycling prevents the frequent use of bicycles (Christiaans and Bremner, 1998). Since cycling habit is usually acquired in the younger ages, from childhood to puberty, it is obvious that the corresponding bicycles should provide maximum accommodation and comfort to encourage the use of bicycles and cycling in general.

Because of the wide variance in anthropometric dimensions between children, even of the same age, bicycle manufacturers offer a series of bicycles of various sizes. The design of these bicycles involves the definition of frames of different size and dimensions as well as the definition of the corresponding adjustment ranges for the seat and the handlebar. In order to fully accommodate the majority of possible users, the design of the bicycles should be based on data that take into account the distribution of anthropometric dimensions among the children. It is not uncommon among bicycle manufacturers to define the frame dimensions of the children' bicycles, as well as the allowable adjustment range for the various components, according to assumptions regarding the dimensions of the children. According to the designers of the examined bicycles, these assumptions were mostly based on prior experience and data from other non-Greek bicycle manufacturers. This practice, obviously, does not take into account the vast individual differences in the anthropometric dimensions of the Greek children.

In the present study the ergonomic evaluation of the design of a series of child bicycles, produced by a major Greek bicycle manufacturer, based on Greek children anthropometric data is presented. This evaluation involved the control of the geometry and dimension of the bicycles' frames as well as the control of the permissible adjustment range for the saddle and the handlebar, with respect to the specific population. The objective of the study was to investigate the affordance of the present bicycle design for the investigated population and if necessary to redesign the bicycles so that the best possible fit could be obtained, thereby increasing cycling safety and comfort for the young cyclists.

2. Methodology

Following the basic guidelines proposed by the Human Factors and Ergonomics Society (HFES) for the application of anthropometric data on product design (HFES 300 Committee, 2004) the study involved three basic steps:

1. Problem statement, which includes target population definition, task analysis and the identification of critical design parameters and relevant anthropometric dimensions.
2. Collection and analysis of anthropometric data of the target population and the selection of representative case studies.
3. Investigation of the selected case studies and analysis of the corresponding results.

The constraints that should be considered in bicycle design can be classified into four categories, namely clearance, reach, strength and posture constraints. Clearance constraints ensure that the bicycle design and dimensions allow the adjustment of the posture and free movement of the limbs, especially for the members of the target population with the largest anthropometric dimensions. Reach constraints on the other hand define the minimum acceptable limits for basic bicycle dimensions that are imposed by the users with the smallest anthropometric dimensions. Strength constraints are associated mainly with the use of specific components that require a certain amount of force to be applied, like the brakes or the pedal. The amount of force required depends on the design characteristics of the components themselves but also on their relative position in the bicycle design.

Posture constraints define the angles between the anatomy parts of the cyclist and its relative position on the bicycle (De Vey Mestdagh, 1998). The cycling posture is a very important parameter in terms of power production, energy efficiency, cycling comfort and injury prevention and hence has been the subject of many studies. Most of the studies related with bicycle fit focus on competitive cycling (racing or trail cycling) and the relationship between posture and power maximization, energy efficiency and prevention of injuries which can be caused through long periods of cycling (Berry et al., 2000; Dal Monte et al., 1987; Hull and Gonzalez, 1988; Too, 1990; Yoshihuku and Herzog, 1990). The relationship between posture and the cyclist's feeling of comfort or safety, which is probably the main issue in every-day cycling and the design of commuter bicycles, has been less studied (Christiaans and Bremner, 1998). Comfort is a concept of rather subjective nature but it can generally be defined as the absence of pain and any other similar nuisance and is usually associated in the relevant literature with the design and adjustment of the saddle (Bressel and Larson, 2003; Groenendijk et al., 1992).

All aforementioned studies were conducted on or consider adults who, as it can be reasonably argued, ride bicycles differently from children or teenagers. In their study, Donkers et al. focused specifically on bicycles for relatively young children and assessed their design and dimensions in terms of fit to the Dutch children population and the associated safety regulations (Donkers et al., 1993). According to their findings designers should relate the bicycle dimensions to stature and not the age of the child. Based on the results and recommendations by Donkers et al., as well as on the results of the most relevant of the adult studies (Baker, 2000; Christiaans and Bremner, 1998; De Vey Mestdagh, 1998) and international practice (Bikefitting.com, 2006; White, 2006) the reference cycling posture has been defined (Fig. 1a and b). The main guidelines that have been adopted for the construction of the reference posture are:

- The child should be slightly leaning forward, approximately 15° in respect to the vertical axis. This leaning of the upper body increases the respiratory volume because it transfers part of shoulders weight to the arms and reduces the load to the lower-back area, without overloading the arms and the wrists.
- The knee angle (the angle between the thigh and the crus) should not be more than around 150° when the pedal is in the bottom dead centre position and no less than 65° when the pedal is in the top position. This constraint prevents knee problems due to excessive stretching and flexing of the knee.
- The arms should be slightly bent in the elbows, i.e. the angle between upper and lower arm should be about 20° to reduce the effect of possible vibrations to the shoulders. Furthermore the handlebar should be wider than the shoulders width for better steering.

The above guidelines define a relative up-right posture that is assumed to favour comfort compared to the low bending posture of race cycling that favours cycling performance in terms of speed and endurance. Although, the riding posture of children can be different from the posture of adults, for the purposes of the present study the reference posture has been selected on the bases of safety, comfort and control for commuter cycling in urban and high-traffic areas.

The extent at which the above posture can be obtained by a specific cyclist depends on the bicycle design and of course the cyclist's anthropometric dimensions. In Fig. 1c the critical bicycle dimensions that were examined in the present study are schematically presented. These dimensions are: