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Effects of operation type and handle shape of the driver controllers of high-speed train on the drivers' comfort

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A R T I C L E I N F O

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A B S T R A C T

The design of a high-speed train controller affects the driver's health, operating performance and even safety. Understanding the effects of the design factors on the physical ergonomics of a high-speed train driver controller is essential for optimizing performance and safety. This study experimentally investigated the role of the operation type and handle shape on the physical ergonomics of a driver controller for a high speed train. Two controllers and six handles with pyriform shape, T-shape, sphere shape, cylinder shape and conical frustum shape were used in the experiment. The results indicated that a controller of the sagittal rotation operation type could significantly reduce the workload of the upper limbs compared to a horizontal rotation operation type controller. The handle shape had significant effect on the wrist angles, hand pressures and subjective assessment scores of upper limb fatigue, wrist discomfort and palm discomfort. The handle shape influenced the wrist angles and hand pressures depending on how the participants held the handle. The results demonstrated that the preferred operation type was rotation in the parasagittal plane and that the handle shape should be convenient for operating with a downward-facing palm posture. Among the tested shapes, the pyriform shape and T-shape were considered to be preferable.

1. Introduction

Hand tools are ubiquitous and integral to technological progress. Working with a poorly designed hand tool for long periods can cause upper limb fatigue or discomfort, perhaps even resulting in musculoskeletal injury or carpal tunnel syndrome (Konz and Mital, 1990; Myers and Trent, 1988; Tung et al., 2014). A poorly designed hand tool can also reduce operation precision (Van Veelen et al, 2001), resulting in operation accidents. The driver controller is a hand tool used by a high speed train driver to set the traction or braking level of a high-speed train. The driver controller is the most frequently used tool on the driver's desk in a high-speed train. Furthermore, when driving the train, the high speed driver needs to hold the controller all time according to the high speed train operating rules. The design of the controller influences the driver's health and operation performance and, thus, indirectly influences the operational safety of the train.

Functionality, physical interaction and appearance, which are the factors that should be considered in hand tool design, focus on the reliability, physical ergonomics and aesthetics of hand tools, respectively (Kuijt-Evers et al., 2004). In the factors identified above, physical interaction has many of its own metrics: posture and muscles, irritation and pain of hand and fingers, irritation of hand surface, and handle characteristics (Kuijt-Evers et al., 2004). The metrics correspond to the design factors of handle operation type, angle, size, shape, and surface, among others (Patkin, 2001).

Considerable research has been undertaken to analyze the effects of the above design factors on the physical ergonomics of various hand tools, such as how the grip force (Lowndes et al., 2015) is affected by the operation type; how wrist posture (Wang et al., 2000), wrist motion (Schoenmarklin and Marras, 1989a) and muscle fatigue (Schoenmarklin and Marras, 1989b) are affected by the handle angle; how grip strength (Marcotte et al., 2005; McDowell et al., 2012), pinch grip capacity (Ng and Saptari, 2014) and subjective comfort rating (Gonzalez et al., 2015) are affected by the handle size; how the hand performance (Dianat et al., 2015), hand muscle load (Dong et al., 2007), wrist and finger muscles activation (Popp et al., 2016), and grasping strategies (Seo and Armstrong, 2011) are affected by the handle shape; and how musculoskeletal disorders (Singh and Khan, 2014) are affected by

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the handle surface. Subjective methods such as questionnaires (Kuijt-Evers et al., 2005), Borg RPE scales and Borg CR-10 scales (Eksioglu, 2006; Li et al., 2013b) and objective methods such as EMG (Agostinucci and McLinden, 2016; Eksioglu, 2011; Hägg and Runeson, 2015), pressure mapping (Eksioglu and Kızılaslan, 2008; Kalra et al., 2015; Yun et al., 1992) and grip force (Eksioglu, 2004; Welcome et al., 2004) are common methods used to determine the physical ergonomics of hand tools.

Most of the previous research has focused on the handles of various surgical instruments or multipurpose instruments. Few studies have investigated the control handles of vehicles; those that have done so include the investigation of repetitive strain injuries when using hydraulic-actuation joystick controls in heavy vehicles (Murphy and Oliver, 2011; Oliver et al., 2007), which indicate that the operator upper limb movement direction has the most effect on upper limb angles and the dynamic armrest can significant decrease operator shoulder muscle activation, studies on the effect of gender, speed and road condition on the grip force of the steering-wheel in a full-size passenger car (Eksioglu and Kızılaslan, 2008), which shows that the absolute force and net grip force values for male drivers are significantly higher than those for female drivers while the vehicle speed and the road condition have no significant effects on these response variables, and studies on the subjective comfort of driver controllers in suburban electric trains (Stevenson et al., 2000), which show that the position of the master controller and brake controller can significantly affect the satisfaction of the driver.

The layout of the driver's desk, operation force, handle size, handle shape and operation type are design factors that should be considered when designing a high-speed train driver controller. There are a variety of standards and specifications associated with the design of high-speed train driver controllers. UIC 651 specifies that driver controllers must be located in the area of the optimal operational field for the driver (UIC 651, 2002). The operational forces of driver controllers are defined in TB/T 1391–2007 (TB/T 1391, 2007). Moreover, the handle diameter size of the driver controller is specified in GB/T 14775-1993 to be in the range of 35–50 mm with a recommendation size of 40 mm. The operation type of the driver controller is not subjected to compulsory requirements, although the operation type must have one of only two forms: rotation movement in the horizontal plane and rotation movement in the parasagittal plane, according to ISO9355-3(ISO 9355-3, 2006; Li et al., 2013a). The handle shape is also not subjected to compulsory requirements, although there are some recommended handle shapes provided by the UIC standard (UIC 612, 2009). In China, high speed train drivers have also reported discomfort in the arms and hands and have complained about the unreasonable design of the handle shape and operation type. Hence, in the present study, two repeated-measurement experiments were conducted to investigate the effects of controller operation type and controller handle shape on the comfortable use of the driver controller in a high-speed train. In the experiments, the wrist angle, grip pressure and subjective assessment scores of upper limb fatigue, wrist discomfort and palm discomfort were used as criteria to determine the suitable operation type and handle shape for the driver controller in a high-speed train. These results can be used as a basis for the design of driver controllers.

2. Method

2.1. Participants

In total, fifteen male participants were recruited from the student body at Beijing Jiaotong University. The participants were all right-handed. Table 1 shows the demographics of the participants.

Table 1
Demographics of the participants.

	Range	Mean	SD
Age (years)	21–29	23.27	2.43
Weight (kg)	60–79	70.87	6.10
Stature (cm)	170–179	174.20	2.91
Hand length (mm)	173–194	187.13	6.96
Hand breadth[a] (mm)	78–94	87.47	4.96
Hand thickness (mm)	25–40	31.47	4.55
Grip diameter[b] (mm)	43–48	45.37	1.48

[a] Hand breadth across finger knuckles.
[b] Thumb-middle finger grip diameter.

The participants were not high-speed train drivers but were trained to be familiar with the methods for operating driver controllers on the driver's desk. Participants with previous hand and upper extremity injuries, musculoskeletal disorders and surgeries were excluded from the study. Participants were asked to avoid strenuous exercise and physical activity for twenty-four hours before the experiment to preclude possible variations in fatigue sensation. The participants were able to understand the test procedures.

2.2. Experiment setup

A real CRH380A traction controller (see Fig. 1(a)) and a real CRH380A braking controller (see Fig. 1(b)) were used in the study. The traction controller is a hand tool used to increase or decrease power, and the braking controller is a hand tool used to apply the brakes. There were two handles on the traction controller. As shown in Fig. 1(a), to the left of the two handles is the traction level set handle and to the right is the direction set handle. Only the traction level set handle was used in the study. The handles of the two controllers featured a quick release structure and could be changed easily. The operation types of the traction controller and the braking controller were the parasagittal plane rotation type and the horizontal plane rotation type, respectively. The operation type of the braking controller could be changed to the parasagittal plane rotation type by rotating the controller 90° to the left, as shown in Fig. 1(c). The traction controller has a total of eleven traction level positions. The operation force of each traction level is 3.0 ± 0.5 kgf. The braking controller had a total of eight braking level positions. The operation force of each braking level is 1.3 ± 0.6 kgf.

Two simulated driver desks (desk I and desk II) were designed to provide participants with operation interfaces to use the controllers (see Fig. 2). The length, width and height of the desks were 1200 mm, 350 mm and 900 mm, respectively. A manual adjusted footrest whose angle range could be adjusted from 15° to 25° was placed under the desk. The space for knees, which is the space between the topside of the footrest and the underside of the desk, was 667 mm. All dimensions conformed to the requirements of UIC 651(UIC 651, 2002). The traction controller and the braking controller were assembled on desk I with normal installation mode and installation mode of rotating the controller 90° to the left, respectively. The normal installation mode represents the way the controller is installed on a real driver desk of CRH380A. The braking controller was assembled in desk II with the normal installation mode. Participants could operate the controller from both sides of the desk to ensure that they used their right hands. The desks came with a driver seat that was adjustable to ensure that the participants could obtain the most comfortable sitting position.

From a survey of fifty-two high speed trains and electric multiple unit trains around the world, six handles, representing the typical shapes of high-speed train driver controllers, were prepared. As shown in Table 2, the abbreviated name of the cylinder