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Application of the TRIZ Innovation System Method to Bicycle Handlebars

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Abstract: This study investigated the application of the TRIZ innovation system method to bicycle handlebars and used a satisfaction survey to evaluate whether the bicycle handlebars met the users' requirements, in order to reduce the cost and time needed for product development. First, we conducted a literature search and expert consultation, to explore the improvement requirements for handlebar design and bicycle motion injury; then, we used a contradiction matrix and the invention principle of the TRIZ method for analysis and design; and finally we used a human–machine system and the human measurement method of human factor engineering to analyze the user and bicycle handlebar operation and related dimensional definitions, as a reference for the design and to make a prototype bicycle handlebar. The SERVQUAL questionnaire was developed to compare the differences between the designed bicycle handlebar prototype and commercially available bicycle handlebars, and a practical analysis of the design was conducted using a two-dimensional quality model (Kano model) and the important–performance analysis method (IPA). Research results: 1. Innovative design of the bicycle handlebars: the development of height adjustment slots, front and rear angle design, front and rear swivel left and right extension mechanism, the user can clearly determine the current position and adjust to the most comfortable position to avoid waist, cervical vertebrae, and arm injuries. 2. Satisfaction assessment of bicycle handlebar innovation design: analyse the importance and satisfaction of bicycle handlebar innovation design, determine the production time and mass production value of the product, use questionnaires to conduct IPA and Kano model cross-analysis matrix, in order to reduce the time and cost required for product development.

Keywords: bicycle handlebar; human factors engineering; TRIZ; IPA; Kano model

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1. Introduction

Global warming and greenhouse effect has become an important problem for human beings in today's society, and "carbon reduction and energy saving" has become a hot topic nowadays. Bicycle is not only a means of transportation, but also a popular product for sports, fitness, leisure and entertainment [1]. To meet different needs, different types of bicycles and corresponding handlebars have been developed, and the commonly used handlebars can be broadly classified as top, flat or bottom [2,3]. Bicycle use involves long rides, repetitive movements and high stationary positions. Improper movement and posture, or inappropriate cycling accessories, can cause discomfort to the body parts involved, and in severe cases, even muscle or nerve damage [4]. There are many different types of bike handlebars, but most do not have the ability to adjust posture, determine and change height angles to suit the different heights and arm lengths of users.

2. Literature Review

This study was conducted to investigate the possibility that cyclists who maintain the same posture for a long period may be immobile for too long, resulting in sports injuries. First, we collected information on the available types of bike handlebar. Types of bicycle handlebar, prolonged fixed posture, and sports injuries formed the basis of this study. Then human factors engineering methods, TRIZ innovation methods, and universal design methods are applied to the innovative design process, and actual design analysis is performed using IPA and Kano modeling methods.

2.1. Literature Review of Bicycle Models and Handlebar Types

From ancient times to the present day, the development of bicycles has given rise to a wide range of bicycles. According to the needs of the bicycle rider, they have different functions and offer a wide range of bicycles for people to use [5–8], as shown in Table 1. The corresponding handlebars are not consistent between the different vehicle types, but are mainly either uplifted, straight, or downward [2], as shown in Table 2.

Table 1. Types of bicycles.

Bicycle Type	Function
Road Racing	Suitable for riding on tarmac.
Mountain Bike	A bike designed for forest roads and recreational sports needs.
Multifunctional Bike	A racing and recreational bike, with front and rear shocks for different race courses.
Downhill Bike	A race bike, where most of the races are downhill oriented.
Course Bike	A stunt bike that races mainly on obstacle courses.
Technical Bikes	A bike for performing special techniques and not suitable for racing.
Folding Bikes	A small folding bike that is easy to carry.
General Commuter Bike (Lady Bike)	A bike that is used by the general public for commuting. No special design, more attention to aesthetics and practicality.

Source: self-drawn.

Table 2. Bicycle handlebar types.

Bicycle Handle Types	Function
Uplift type	The handlebars are raised on both sides, and the angle between the grip and the handlebar axis is about 45 degrees, suitable for recreational bikes.
Flat type	Handlebar and grip set on the same axis up, suitable for off-road and mountain bike use.
Downward type	The handlebars are bent downwards on both sides, allowing the user to lean forward and reduce the area of wind exposure when riding.

Source: self-drawn.

2.2. Literature on Sports Injuries

Recent years, cycling has become increasingly popular, not only for cardiopulmonary exercise, but also for medium aerobic exercise, to improve muscle strength and muscle endurance, as well as to enjoy the thrill of riding and enjoying the scenery along the way. The both serious and casual riders, if the riding posture is incorrect, it is easy to trigger soreness or cause sports injuries. As each handlebar of a bicycle has a different stance, this can affect the activation of muscles in the upper body if used on different surfaces for long periods of time, which can lead to injuries [3]. For example, entrapment neuropathy, also known as handlebar palsy, is a condition in which the most common nerves under pressure are the ulnar and median nerves, and is characterised by sensory disturbances. This is mainly due to prolonged gripping of a bicycle handlebar, which compresses the ulnar nerve or the median nerve in the carpal tunnel [9], as shown in Figure 1 [10].

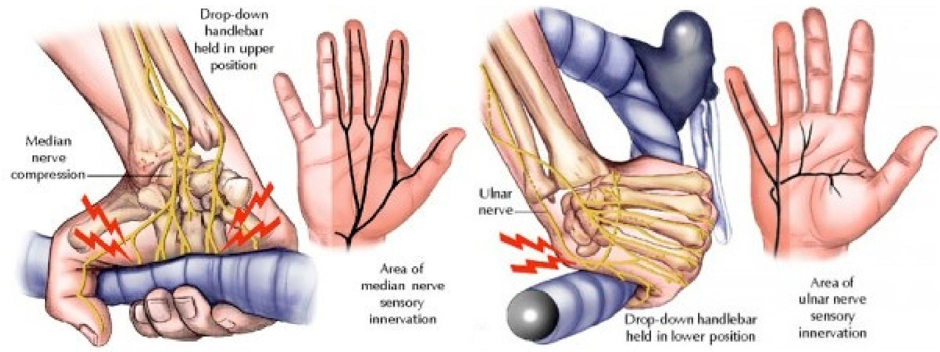

Figure 1. Schematic diagram of ulnar nerve compression. Source: Eckman, Perlstein, and Altrocchi (1975).

2.3. TRIZ Method Literature Review

One of the main uses of TRIZ, which can resolve relatively minor inherent design conflicts in research cases, is to recognise the difficulties that arise when using the theory to solve complex problems [11–14]. Genrich Altshuller developed the Theory of Inventive Problem Solving (TRIZ) when he observed and drew up a model of inventive thinking used by the former Soviet Patent Office [15]. In short, TRIZ is a set of tools for guiding creative thinking while avoiding repetitive experimentation [16,17]. TRIZ can identify contradictions in the invention and creation process and then provide solutions [18]. In the TRIZ contradiction matrix, the parameters that you want to improve without making compromises are listed in the first column, and the parameters that you do not want to worsen are listed in the first row [19–22]. TRIZ provides 39 general engineering parameters and 40 inventive methods as solution patterns, to help find specific solutions [23–26]. The first two parameters are input into a contradiction matrix and a junction, both of which contain TRIZ solution quotes extracted from 40 inventive methods [27]. For those seeking a more in-depth explanation of the TRIZ principles used here, we recommend Cameron's book [28].

The product design and development phase aims to simplify all production and assembly processes, shorten the development time, reduce costs, increase production efficiency and reduce the learning time required for customers to adapt to new products and make them easy to use. The process of introducing TRIZ innovation principles into the application of generic component design can also generate associations and inspiration for creators within the limited constraints of generic components, and by applying generic component design elements to achieve functional and aesthetic values [29].

2.4. Human Factors Engineering Literature

Human Factors Engineering aims to discover knowledge of human behaviour, capabilities, limitations and other characteristics that can be applied to the design of tools, machines, systems, tasks, jobs and environments [30,31]. Formative Human Factors (HF) assessment is an important activity in control room design. Its purpose is to provide design feedback, preferably as early as possible in the development process to reduce the risk of late and suboptimal design changes. As design decisions made as the development process progresses become progressively more specific, early evaluation requires assessment of higher-level design decisions [32].

In order to improve the situation of musculoskeletal injuries in the workplace, advanced human factors engineering improvement methods were used to improve certain operations at the workplace in the energy industry, to reduce the risk of labor musculoskeletal injuries in that operation; and the result could be used as a case study of human factors engineering improvements for the workplace safety of personnel in a business unit. [33]. In addition, in long-term care facilities addressing complex medical problems, the human factors engineering approach has been used to address patient safety issues and develop interventions to support the health care work system (i.e., tools, technologies, tasks, organisation, and physical environment), which can lead to improvements in processes (e.g., adherence to infection prevention guidelines) and outcomes (e.g., reduction in infection rates) [34].

2.5. Literature on Universal Design

The philosophy of Universal Design aims to create an inclusive and sustainable society in which everyone can participate as much as possible [35]. With the rapid growth of the elderly population, it is the responsibility of designers to provide products that meet the needs of this aging population [36]. There are many products that use universal design, such as double-opening refrigerators that make it easy for left-handed people to open the refrigerator door, tumble dryers that make it easy for people of all heights to pick up clothes, and pocket knives that can be used in all kinds of situations to make life easier [37].

In addition, Universal Design for Learning (UDL) is a framework for scientifically effective educational practice that emphasises that students with different learning needs, regardless of their cognitive and sensory abilities, have access to the same resources and receive the same amount of information. It not only facilitates the delivery of information through assistive technology, but also allows for greater choice and adaptability in curriculum, materials, teaching, activities and assessment, effectively reducing the need for teaching teams to adjust, revise and find alternatives afterwards to help all students achieve their intended learning goals [38,39]. Given the importance of achieving social justice, UDL is a more promising approach that can more effectively meet the needs of all learners. The framework of Universal Design is also reflected in the EU's transport policy, which aims to ensure the rights of passengers with reduced mobility. However, local standards for public space and transport infrastructure vary considerably and specific cities choose different strategies to improve public transport accessibility [40].

2.6. Importance & Performance Analysis (IPA)

Martilla and James introduced the concept of Importance & Performance Analysis (IPA) in 1977. It is a method for measuring service quality and is widely accepted for its simplicity and stress-free nature. Each question in one of the scales has two dimensions, 'importance' and 'satisfaction', and the total mean of these two dimensions is set as the central point, with the vertical axis being importance from low to high and the horizontal axis being satisfaction from low to high [41]. The four quadrants represent different service quality management problems and improvement strategies [41,42].

IPA quadrants.

1. Quadrant I (keep up the good work): Items located in this quadrant indicate that customers score higher than the overall average for the satisfaction and importance of the item and are 'Keep Up the Good Work' items, which are a competitive advantage in the company or organisation's primary market.
2. Quadrant II (Possible Overkill): An item in this quadrant indicates that the customer satisfaction score for this item is higher than the overall average, but the importance score is lower than the overall average, which is a 'Possible Overkill', meaning that the company or organisation may be devoting too much resources to this item and may try to reduce the resources devoted to it.
3. Quadrant III (Low Priority): Items located in this quadrant indicate that customer satisfaction and importance of the item is below the overall average and is a 'Low Priority' item that does not require immediate improvement.
4. Quadrant IV (Concentrate Here): Items located in this quadrant indicate that customer satisfaction with this item is lower than the overall average, but the importance score is higher than the overall average, which is a 'Concentrate Here'.

Noriaki Kano, a Japanese scholar, proposed a two-dimensional quality model in 1984, using Herzberg's two-factor theory [43]. This theory states that not all qualities and the overall satisfaction have a one-dimensional linear relationship, and Kano's two-dimensional quality model distinguishes product quality attributes into attractive quality elements, one-dimensional quality elements, and must-be quality elements. The Kano two-dimensional quality model classifies product quality attributes into five categories: reverse quality element, indifferent quality element, one-dimensional quality element, must-be quality element and attractive quality element.

3. Research Design

Based on the aforementioned objectives and the discussion of literature on bicycle handlebars, the application of the TRIZ innovative system approach to bicycle handlebars is combined. Based on the study and analysis of the literature on bicycle handlebars and motion damage, the innovative design of bicycle handlebars was developed by combining TRIZ design, human factors engineering method analysis and overall design improvement. In order to explain the research process more clearly, through the analysis of bicycle handlebars related products and literature, the TRIZ method paradox matrix and 40 invention principles were applied to analyse the design basis of the bicycle handlebars product and the human-machine interaction analysis and operation of the human factors engineering method.

3.1. Discuss the Design of Bicycle Handle Height Adjustment and Front and Rear Rotation Mechanisms

This section focuses on the TRIZ innovative system approach to the design of the bicycle handlebar height adjustment and bicycle handlebar front and rear rotation mechanism. The TRIZ design and ergonomic analysis was used to improve the handlebar height adjustment and front and rear rotation mechanism of the bicycle, as described below.

3.1.1. TRIZ Method Applied to the Design of Bicycle Handlebar Height and Front/Rear Rotation

Currently, bicycle handlebars and dragons use a single type of fixation, but each user's body type and riding position are different. Using the wrong riding position can cause sports injuries such as inflammation of the neck, back and hands. We analyzed the thirty-nine engineering parameters using the TRIZ technical contradiction matrix and determined that the parameters that should be improved No. 14 (strength), to improve the strength of the handlebar vertical rotation; No. 27 (reliability), improve the durability in use; No. 33 (ease of use), improve the ease of operation; No. 35 (adaptability), improve the versatility of the handlebar. The parameters that should be worsened were No. 25 (wasting time), avoiding excessive time spent on operations; No. 32 (manufacturing), reduce the difficulty of manufacturing; No. 36 (device complexity), reduce the complexity of the mechanism action. The data content of improvement parameters was determined using the 39 engineering parameters, and the corresponding invention principle was revealed with the contradiction matrix table. Therefore, when the improvement parameters and the deterioration avoidance parameters were different, different invention principles were produced. The above engineering parameters are shown in Table 3 and are plotted as a contradiction matrix.

Of the inventive principles corresponding to the matrix of technical contradictions summarised, No. 10 (pre-action) and No. 28 (replacement mechanical system) appear four times; No. 13 (reverse operation principle) appears three times; No. 1 (segmentation), No. 2 (separation), No. 3 (principle of improved local properties), No. 4 (principle of asymmetry), No. 12 (principle of equipotential energy), No. 29 (pneumatic or hydraulic structure), No. 32 (change color), No. 35 (change material properties) appear twice; the rest appear once. No. 32 (change color), No. 35 (change material properties) appear twice; the rest appear once. We have adopted the following inventive principles after discussion and analysis in order to solve the problem of designs for the height and fore-aft adjustment of bicycle handlebars: No. 1 (segmentation), the bicycle nose division is divided into two parts: the slide mechanism and the rotating shaft. The angle control changes the front and rear distance, using the slide rail mechanism to raise and lower the height, as shown in Figure 2. No. 10 (pre-action), creating a linkage mechanism at the front of the faucet to realise the pre-angle function, as shown in Figure 3. No. 13 (reverse operation principle), using the screw principle to precisely control the angle of the bicycle faucet, and the locking mechanism of the slide groove to control the upward and downward changes, as shown in Figure 4. No.28 (replacement mechanical system): the front and rear angle adjustment is replaced by a screw lift structure, as shown in Figure 5.

Table 3. Bicycle handlebar height and front and rear rotation in the technical contradiction matrix.

Avoid Deterioration ParametersA888Want to Improve Parameters	25. Time Wasting	32. Manufacturability	36. Device Complexity
14. Strength	29, 03 28, 10	11, 03 10, 32	02, 13 16, 18
27. Reliability	10, 30 04		13, 35 01
33. Easy to Use	04, 28 10, 34	02, 05 12	32, 26 12, 17
35. Adaptability	35, 28	01, 13 31	15, 29 37, 28

Source: Self-drawn.

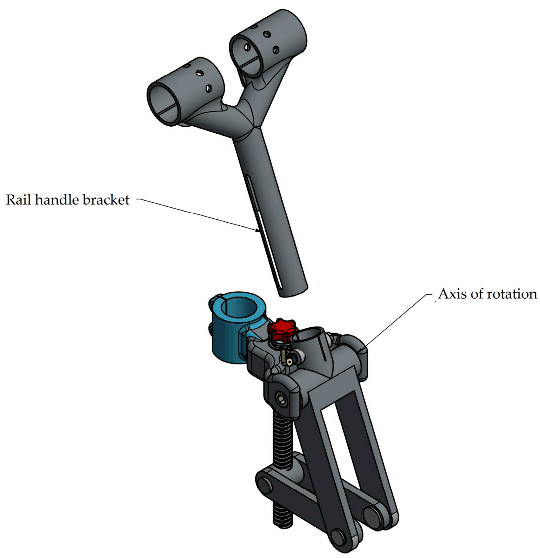

Figure 2. No. 1 (segmentation) operation explanatory diagram.

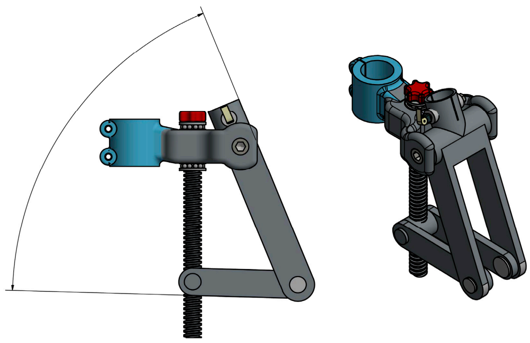

Figure 3. No. 10 (pre-action) operation explanatory diagram.

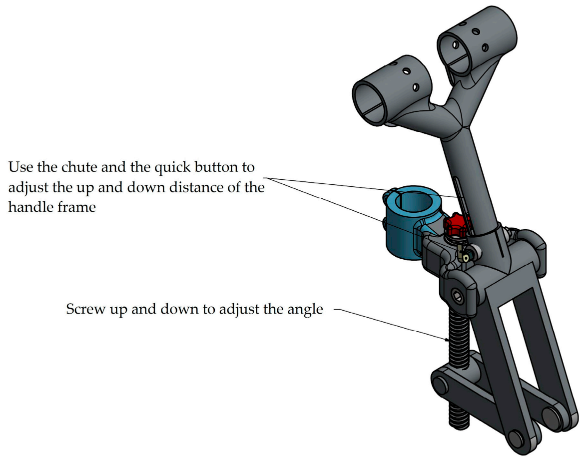

Figure 4. No. 13 (reverse operation principle) operation explanatory diagram.

Figure 5. No. 28 (replacement mechanical system) operation explanatory diagram.

3.1.2. Human Factors Engineering Introduces the Design of Vertical Height and Front-to-Back Rotation of Bicycle Handlebars

Currently, bicycle handlebars and faucets are fixed in one position, but each user's body type and riding posture are different. Using an improper riding position can lead to back, neck, back and hand injuries. This research focuses on the design of handlebar height adjustment and front-to-back rotation mechanism, using human factors design to analyze human-computer interaction and user operation styles.

1. Bicycle handlebar height adjustment mechanism: the bicycle handlebar can be adjusted up and down, allowing users to adjust the most suitable riding posture according to their body shape and hand length.
2. Front and rear swivel mechanism of the bike handlebar: the user can use the swivel mechanism to adjust the distance of the front and rear angle of the bike handlebar to change the posture and avoid sports injuries.

3.1.3. The Overall Design Presents the up and down Height of the Bicycle Handlebars and the Front and Rear Swivel Design

The design of the bicycle handlebar height adjustment and front-back otation mechanism, the design of the connecting tube and locking knob under the bicycle handlebar tap, so that the bicycle handlebar tap can be adjusted up and down to move the distance. The bicycle handlebar height adjustment and front-back swivel mechanism is designed with a screw and a linkage mechanism under the bicycle handlebar tap. The bicycle handlebars were designed using the TRIZ method of 39 item contradiction matrix design and human factors engineering, together with general design methods such as fair use, simple and intuitive use, appropriate size and space use, to achieve an innovative design.

1. Fair use: The handlebars of the bicycle can be adjusted up and down height dis-tance and front and rear angle distance, and can reduce sports injuries by chang-ing the posture. This design is suitable for most users to operate, and this design is suitable for the fair use principle of universal design.
2. Simple and intuitive use: Quick adjustment of the height and distance of the bike handlebars using the connecting tube and locking knob, and then the angular distance behind the ball using the turning screw, makes it easy and intuitive for the user to use. This design lends itself to simple universal design and intuitive use.
3. Appropriate size and space for use: the vertical height and angle of the bicycle handlebars are designed to suit general adult use, and a mechanism is used to adjust the vertical height and angle so that users can change their position at will.

3.2. Discussion of Innovative Designs for Bicycle Handlebar Swivel Angles and Left-Right Extensions

This section focuses on the application of the TRIZ innovation system approach to the innovative design of the handlebar swivel and left-right extension of a bicycle. This study uses TRIZ design methodology, human factors engineering analysis and overall design to improve the bicycle handlebar swivel and left-right extension mechanism.

3.2.1. Application of the TRIZ Design of Bicycle Handlebar Rotation and Extension

At present, bicycle handlebars and faucets use a single fixed type, but each user's body shape and riding posture are different. Using an inappropriate riding posture will cause waist, neck, back, hand inflammation and other movements harm. To solve this problem, an innovative design to change the angle of the bicycle bar was developed using the 39 engineering parameters of the TRIZ contradiction matrix. The parameters to be improved were identified as follows: No. 33 (ease of operation), reducing the difficulty of rotating and extending the handlebar; No. 37 (difficulty of detection and measurement), reduce the difficulty of adjusting the angle of the handle; No. 27 (reliability): improve the durability in use; No. 36 (device complexity), improve device operation complexity. The parameters that should avoid deterioration were as follows: No. 25 (wasting time), avoiding excessive time spent on operations; No. 35 (adaptation), reduced adaptability to manipulation; No. 12 (shape), avoid changing the shape and contour of the handle. The improvement parameter data content was determined using the 39 engineering parameters, and the corresponding invention principles were revealed through the contradiction matrix table. Therefore, when the improvement parameters and the avoidance of deterioration parameters are different, different inventive principles are generated and a table of contradiction matrices is produced using the engineering parameters mentioned above, as shown in Table 4.

Among the inventive principles corresponding to the matrix of technical contradictions, No. 15 (dynamic principle) appears five times; No. 1 (division), No. 28 (replacement of mechanical system) and No. 29 (pneumatic or hydraulic construction) four times; No. 16 (partial or excessive principle) and No. 34 (removal and generation of parts) three times; No. 18 (vibration principle) and No. 35 (change of material properties) twice; and the remaining once. To solve the innovative design problem of changing the angle of bicycle handlebars, the following inventive principles were adopted after discussion and analysis: No. 1 (division); using only the segmentation principle, the handlebars were divided into five parts. The left handlebar and left universal joint, extension bar, handlebar rotation bar, right universal joint extension bar, right hand handlebar can use universal joint to change the angle of the handlebar, the left has an extension, as shown in Figure 6; No. 15 (dynamic principle), the handlebar of the rotating handle, the handlebar can be rotated 360 degrees, as shown in Figure 7. No. 16 (partial or excessive principle), the use of fastener mechanism to adjust the rotation of the left and right handle angles to 30 degrees, as shown in Figure 8; No. 28 (replacement of mechanical system): a screw for adjusting the left and right handle extensions, as shown in Figure 9.

Table 4. Bicycle handlebar rotation and extension technical contradiction matrix.

Avoid Deterioration ParametersA888Want to Improve the Parameters	25. Time Wasting	35. Adaptability	12. Shape
33. Ease of operation	04, 28 10, 34	15, 34 01, 16	15, 34 29, 28
37. Difficulty of detection and measurement	18, 28 32, 09	01, 15	27, 13 01, 39
27. Reliability	35, 38 18, 16	15, 03 29	35, 01 16, 11
36. Device complexity	06, 29	29, 15 28, 37	02, 22 17, 19

Source: Self-drawn.

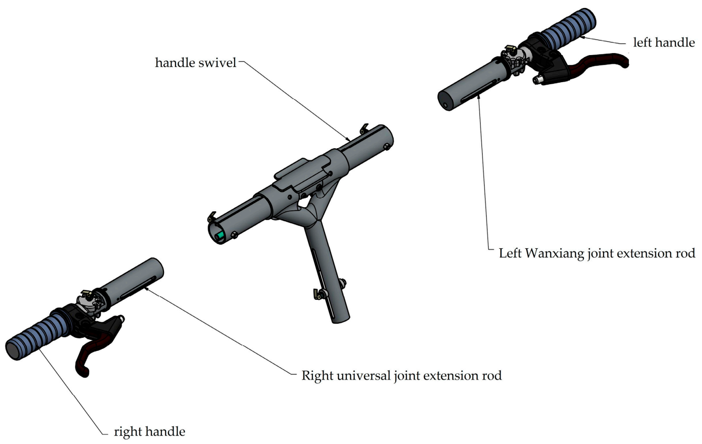

Figure 6. No. 1 (segmentation) operation explanatory diagram.

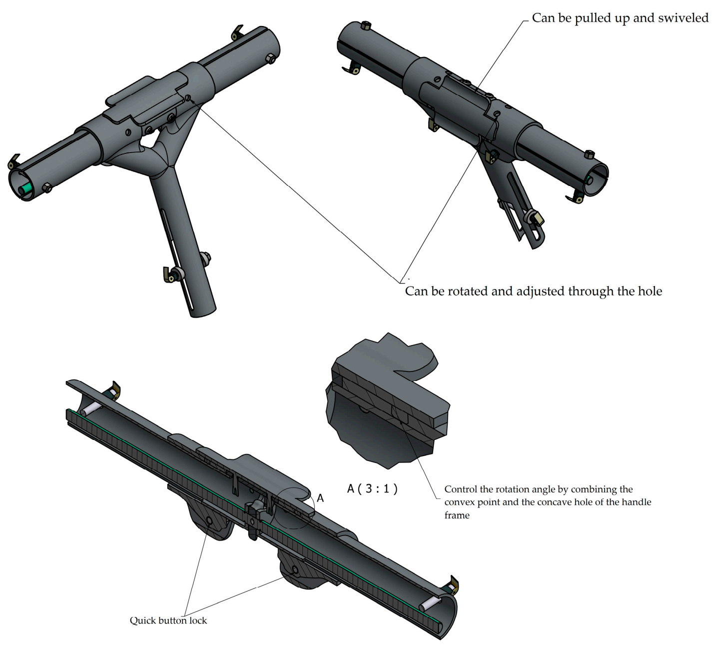

Figure 7. No. 15 (dynamic principle) application diagram.

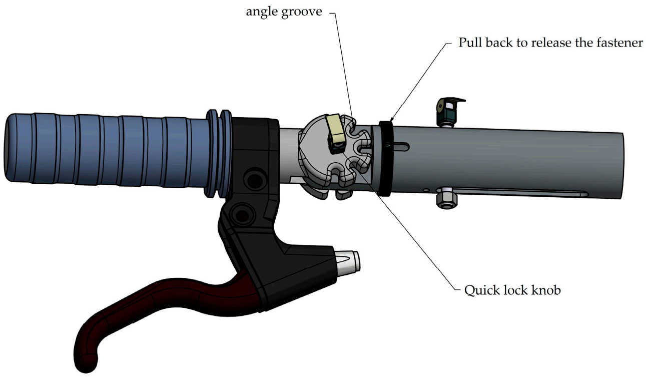

Figure 8. No. 16 (partial or excessive principle).

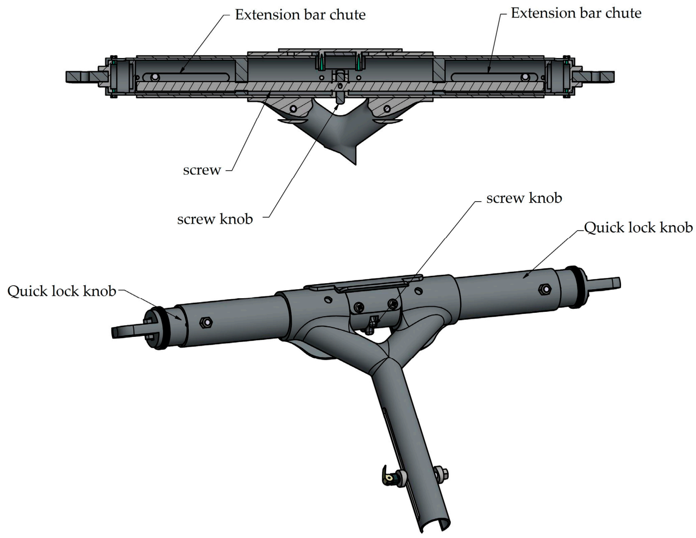

Figure 9. No. 28 (replacement mechanical system) operation explanatory diagram.

3.2.2. The Human Factors Engineering Method Is Introduced into the Design of the Rotation and Extension of the Bicycle Handlebar

Currently, most bicycle handlebars are fixed in a single position and cannot be adjusted by the user. However, each user has a different body type and riding position, and using an inappropriate riding position can cause back, neck, back and hand injuries. To address this issue, this study focuses on the innovative design of the rotational angle and left-right extension of the bike handlebars, using ergonomic design and ergonomic system analysis to change the angle of the handlebars to allow the user to adopt a position that reduces motor injuries. The analysis of user handling suggests that the handlebars must include two modes of operation:

1. Handlebar rotation mechanism: The handlebars on the left and right sides of the bicycle can change the angle of rotation up and down and forward and backward, so that the user can adjust the wrist posture arbitrarily during riding to avoid hand movement injuries.
2. The left and right extension mechanism of the handlebar: the left and right handlebars of the bicycle can change the length of the left and right stretching, so that the user can adjust the posture of the arms and shoulders arbitrarily during riding, so as to avoid sports injuries to the hands and shoulders.

3.2.3. Introducing Universal Design to the Swivel and Extension of Bicycle Handlebars

The innovative design of the bicycle handlebar rotation angle and left-right extension, through the angle adjustment of the handlebar joint and the rotation function of the middle link of the handlebar, allows the handlebar to be rotated up and down and back and forth, and then through the telescopic mechanism of the middle link of the handlebar to adjust the left-right extension length, using the 39 items of the previous TRIZ method of contradiction matrix design and human factors engineering adjustment, combined with the general design method of fair use, simple The innovative design of the bicycle handlebar was improved by combining the fair use, simple and intuitive use, appropriate size and space use of the general design method.

1. Fair use: Through the angle adjustment of the handle joint and the rotation function of the middle link of the handle, multiple riding postures of the wrist and arm can be adjusted to reduce sports injuries of the wrist and arm. It is suitable for operators of various sizes. This design fits within Universal Design's fair use principles.
2. Simple and intuitive use: Use the locking knob at the connection between the middle link and the left and right handlebars to quickly adjust the angle distance between the left and right handlebars of the bicycle, and then use the middle link to rotate the screw to adjust the left and right extension distance, so that ordinary users can Easy and intuitive operation, this design is suitable for easy and intuitive use of universal design.
3. Appropriate size and space use: design the size of the left and right handlebars of the bicycle and the extension length of the middle link to suit the size of ordinary users, and use the rotation angle of the bicycle handlebar and the left and right extension to adjust the size. This design is suitable for general use when the size and space use.

3.2.4. Questionnaire Design

To evaluate the value of this product, the SERVQUAL scale was used as a basis in this study, which contains five major components: tangibility, reliability, responsiveness, assurance, and care. Therefore, this study used the SERVQUAL scale of Parasamanur et al. (1985), with the bicycle handlebar function as the reference for the questionnaire content. Five experts, academic professors, manufacturers, and vendors, were invited to conduct expert interviews, to revise and adjust the questionnaire content, and the two-dimensional quality model (Kano model) and the important–performance analysis method (IPA) were used for the practical analysis [44].

4. Product Design

As bicycle handlebars are not adjustable in posture and cannot meet the individual differences of different users, this study designs a bicycle handlebar that can be adjusted in posture to avoid sports injuries. Based on the above research objectives, the TRIZ method, ergonomics and universal design were used to explore how to improve the design of the bicycle handlebar by making the product more consistent with general principles. The results of the design of the bicycle handlebar products are described below:

(1) Explains the part structure of bicycle handlebar products.

(2) The design of handlebar height adjustment and front and rear rotation mechanism.

(3) Innovative design of bicycle handlebar swivel angle and left/right extension.

(4) Comprehensive analysis of IPA and KANO models for various services of bicycle handlebars.

After the content of the assembly structure of the product parts is mastered, the IPA and KANO models of various services of the bicycle handlebar are combined and analysed to determine whether the user needs are met, and then the product parts and structure are designed using drawing software to show the details of the product more clearly. The design is illustrated with a complete product structure, part diagram and operation diagram. Details are shown below.

4.1. TRIZ Innovation System Approach in the Overall Structure of Bicycle Handlebar Products

In this section, the TRIZ innovation system approach is presented and discussed in the context of bicycle handlebar products and their use Citing discussions of bicycle-related literature in Chapter 2, as well as applied research and design, human factors analysis and general design principles of bicycle handlebar products. In the third chapter, the product was improved by applying the principles of the TRIZ paradox matrix to the product, and two problems were identified with the ordinary bicycle handlebar product. (1) The handlebars are fixed to the body of the bicycle and require tools to adjust the riding posture. (2) The riding position cannot be adjusted according to the size of the user. The size of the handlebars and the distance between the front and rear of the bike are fixed, so it is impossible to adjust the riding position correctly. Incorrect riding position can lead to poor seating position. Incorrect posture can lead to sports injuries. Therefore, the TRIZ innovative system approach in this study can adjust the riding posture in the bicycle handlebar product to avoid sports injuries caused by long term riding posture, as shown in Figure 10.

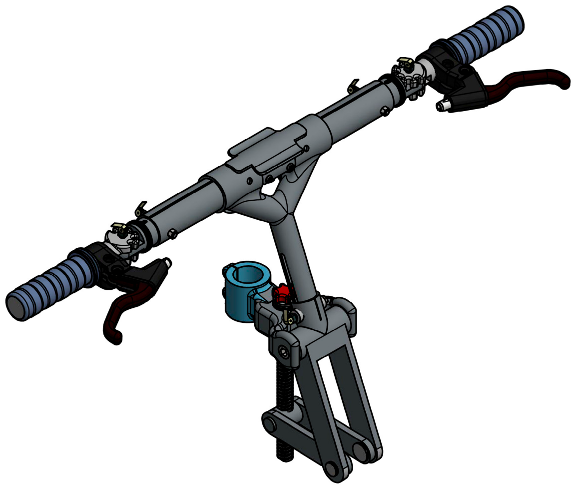

Figure 10. Product image of a bicycle handlebar.

4.2. Innovative Design of Bicycle Handle Height Adjustment and Front and Rear Rotation Mechanism

Currently, bicycle handlebars and faucets are all fixed in a single position, but each user has a different body type and riding position. Using an inappropriate riding position can cause back, neck, back and hand inflammation and other motor injuries. In order to improve the problem of bicycle handle design, this study focuses on the design of the handlebar height adjustment and front and rear rotation mechanism, using TRIZ design and ergonomic analysis design and general design improvement, the user can adjust the handlebar height upwards and backwards. This allows the user to adjust the handlebar height upwards and backwards. The lowering distance and front and rear angle rotation distances are designed to avoid wrong riding postures caused by motion damage.

After reviewing the relevant literature in chapter 2, the paradoxical matrix design and TRIZ techniques are applied to the design principles and improvements of the general design method in chapter 3 to obtain TRIZ development principle No. 1 (segmentation) Application: The bicycle handle is divided into two parts with a rotary axis and a sliding mechanism. The rotary axis is used to control the angle and change the front and rear distances, and the height is raised and lowered using the sliding mechanism. No. 10 (pre-action) and No. 13 (reverse operation principle): precise control of the angle of the bicycle lever and the locking mechanism of the slide to control up and down movement using the screw principle. No. 28 (replacement mechanical system): the front and rear angle adjustment method is replaced using a screw lift structure, as shown in Figures 11 and 12.

Figure 11. Illustration of the front and rear rotation of the bicycle handlebars.

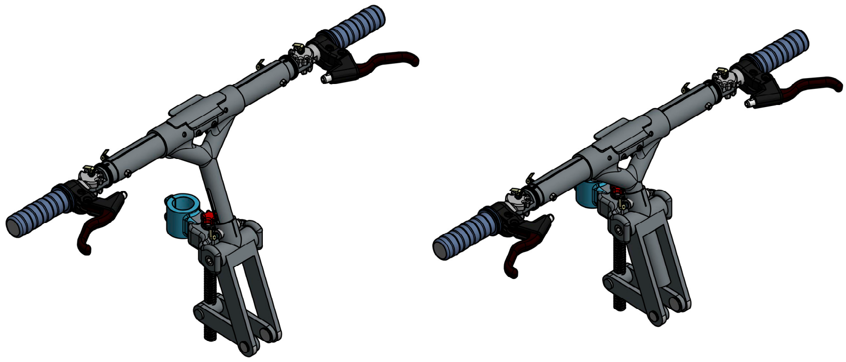

Figure 12. Diagram of bicycle handlebar height adjustment.

4.3. Innovative Design of the Handlebar Swivel Angle and Left and Right Extension

Currently, bicycle handlebars and faucets are all fixed in a single position, but each user has a different body type and riding position. The use of inappropriate riding postures can cause back, neck, back and hand inflammation and other motor injuries. In order to improve the problem of bicycle handle design, this study focuses on the design of handlebar swivel angle and left-right extension, using TRIZ design and ergonomic analysis and general design improvement, the user can adjust the left and right handlebars upward up and down, front and rear swivel angle and left-right extension distance, to avoid the sports injury caused by wrong riding position.

After reviewing the relevant literature in Chapter 2, the following TRIZ invention principles were applied in conjunction with the application of the TRIZ paradox matrix to the invention principles in Chapter 3, using human factors engineering methods and universal design methods: No. 1 (segmentation), using the segmentation principle to divide the handle into five parts: left handlebar, left universal extension, handlebar rotation, right universal extension, right handlebar; No. 15 (dynamic principle), the handle rotates with the lever to No. 16 (partial or excessive principle): the left and right handlebar rotation is adjusted by 30 degrees using the snap mechanism; No.28 (replacement mechanism system), the left and right extension functions are adjusted with screws, as shown in Figures 13 and 14.

4.4. Analysis of the Combination of IPA and the KANO Model for Bicycle Handlebar Design

Kano divided the quality elements into five dimensions: attractive quality, one-dimensional quality, must-be quality, indifferent quality, and reverse quality.

According to the data collected, a total of 108 people filled out the survey, including 53 males and 55 females, with a brief report of the relevant information of the respondents for age, education, average monthly income, and occupation, as shown in Figures 15–19. The analysis in this chapter focuses on combining the distribution of service items in each quadrant of the IPA with their respective Kano quality elements for cross-analysis; and then, according to their importance, finding the most effective bicycle handlebars using the two models, to improve satisfaction. The purpose of combining these analyses was to avoid the use of IPA and to avoid the existence of two-dimensional quality characteristics of the service quality items, or a lack of consideration of the importance of the shortcomings when only using the Kano model, as is shown in Figure 20. According to this figure, the fourth quadrant should be targeted as a priority improvement. The product was then installed on a bicycle, as shown in Figure 21.

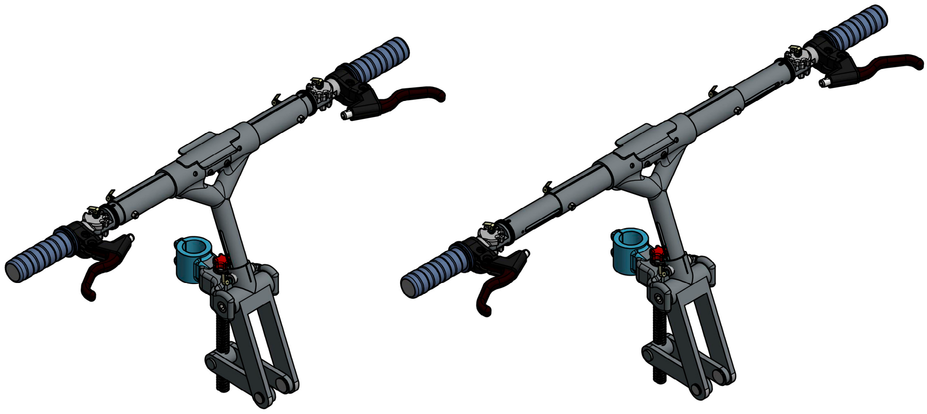

Figure 13. Schematic diagram of the left and right extension of the bicycle handlebars.

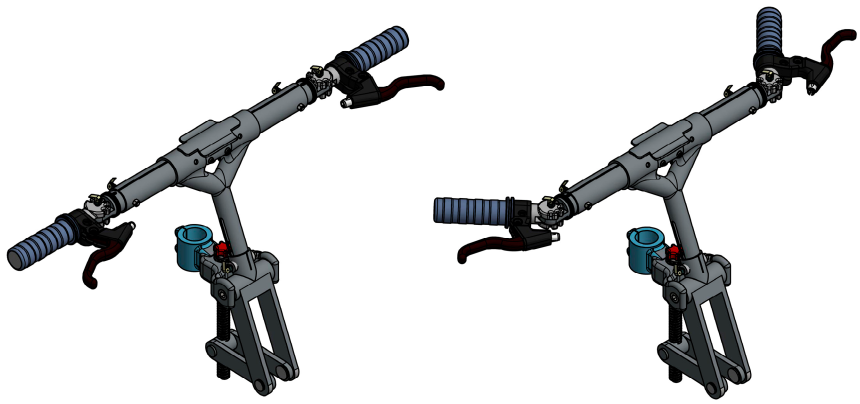

Figure 14. Diagram of the bicycle handlebar rotation.

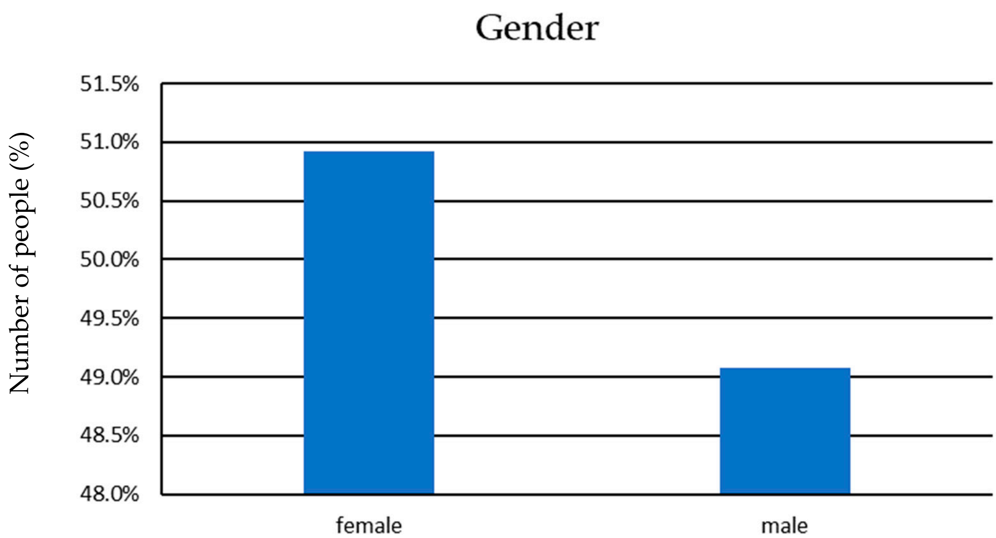

Figure 15. Gender distribution bar chart.

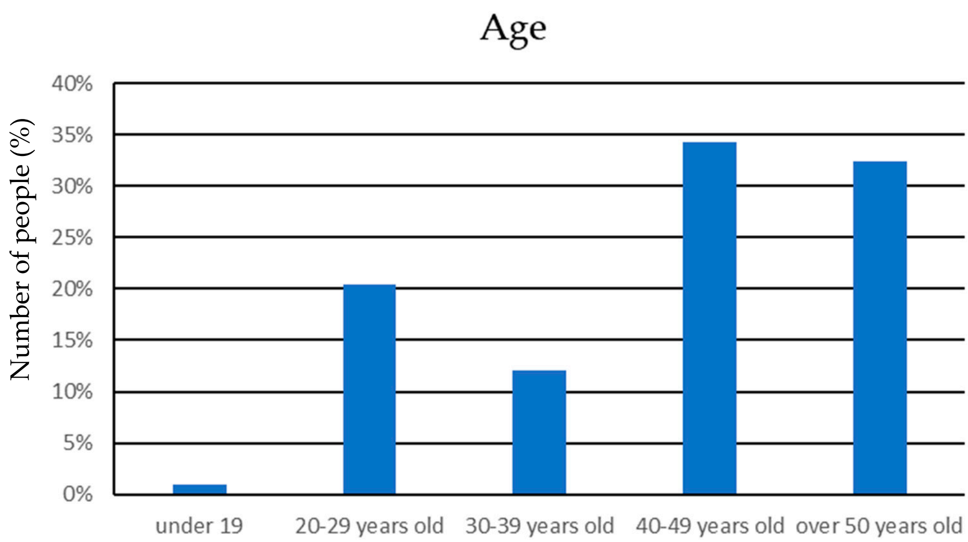

Figure 16. Age distribution bar chart.

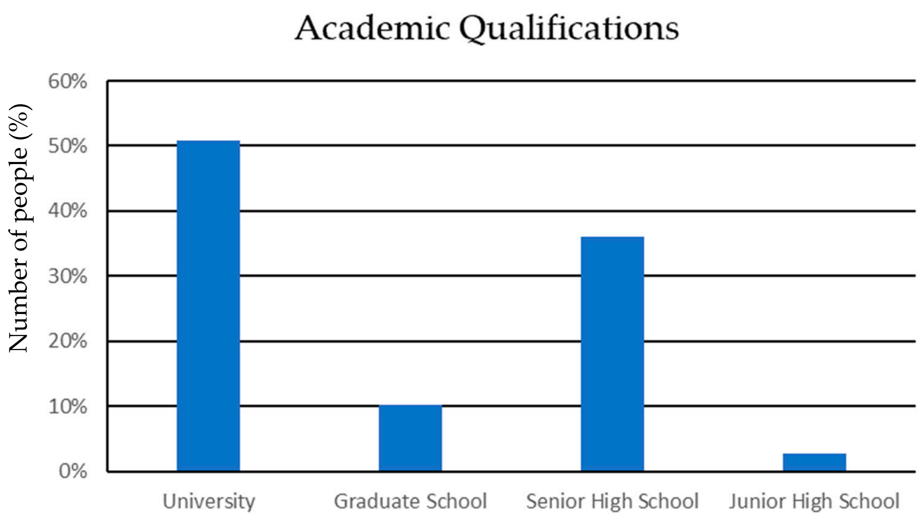

Figure 17. Bar chart of educational background distribution.

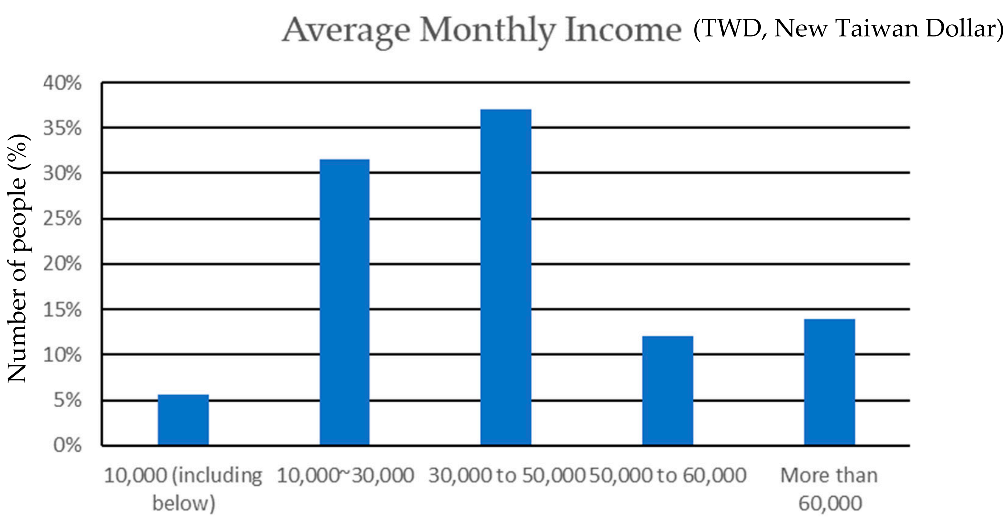

Figure 18. Bar chart of monthly average income.

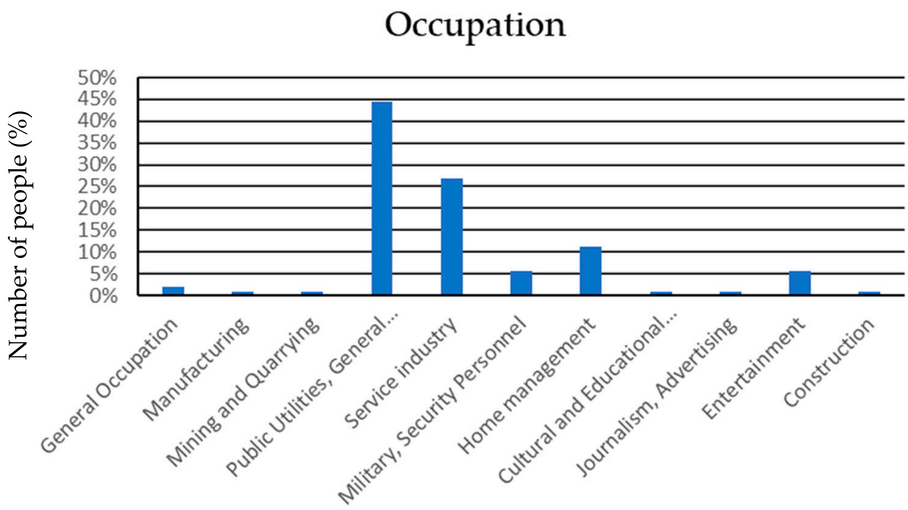

Figure 19. Occupation bar chart.

Degree of performance High

Quadrant II

(Oversupply, consumption costs)

Service quality items	Kano	Importance
4.Bicycle handlebar replacement parts material, reduce weight	O	4.179
11.Self-adjustment of fatigue caused by prolonged use	O	4.077
15. Bicycle handlebar can be judged from the sensor data whether the body does not burden	O	4. 094

Quadrant I

(For its advantage, it needs to continue to maintain)

Service quality items	Kano	Importance
1. The bicycle handlebar uses the rotary axis to control the angle to change the distance between front and back	A	4.227
2.Bicycle handlebars use the slide mechanism to lift the height	M	4.216
3. Bicycle handle uses quick release screws to speed up the adjustment of handle height and front and rear functions.	A	4.232
6. Bicycle handlebar uses universal joint extension to achieve 360 degree rotation of the left and right handlebars	A	4.283
7.The bicycle handle uses the universal joint to achieve fast fixation.	A	4.299
8. The spacing between the extension of the bicycle handle is appropriate.	M	4.283
9. Easy to use and clear	O	4.283
12. The bicycle handle can be quickly adjusted and fixed	O	4.285
13.The bicycle handle can be adjusted directly	O	4.283
16. Bike handle can be adjusted according to different people	O	4.293
18. Bike handle is safe to use	O	4.295

Importance Low

Importance High

Quadrant III

(Sub-improvement targets, future potential problems)

Service quality items	Kano	Importance
5. Bicycle handlebar installed sensor device	O	4.141
17. The bicycle handlebar is designed to avoid sports injuries caused by maintaining the same posture for a long time	O	4.173

Quadrant IV

(Major deficiencies, need immediate improvement)

Service quality items	Kano	Importance
10. The bicycle handlebar can be adjusted by itself according to different road sections	O	4.224
14.The bicycle handlebar can judge whether the posture is wrong from the sensor, and correct it in time to avoid causing human injury.	O	4.219

Low level of performance

Figure 20. Cross-tabulations of IPA and Kano model.

Figure 21. Diagram of the handlebars mounted on a bicycle.

5. Conclusions

Cycling is mainly a prolonged ride with extremely repetitive movements and fixed postures, which can easily cause pain in the neck, upper back, shoulders, elbows and hands.

Muscle ache occurs in various areas of the stabilising muscles such as the wrist. Overexertion can lead to sports injuries, such as muscle strains. In this design study, TRIZ's innovative systems approach to bicycle handlebar design can change riding posture and avoid the sports injuries.

1. Design of handlebar height adjustment and front and rear swivel mechanisms for bicycles.

The handlebars of ordinary bicycles are mostly fixed and cannot be adjusted according to the user's body shape and arm length, resulting in an incorrect riding position and causing sore arms and back muscles or other sports injuries. Holding a fixed riding position for long periods of time can also lead to sports injuries to the elbows, wrists and arms. The design of this study allows the user to adjust the height control of the bike handlebars and the distance between the front and rear swivel angles to change the posture to relax the muscles of the body and reduce sports injuries more effectively.

2. Innovative design of handlebar rotation angle and left-right extension

The handlebars of ordinary bicycles are mostly fixed and cannot be adjusted according to the user's body shape and arm length, resulting in incorrect riding posture and causing arm and back muscle pain or other sports injuries. The design of this study allows for the adjustment of the front and rear, up and down rotation angles and extension length of the left and right handlebars, allowing the user's wrists, arms and shoulders to change position and effectively reduce sports injuries.

Based on the suggestions in the expert interviews, the questionnaire was revised and the IPA analysis showed that this product had total averages of 4.212 and 3.628 for the rider's importance and satisfaction, and a cross analysis was conducted with the Kano method to determine the areas that required immediate improvement, in order to maintain the advantage of this product and enhance the visual appeal of the bike handlebars. We hope to establish our unique type of bicycle handlebar, which was developed through the TRIZ design combined with human factors engineering, and to continue the development of our products, to make them more convenient.

6. Expected Impact

Human factors engineering was used in this design study and the TRIZ design and the products generated during the design process. After determining the prototype design form of the product, the components of the product are assembled and simulated using drawings, and mass production is carried out after evaluating the satisfaction of the product through IPA. The specific contributions of this study are as follows:

Academic field: The research method can be used for product design and initial feasibility evaluation, and it can also be applied to other product designs to verify its applicability.

Industrial field: With this research method, product shortcomings can be identified prior to product development and evaluated prior to manufacturing and production, thereby reductions in the cost of mass production and avoiding wasted time.

Social sector: Through this research method, ideas can be turned into designs, so that more people can understand how to design and raise funds for product design.

7. Patents

The research results were awarded a patent for invention by the Intellectual Property Office, Ministry of Economic Affairs, Republic of China. (Patent No. I690450).

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