ANALYSIS OF HUMAN FACTORS ISSUES RELATING TO THE DESIGN AND FUNCTION OF BICYCLES

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Abstract

The cycling industry is now the largest sporting goods market in the world, with global sales of £28billion (€33 billion) amounting to 15% of all sporting goods revenue. There is a large body of research relating to bicycles and cycling related activities and mostly these relate to the common diamond “safety” framed bicycles, although there are clear performance benefits associated with recumbent bicycles. There are a number of areas that could benefit from direct input from ergonomic design experts, including the redesign of braking grips for drop handlebars on road bicycles, and the verification and validation of products for specialist performance. Fundamentally the design of bicycles for human wellbeing and performance comes into question with the ubiquity of standard upright "safety" bicycles when compared with the performance and ergonomic benefits of recumbent bicycles.

Introduction

In 2010 the cycling industry became the largest sporting goods market in the world, with global sales of £28billion (€33 billion) amounting to 15% of all sporting goods revenue and approximately 137 million bicycles (including electric bicycles) sold that year (NPD group, 2011). Recent victories for British athletes in high profile events such as the 2012 and 2013 Tour de France and the 2012 Olympics have ensured that cycling is one of the top sports in the UK. Cycling is the fourth most popular sport in the UK in terms of weekly participation with just under 1.9million people cycling each week compared with swimming which is the most popular sport at almost 2.9 million participants (Sport England, 2013). Over £26m was invested for the 2012 Olympic cycling team through UK sport, second only to rowing (UK Sport, 2013). There is considerable evidence of increasing participation and interest in cycling (Grouse, 2011), and the UK has seen the National Cycling Network grow from 5,000 miles in 2000 to over 12,000 miles in 2013 (Sustrans, 2013).

There is a large body of research relating to bicycles and cycling related activities. Mostly these studies relate to the common diamond “safety” framed bicycles, ranging from the biomechanics and physiology of cycling, design requirements and manufacturing technology of bicycles, injury prevention and safety of cyclists, and the ergonomic and anthropometric requirements of cyclists. From a human factors perspective, much of this research appears fragmented as it draws from various subject areas with pockets of large amounts of very specific research in some areas, and gaps elsewhere with less research focus. The aim of this paper is to bring much of this research together, along with an analysis of the bicycle designs and their components as part of a literature and product review of the design and use of bicycles from a human factors perspective. Our research question is: “to what extent has the bicycle design been optimised for human wellbeing and performance, according to a standard defined goal of ergonomics (Dul and Weerdmeester, 2003). This review has been broken down into analyses of research and products relating to the user and the task according to the BS ISO EN standard for Ergonomics (BS EN ISO 26800:2011), using subheadings and key questions from the ergonomic approach suggested in Dul and Weerdmeester (2003).

The user

Biomechanical, physiological and anthropometric factors

Men dominate cycling in the UK, setting out on 70% of all bicycle trips -for comparison in the Netherlands the roles are reversed where men undertake only 45% of all bicycle trips (Grous, 2011). The key reasons why women cycle more in northern Europe are safety and accessibility to appropriate cycling infrastructure (e.g. bike lanes and parking) (Grous, 2011). There is an “under-representation of women in cycling journeys, which is believed by some to have ‘turned a corner’ as more women look to cycling within their local communities” (Grous, 2011, p8). The dominance of men in the UK cycling scene is reflected in (perhaps exaggerated by) the dominance of male specific bicycles that are available on the market. We analysed four major online bicycle stores in the UK in terms of the number of bicycles on offer specifically for men and women (although some stores forgo the classification of bicycles for males and instead use “unisex” as the alternative option to bikes for females). Female specific bicycles currently available in these stores make up only 21% of the total bicycles available. For adult bicycles, this figure drops to 19%, for adult hybrid/city bicycles this is 38%, and for adult road/MTB bicycles this is only 12%. Overall it seems the proportion of female specific bicycles on the market (19%) is below that of the proportion of UK cyclists who are female (30%) (Grous, 2011), and this could be a result of the female market being under represented, or simply it is a response to female riders preferring to ride men's bicycles.

There are many basic requirements for users of bicycles ranging from the ability to store, ease of maintenance, ease of cleaning, ease of disassembly, comfort when riding, ease of mounting, specific gear ratios for climbing and descending, protection from road spray, visibility in traffic or at night, security and so on. Clearly these differ depending on whether the user is riding for sport, riding for pleasure or riding for transport, although this paper does not cover these specifically. Instead we focus on some of the fundamental requirements that relate most significantly to the human wellbeing and performance associated with riding a bicycle.

Table 1: Analysis of male and female bicycle models available at four large UK stores.

		Female	Male	Total	% Female
Chainreaction (female vs male)	Road	12	121	133	9%
	MTB	18	235	253	7%
	Hybrid/city	36	67	103	35%
	Kids	25	27	52	48%
Wiggle (female vs unisex)	Road	11	126	137	8%
	MTB	4	57	61	7%
	Hybrid/city	12	33	45	27%
	Kids	4	4	8	50%
Evans (female vs unisex)	Road	74	373	447	17%
	MTB	58	402	460	13%
	Hybrid/city	115	200	315	37%
	Kids	24	46	70	34%
Halfords (female vs male)	Road	2	76	78	3%
	MTB	29	70	99	29%
	Hybrid/city	47	49	96	49%
	Kids	32	38	70	46%
TOTALS (all)		503	1924	2427	21%
TOTALS (adults only)		418	1809	2227	19%
TOTALS (adults hybrid/city only)		210	349	559	38%
TOTALS (adults road/MTB only)		208	1460	1668	12%
TOTALS (kids only)		85	115	200	43%

The process of fitting bicycles, including saddle position relative to the pedals, head and upper body positions relative to the stem have been covered in great detail in the literature (Kolin and de la Rosa, 1979; Burke, 1994; Burke, 2003). In the more recent literature, further guidelines are provided for setting handlebar heights, adjustments for leg length discrepancies and setting crank lengths, cleat and foot position adjustments and handlebar adjustments (Burke, 2003; Silberman et al 2005). Many of these are supported by research using wind tunnel tests and power tests to analyse the efficiency and effectiveness of (mostly experienced) riders in various positions on the bicycle (Burke, 2003). Alternative methods and details of tools, software and measuring techniques are provided for fitting bicycles to riders (Burke, 1994; Burke, 2003; Silberman et al 2005), not to mention the myriad of websites with guidance and the many professional fitting services that are now available across the country.

The task

The basic functional task of riding the common diamond "safety" framed bicycles of today has developed little since the days of Starley's Rover safety bicycles in 1885 (Wilson, 2004). While the functionality of components, the quality of materials and manufacturing, the inclusion of pneumatic tyres and derailleur gears and the standardisation of components and operation have all vastly improved the usability of bicycles, the basic functionality of direct steering, variable-ratio transmission of chain driven bicycles remains intact.

Factors related to posture: sitting and general performance

While the diamond framed bicycle dominates the commercial world of bicycles (including track, road, touring, commuter, mountain, bmx bicycles), other models do exist which have been "relegated to the fringe" (Sorenson, 1998), while others (e.g. the folding bicycle) have carved out niches of their own. The recumbent bicycle (available in short/long wheel base and trike options) is considered to have advantages over the upright diamond framed bicycles in a number of categories including reduced frontal area (improving aerodynamics), safer head (i.e. behind the body) and body (i.e. lower to the ground) positions, improved visibility (with the head naturally facing forwards), comfort (with the head in a natural forward facing position, the seating position reducing the likelihood of localised saddle related sores and the lower back and wrists are in more anatomically neutral positions) (Ballantine, 2000; Wilson, 2004, Burrows, 2008). Figure 1 highlights the basic differences in design and posture associated with a standard diamond framed road bike (left) and a recumbent bike (right). While there are clear advantages in some areas, the recumbent position has the disadvantage in that it may not allow for peak power production and sustained aerobic performances as those obtained in the upright "safety" position (Kolin and De La Rosa, 1979; Reiser, 2000). Other more practical disadvantages are the higher baseline cost of recumbents and that they are generally longer and often more cumbersome to store (although generally less wide than most mountain bikes). A common objection to recumbents is the perception that they are unsafe in traffic. We use the term perceived, since we could find no specific evidence in a literature search on bicycle related injuries and cycling accident risks on the risk factors associated with recumbent bicycles, however some studies provided some implicit insights into the effect of speed (Peden et al, 2004; Kloss et al, 2006; Kwan and Mapstone, 2009), and visibility (Thompson and Rivara, 2001; Kloss et al, 2006; Thornley et al, 2008; Kwan and Mapstone, 2009; Washington et al, 2012) on the risks associated with cycling which are relevant to recumbent riding. In theory the lower visibility and increased speeds associated with recumbents makes them even more vulnerable in urban environments, although it is disputed that this may be offset or even overcome on the basis of riding skill, experience and technique (Ballantine, 2000, Burrows 2008).

Figure 1: The differences in design and posture associated with a standard diamond framed road bike (left) and a recumbent bike (right). Images from http://www.jimlangley.net (left), http://venturecyclist.blogspot.co.uk (right).

Regarding the use of saddles in the most common upright bicycles, clearly there is much evidence regarding the influence of saddle height on power output from the rider (Too, 1990; Burke, 2003). One trend that seems to be emerging however are claims from saddle manufacturers relating to improved power output, impact absorption and other performance measures with no supporting evidence available on their websites or references to published work on the studies conducted. A recent study by Heneghan et al (2012) began to assess the evidence underpinning sports performance products with a rather damning conclusion such that: “The current evidence is not of sufficient quality to inform the public about the benefits and harms of sports products. There is a need to improve the quality and reporting of research". Whilst there is much evidence surrounding the general fitting, biomechanical and physiological aspects of cycling, including the problems associated with saddle pain, discomfort and other symptoms (Keytel et al, 2002; Bressel & Larson, 2003; Partin et al, 2012) there is often a lack of published data relating to the performance, comfort and behaviour of specific products even where benefits or advantages are explicitly claimed.

Factors related to posture: gripping

With more recent focus on women cyclists, the ability for females and smaller males to grip brake levers -which is a fundamental requirement of riding a bicycle, has been shown to be inadequate. As one rider (Jami) claims “I don’t feel confident with my brakes because I have to strain to reach the brakes when I’m in the drop bars. Gripping the brakes on the hoods is also tiring because the levers are out so far” (McKee, 2010). Apart from a few smaller components that are now more suitable for women and men with smaller hands, typical solutions are simply adjustments that can be made to the component from the “male” default, e.g using a shim within the brake lever or make adjustments from the default setting, softening brakes to bring the actuation point of the brakes closer to the bar allowing the braking action to occur in a closed position, but as McKee puts it: “the only problem is that it doesn’t really address the real root cause of the problem and that is that I can’t reach my brake levers easily”, followed by a disclaimer that “This is NOT a long term fix, for some people it may work. But there can be safety concerns if the brakes are not perfectly adjusted” (McKee, 2010). It seems the designs of braking components need a rethink, to allow for more inclusive solutions for riders with smaller hands and fingers, and to improve wrist and finger positioning on drop handlebars.

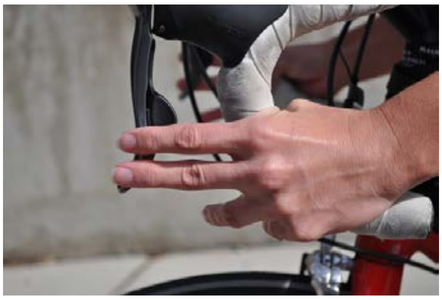

Figure 2: Extended fingers on braking levers can cause strained wrist and fingers joints especially for longer rides. Image from http://cycleandstyle.com.

Factors related to information and operation

There has been much progress in terms of information afforded to the rider and in terms of operation of a bicycle. The moving of gear levers from the downtube to the handlebars (e.g. Shimano Total Integration (STI) shifters) has allowed users to operate without looking down at ill placed gear levers, which also ensures both hands can be kept on the handlebars. Perhaps the biggest impact on safety however is that the fingers and hands are kept away from the moving wheel during this operation. Furthermore, an important milestone for the affordance of gear shifters has been greatly improved by the inclusion of optical gear display systems to display current gear status rather than looking down at the drivetrain to assess the combination of gears (see Figure 3).

The standardisation of components and tools required to support the ease of maintenance and affordability of bicycles has come a long way in recent years. The use of Allen keys and standard components makes maintenance of most bicycles more straightforward and intuitive. There remain issues however with some awkward tasks, for example the alignment of brake pads which sit on spherical seatings for cantilever brake pads can be problematic and similarly the installation of a front derailleur installation, both requiring a skilful technician or even a "third hand" product to support the action.

There are also potential issues with such expensive high end specialist components that there is a reluctance to adjust/handle because of fear of damage. In some cases components are so lightweight they are damaged easier, either during general maintenance or use. Similarly, the use of specialist performance components (e.g. deep rims), makes maintenance difficult or cumbersome (e.g. requires the tyre to be taken off in order to true the wheel).

Figure 3: Progress in gear shifters now allows more affordance in their design, with road (left) and mountain bike (right) shifters containing an optical gear display. Images from http://www.leisurelakesbikes.com

Conclusion

Clearly there has been much progress in terms of the ergonomic interface of many bicycle components and the bicycle frames themselves. There is however a number of areas that could benefit from direct input from ergonomic design experts, including the redesign of braking grips for drop handlebars on road bicycles, and the verification and validation of products for specialist performance and comfort. Fundamentally the design of bicycles for human wellbeing and performance comes into question with the ubiquity of standard upright bicycles when compared with the performance and benefits of recumbent bicycles since recumbents offer clear ergonomic advantages in many respects.

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