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How does lever length and the position of its axis of rotation influence human performance during lever wheelchair propulsion?

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ABSTRACT

The purpose of this study was to investigate empirically how lever length and its axis of rotation position influences human performance during lever wheelchair propulsion. In order to fulfill this goal, a dedicated test stand allowing easy implementation of various lever positions was created. In the experiment, 10 young, healthy, male subjects performed 8 tests consisting of propulsion work with levers of different lengths and lever axis of rotation positions. During tests heart rate, oxygen consumption and EMG assessment of 6 muscles was carried out. Measurements of power output on the test stand were done as well. Together with oxygen consumption analysis, this allowed calculation of human work efficiency. The results show significant ($p < 0.05$ and $p < 0.001$) differences between lever configurations when comparing various parameters values. From the carried out experiments, the authors conclude that levers' length and their axis of rotation position significantly influence human performance during lever wheelchair propulsion. For the examined subjects, placing the levers' axis of rotation close behind the back wheels axis of rotation offered advantageous work conditions.

1. Introduction

Present day lever wheelchairs differ in terms of lever mechanisms design: various lever lengths and levers' axis of rotation positions can be found (Taylor, 1999; Lucken, 1984; Korosue, 1985, 2001; Hanna, 1991; Schaeffer, 1976). At the same time there is a lack of scientific ergonomic analysis of existing designs – besides few papers (Engel and Hildebrandt, 1974; Neikes et al., 1976; Brubaker et al., 1984), which are not consistent in their conclusions, to our knowledge no further research on the latter was carried out. The study was aimed at experimental comparison of different combinations of lever lengths and levers' axis of rotation for an anthropometrically similar group of users. This comparison was carried out in view of the parameters related to the efficiency of human labour, heart rate and muscle activity during driving the lever wheelchair. 3 research questions were formulated:

- Which of the analysed lever configurations offered the least straining conditions for human performance?
- Is it better to place levers' axis of rotation in front or back part of the wheelchair?
- Is it advantageous to have a longer lever and the levers' axis of rotation positioned lower, or the opposite?

The desire to answer these questions required creating a dedicated test environment. For classic push-rim wheelchairs test stands can be easily found in the literature (Faupin et al., 2008; Niesing et al., 1990; Finley et al., 2002), however only 2 designs for lever wheelchairs are known to the authors (Neikes et al., 1976; Brubaker et al., 1984). Since these designs did not meet our requirements, we decided to design our own laboratory test stand.

2. Methods

2.1. Laboratory test stand

The laboratory test stand used in the experiments is demonstrated in Fig. 1. The concept of test stands work is the following: the subject is sitting on the fixed wheelchair (1) and carrying out propulsion work of pushing two levers (2). The force exerted by human upper limbs is measured by strain gauges on both levers and transferred to two flywheels (7) through changeable gears (6). Each lever is connected to a separately spinning flywheel.

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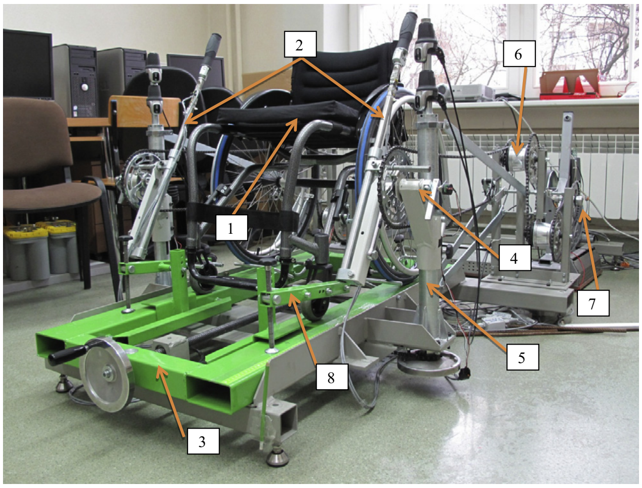

Fig. 1. Overall view of the test stand. Legend: 1 – wheelchair; 2 – levers; 3 – wheelchair's platform; 4 – lever's axis of rotation; 5 – column for the vertical movement of the lever; 6 – changeable gears; 7 – flywheel along with electromagnetic brake; 8 – adjustable wheelchair fixation.

The more force exerted by the subject, the faster the flywheels rotate. Rotation velocity of both flywheels is measured and allows for the computation of wheelchairs velocity and simulation of its motion. Wheelchair ride simulation is projected in front of the subject which increases the reality of experiment. Changeable power output during wheelchair ride which can be an effect of e.g. slope or wind, is simulated through electromagnetic brakes that can slow down the flywheels (7). The brakes are controlled via National Instruments Compact Rio system and thus the actual power output that should be carried out by the subject can be rapidly adjusted.

Wheelchair fixing system (8) is adjustable so that various wheelchairs can be mounted on the test stand and thus users with various anthropometrical features can be assessed on the test stand. Levers are designed in a manner that allows changing their length from 300 to 660 mm. The test stand also allows for the changing of the position of levers' axis of rotation (4) both in vertical direction (250 mm range) and horizontal direction (520 mm range). Changing the horizontal position of levers' axis of rotation position (4) in reference to the wheelchair requires moving the platform (3) in the desired direction, whereas changing in vertical direction requires moving (4) up or down on the column (5).

Apart from the above mentioned features the test stand allows also for:

- regulation of levers inclination to the wheelchair-users sagittal plane in range of 0–15 (°) (increase in the (°) value of this inclination results in shorter distance between hand grips on the levers to the sagittal plane);
- bending of levers' hand grip in range of 0–180° (in Fig. 1 the value is set to 90°);
- rotation of levers' hand grip in rage of 0–360°;
- changing gears between levers and flywheels (2 planetary gears for each lever, 8 gears each);
- performing tests with or without projection of the wheelchair's ride simulation;
- optionally, braking can be accomplished through pushing the levers to the wheelchair-users sagittal plane. Measurement of applied force in this direction with strain gauges allows for changing of the current applied to the electromagnetic brakes in a desired pattern.

Altogether, the test stand allows assessment and recording of the following mechatronic information during each experiment:

- human force exerted in the levers' motion plane;
- human force exerted in the plane perpendicular to the levers' motion plane;
- angular position of the levers in their motion plane;
- flywheels' rotation (angular velocity).

2.2. Anthropometry of the subjects

The experiments with use of the described test stand were carried out on 10 young, healthy males. Their anthropometric characteristics are shown in Table 1. The subjects were informed about the scope and methods used in experiments and provided with a written consent for participation. The experiment's design was approved by Bioethical Committee of the District Medical Chamber in Warsaw.

2.3. Examined parameters of the wheelchair lever system

As mentioned before, the carried out experimental research regarding lever system for wheelchairs was dedicated to assess the influence of position of levers' axis of rotation and levers' length on human performance during lever wheelchair propulsion. To achieve these, certain assumptions were made. It was assumed, that the height of human hand grip on the lever in relation to the ground will be constant and equal to 730 mm. From all possible combinations of lever lengths and levers' axis of rotation positions 8 different combinations (number 2 through 9) were chosen according to the Box–Willson design of experiments methodology. Originally Box–Willson design for this experiment included also a central point that was numbered combination 1. The authors however decided to follow a different research protocol in case of combination 1 and therefore it is not discussed further in this paper. Resulting combinations taken into consideration are presented in Table 2 and Fig. 2. Values in the horizontal direction *X* in Fig. 2. are calculated in relation to the initial position of the subject's shoulder joint and values in the vertical direction *Y* are calculated in relation to the green platform. In this example the position of the levers' axis of rotation was situated 280 mm in front of the initial shoulder joint position and 335 mm above the green platform.

2.4. Experiment conditions

Experiments were performed in random order which enabled the independence of research results from the order in which they were performed. Experiments in each of the examined combinations consisted of 8-min-long continuous work of pushing the levers. The test stand allowed setting changeable power output (W) to be achieved with use of the levers during work. In the carried out experiments each subject had the power output adjusted individually according to their physical capacity, which was assessed in the pre-test (the design of the pre-test is shown in Table 3). The subjects carried out the pre-test sitting in the same wheelchair on the test stand as the one used further in the experiments. During the pre-test subjects had to maintain constant wheelchair velocity of approximately 6 km/h, which was displayed visually in front of them. The power output in the progressive pre-test was rising every 2 min and the pre-test lasted until refusal of continuation by the subject. In the progressive pre-test various human performance-related parameters were measured: heart rate, minute ventilation, oxygen consumption, carbon dioxide production, breath frequency. The individualised power output for each subject for the purpose of further experiments was set to