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Influence of folding mechanism of bicycles on their usability

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ABSTRACT

In this study, foldable bicycles were evaluated in terms of their usability. Four types of folding mechanisms were identified depending on the number of pivots and the pivot axis direction: single lateral pivot (SLP), single vertical pivot, dual lateral pivot, and combined vertical–lateral pivot. Next, four bicycles—one each of these four types—were selected as test specimens. Ten subjects performed folding and unfolding tasks on each of these bicycles, and three-dimensional body motions and ground reaction forces were measured. The maximum trunk flexion angles and maximum increments in the ground reaction force were used as governing parameters for evaluating the comfort level for each bicycle type. The SLP type provided the lowest upper body flexion and ground reaction force and was hence judged to be the most comfortable folding system. Hence, a promising type of easily foldable bicycle was proposed, thereby encouraging its incorporation into public transit systems.

1. Introduction

Bicycles are an environmentally friendly and economical mode of personal transportation powered by human force, and the use of bicycles as a mode of public transportation is the most promising step toward developing green transportation alternatives considering environmental and economic factors (Cheng and Liu, 2012). Therefore, the use of bicycles in urban environments is being increasingly encouraged. Meanwhile, a high-priority requirement for urban bicycles is not their riding performance but their availability in compact sizes, which can be achieved by incorporating a feature in their design that facilitates them to be folded into portable sizes. In other words, by minimizing their volume, bicycles could be carried on trains, buses, or any other mode of public transportation and could also be stored in narrow residential and office spaces (Pirnat et al., 2011).

The feature that facilitates the folding of a bicycle is the incorporation of a pivot in the frame; the frame could then be folded around the pivot, thereby reducing the bicycle dimensions (Singh et al., 2014). Although the geometry of a bicycle must essentially be the same as a normal city bike to facilitate easy riding, its size must be temporally minimized to enable it to be carried to locations such as the inside of buildings or underground passages. Therefore, foldable bicycles generally employ relatively small wheels at the cost of their riding performance. One of the most important specifications of foldable bicycles is the extent to which their size can be compressed by folding.

Commuters who travel by bicycle and then cover part of the commute through other modes of public transportation should be able to fold and unfold a bicycle repeatedly. Thus, the ease with which a bicycle could be folded directly influences user satisfaction. This ease of folding is closely related to the type of folding mechanism, which is determined by the number and directions of pivot axes (Hyeong et al., 2016). This simply implies that if the folding mechanism were simple, the folding action would also be simple, whereas if the folding system were complex, the folding action would also be complicated and time-consuming. To date, neither have bicycle-folding mechanisms been defined nor have any studies been performed toward the evaluation of such mechanisms.

The fastest and most effective method to evaluate usability is to measure the time required for performing a task successfully. Tullis and Albert (2008) noted that the parameter “time-on-task” could be used for the usability evaluation of various products and stated that the shorter the task time, the better is the experience. In addition, Groenesteijn et al. (2009) reported that user satisfaction was high when the task time required for making some adjustments to the armrest position, backrest reclining position, and weight resistance of office chairs was short. However, for the usability evaluation of products whose adjustment requires more complex steps, it is important to simultaneously analyze the results of the task execution time and the step-by-step procedure. Recently, methods have been developed for observing various body motion changes as well as the quantitative time-on-task between a product and its user by using three-dimensional optical equipment, and these methods have found widespread use, e.g., human–product motion usability evaluation (Chang et al., 2017; Rajan et al., 1999) and divided human motion definition (Chateauroux and Wang, 2010). Such three-

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dimensional optical equipment uses kinetic and kinematic analysis for human–product interactions. Moffet et al. (2002) analyzed the joint angles of the neck, elbow, and wrist of a person operating a laptop computer, correlating small angle changes to comfort. Davis and Anés (2014) measured the trunk posture and Shin et al. (2006) measured the trunk kinematics and ground reaction force (GRF) simultaneously to evaluate the risks of low back injury associated with lifting tasks. The results of the previous studies indicate that by using the three-dimensional optical equipment, usability can be evaluated effectively in terms of not only the execution time of the task but also many other evaluation indexes such as the user motion (e.g., joint trajectory and joint angle) and biomechanical factors (e.g., joint moment and joint power).

The aim of this study was to identify different bicycle-folding mechanisms and quantitatively evaluate the folding action of users from a biomechanics (or ergonomic) point of view. The three-dimensional kinematics of the folding action was investigated to determine the comfort and usability of probable foldable bicycle types. Experiments were performed to measure the trunk flexion angles, hand movements, and GRFs when four types of bicycles were folded.

2. Experiment

2.1. Identification of types of folding mechanisms

The basic principle of foldable bicycles is the side-to-side alignment of the front and rear wheels, produced by the action of one or more hinges in the frame. Design variables such as the number of pivots and the direction of the pivot axis differentiate various types of folding mechanisms. For example, the number of pivots differentiates between single- and multiple-pivot-type folding mechanisms, whereas the direction of the pivot axis differentiates between horizontal- and vertical-axis folding mechanisms. These mechanisms can be categorized as shown in Fig. 1. The single pivot types could be divided into a single vertical pivot (SVP) and a single lateral pivot (SLP). These two mechanisms are the simplest, with a pivot located at the midpoint between the front and rear wheels. On the other hand, the dual lateral pivot (DLP) and dual vertical pivot (DVP) types have two pivots placed in different locations with identical axial directions. The combined vertical–lateral pivot (CVLP) type has a vertical front pivot and a horizontal back pivot or opposite mechanism directions. Folding mechanisms with three or more pivots are not included in this classification because of their structural complexity and commercial impracticality.

2.2. Experimental bicycles

Commercial foldable bicycles with four different types of folding mechanisms were selected for this experiment. The selected bicycles with the SLP, SVP, DLP, and CVLP folding mechanism types are shown in Fig. 2. In this study, the DLP type was excluded from the experiment because it was difficult to obtain a commercial DLP model. The wheels of the bicycles had diameters of less than 18 in., and the bicycle weights were within 12.2 kg. The specifications of the folded bicycles are listed in Table 1. When the bicycles were folded, the SLP type demonstrated a vertically elongated configuration whereas the other types were relatively similar in vertical and horizontal lengths, as seen in Fig. 2.

2.3. Subjects

Ten healthy adult males volunteered to participate in the experiment involving the measurement of movements during the folding and unfolding of the bicycles. The average age (± SD) was 27.7 (± 1.5) years, the average height (± SD) was 175.6 (± 4.3) cm, and the average weight (± SD) was 70.4 (± 6.7) kg. Although the subjects had prior experience with riding bicycles, none of them had experience

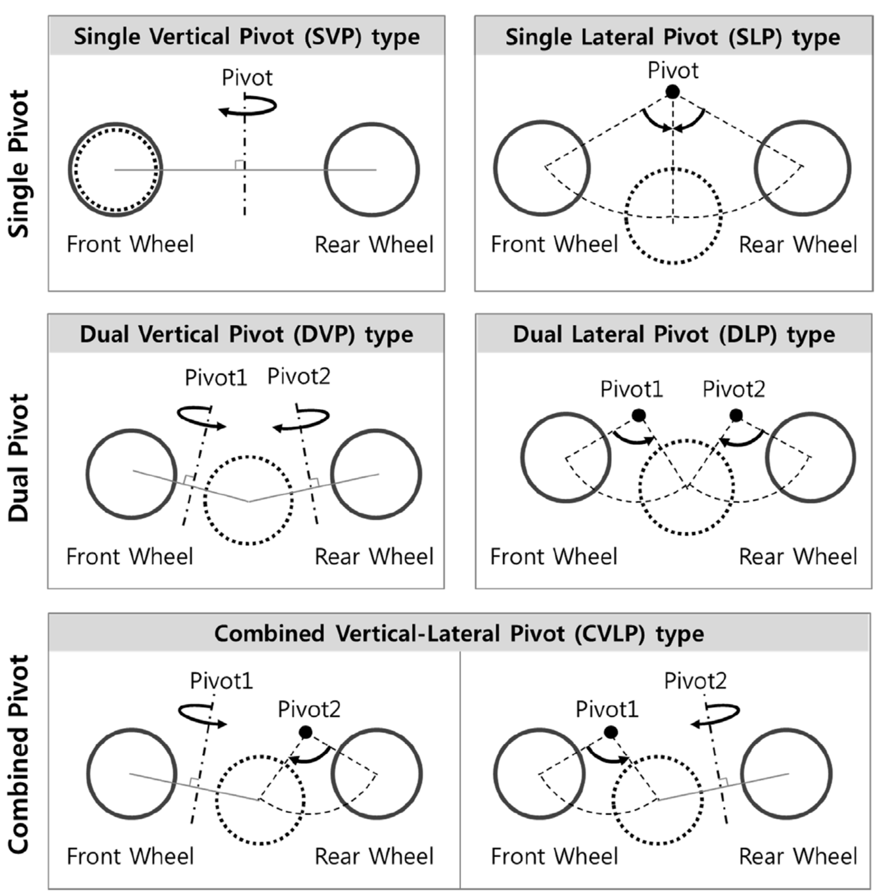

Fig. 1. Definition of folding mechanism types.

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