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About Ride Comfort Due to Differences in Running Speed of Manual Attendant-Controlled Wheelchair

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ABSTRACT

Wheelchairs often cause discomfort to users owing to vibrations during movement, potentially causing motion sickness and annoyance. This study examined the influence of tire pressure on ride comfort in manual attendant-controlled wheelchairs. Traditionally, accurately measuring tire pressure in wheelchairs has been challenging because of the use of the English valve system. To address this issue, we developed a tire pressure indicator specifically for wheelchairs. Our research aimed to evaluate the effect of tire pressure variations on vibration in assistive wheelchairs. We also introduced a novel method to maintain a constant wheelchair speed by utilizing an electric wheelchair, thereby enhancing data reliability. This study investigated the impact of various running speeds on the ride comfort. We tested tire pressures at four different levels: 80, 160, 240, and 320 kPa, across three running speeds: low, medium, and high. We employed the semantic differential method to assess ride comfort, focusing on both stationary and dynamic states. The evaluation criteria included sitting comfort, a sense of security, and comfort of the buttocks in both the static and dynamic conditions, along with an additional criterion for the intensity of shaking during motion. Responses were recorded on a five-point scale ranging from 1 to 5. This paper presented the findings of these sensory evaluations, exploring how variations in driving speed and tire pressure affect the ride comfort.

Keywords: Wheelchairs, Running speed, Tire air pressure, Vibration, Ride comfort, Sensory test

INTRODUCTION

As of 2016, Japan's population with physical disabilities was estimated to be approximately 4.28 million, a number that has been steadily increasing. This includes 1.93 million people have been reported to have significant physical disabilities. With Japan's aging population, the demand for assistive devices is projected to increase annually. Wheelchairs, which are essential for mobility, are widely used by the elderly and individuals with physical disabilities. These include both assistance-type and self-propelled wheelchairs, the latter of which is often operated by caregivers. A notable issue with wheelchair use is the discomfort caused by vibrations during motion, potentially leading to motion sickness and annoyance, as documented in previous studies (Di Giovine et al., 2015a; 2015b; Cook and Polgar, 2008; Kitazaki and Griffin, 1998; LaPlante et al., 2010; Wilder et al., 1994; Booka et al., 2015). This research posits that tire pressure significantly affects wheelchair ride comfort. However, the extent of this impact remains unclear, partly because of the challenges in measuring tire pressure accurately using the conventional English valve system in wheelchairs. To address this gap, we developed a tire pressure indicator in collaboration with the Hiroshima International University (Shoichiro et al., 2019; 2020; 2021; 2022). This study aims to evaluate how changes in tire pressure affect vibrations in assistive wheelchairs using this newly developed tire pressure display. Additionally, we designed a device to propel an assistive wheelchair at a constant speed using an electric wheelchair to enhance data reliability. This study investigated the impact of tire pressure on the ride comfort of wheelchairs, focusing on the reduction of vibration-induced discomfort.

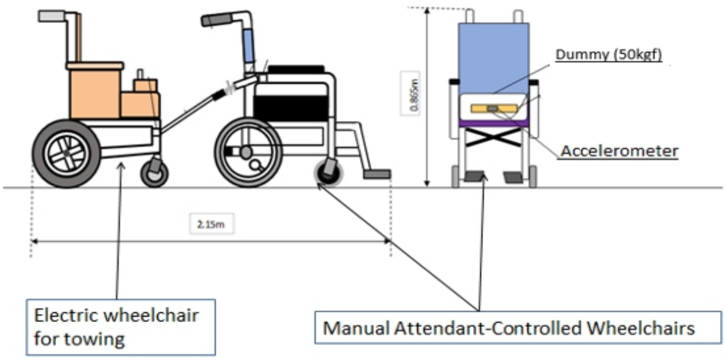
VIBRATION MEASUREMENT EXPERMENT

Experiment Method

A dummy heavy object was placed on the seat of the assisted wheelchair with the vibration measurement device, and a triaxial accelerometer was attached to it. In addition, an electric wheelchair was run at a constant speed on uneven road surfaces at regular intervals. Fig. 1 shows the outline of the vibration-measuring device manufactured in this study.

Vibration Measurement

The tire pressure indicators made for this study were attached to both sides of the rear wheels of the assistive wheelchair, and a 50-kgf dummy weight was placed on the seat. Acceleration in three directions, up-down, front–back and left–right, was measured by a three-axis accelerometer attached on the heavy object.



(a)Side view (b) Front view

Figure 1: Experimental procedure.

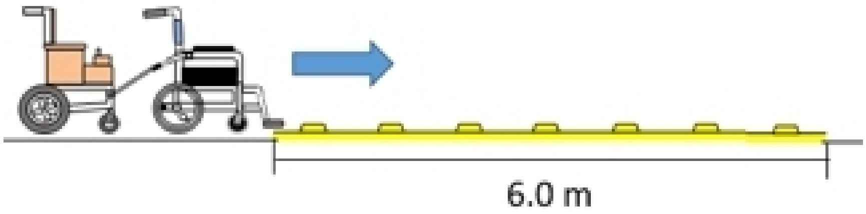


Figure 2: Experiment procedure.

Table 1. Experimental conditions.

Acceleration sensor installation position	Dummy weight (kgf)	Tire pressure (kPa)	Number of trials (times)
On a dummy heavy object installed in an assisting manual wheelchair	50	80 160 240 320	10

Experimental Methods

The vibration-measuring device shown in Fig. 1 is run on a linear block. A linear block of 300-mm square was used. When spread, it is 6.0 m long and 0.9 m wide. The manual assistive wheelchair was pushed out by the electric wheelchair so that the traveling speed was 0.33 m/s. Fig. 2 shows the outline of the experiment. The tire pressure of the manual assistive wheelchair was measured in four pressure conditions: 80, 160, 240, and 320 kPa. Ten trials were made for each tire pressure, totaling to 40 times. Table 1 shows the measurement pattern. The FFT analysis was performed using numerical analysis software for acceleration in three directions measured by a triaxial accelerometer. MATLAB (MathWorks Inc., Natick, USA) was used for the numerical analysis. The maximum power spectrum, frequency at the maximum power spectrum, and integral value from the FFT-analyzed data were obtained. Then, how they change with changes in tire pressure was evaluated.

Experimental Results

FFT analysis was performed on the measured acceleration data in three directions: front and back, left and right, and up and down. Based on the results, comparisons between each tire air pressure and the integrated value of the power spectrum of the manual wheelchair for assistance are shown in Figures 3. It can be seen that the longitudinal and vertical vibrations are larger than the horizontal vibrations. It can be seen that vibration is suppressed between 80kPa and 240kPa at low and medium speeds. In particular, 240kPa is the lowest. Conversely, at medium speeds, the vibration is strongest at 320kPa. It can be seen that at high speeds, the values remain almost the same.

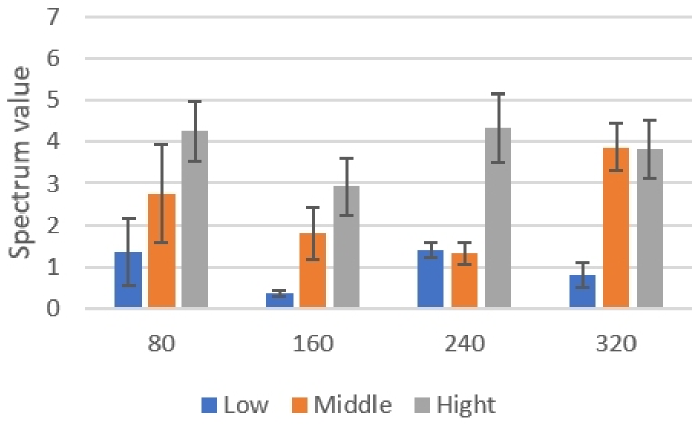


Figure 3: Spectrum integral value.

RIDE COMFORT EVALUATION EXPERIMENT

Overview of Evaluation Experiment

The experiment involved 44 healthy subjects for the stationary evaluation and 16 subjects for the dynamic evaluation at different speeds: low (0.33 m/s), medium (0.66 m/s), and high (1.00 m/s). The semantic differential (SD) method was used for evaluation in two scenarios: stationary and motion. The common evaluation criteria in both scenarios were sitting comfort, sense of security, and buttock comfort. An additional criterion, that is, the strength of shaking, was assessed during motion. Responses were recorded on a 9-point scale ranging from −4 to +4. Four tire pressure settings were tested: 80, 160, 240, and 320 kPa.

Evaluation Method

An electric wheelchair was used to maintain consistent speed while pushing the manual assistance wheelchair (Figure 1). The test track consisted of linear blocks spaced 6.0 m apart. Participants were first seated in a stationary manual assistive wheelchair at each tire pressure setting and then responded to a questionnaire. They then repeated the process after driving in the wheelchair, totaling 12 trials across 4 tire pressures and 3 running speeds.

Evaluation Experiment Results

Figure 4 illustrates the impact of tire pressure on sitting comfort, sense of security, and buttock comfort when stationary, showing no significant variation owing to tire pressure changes. Figures 5–8 present the outcomes for the same comfort parameters, including shaking strength, across different tire pressures at low, medium, and high speeds. Notably, at low speeds, tire pressures of 160 and 240 kPa received better evaluations than the others. At medium speeds, 160 kPa was rated as the highest. At high speeds, the evaluations improved with an increase in the tire pressure. Figures 9–12 detail these comfort parameters at varying speeds for each tire pressure setting (80, 160, 240, and 320 kPa), highlighting that at high speeds, higher tire pressures are favored for better comfort.

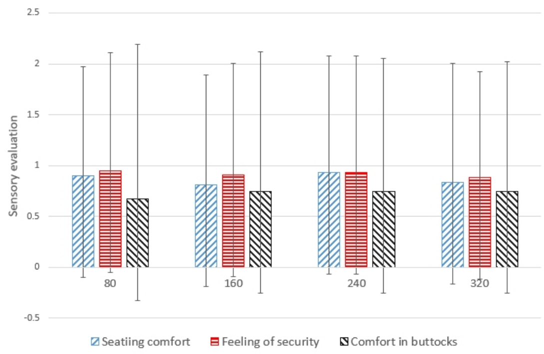


Figure 4: Sensory evaluation when stopped.

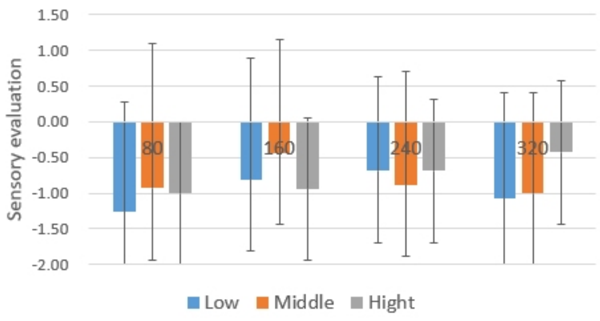


Figure 5: Sensory evaluation of seating comfort based on differences in tire air pressure.

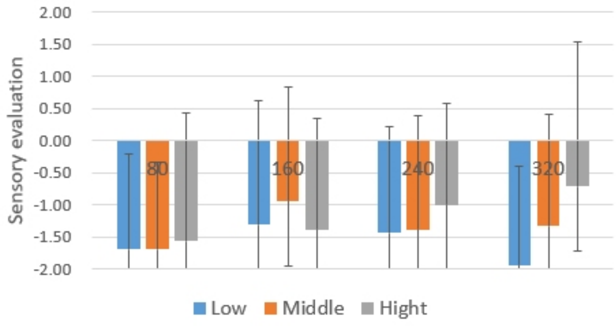


Figure 6: Sensory evaluation of feeling of security based on differences in tire air pressure.

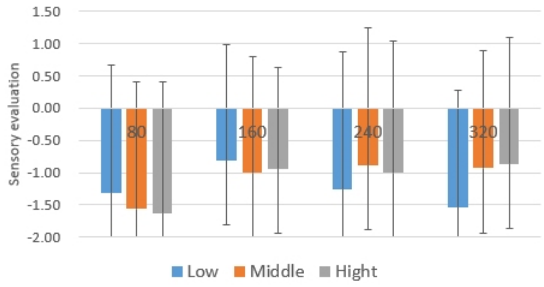


Figure 7: Sensory evaluation of comfort in buttocks based on differences in tire air pressure.

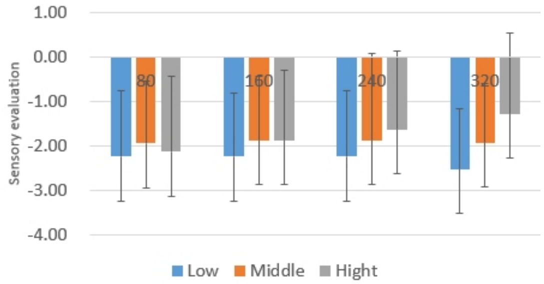


Figure 8: Sensory evaluation of swing strength based on differences in tire air pressure.

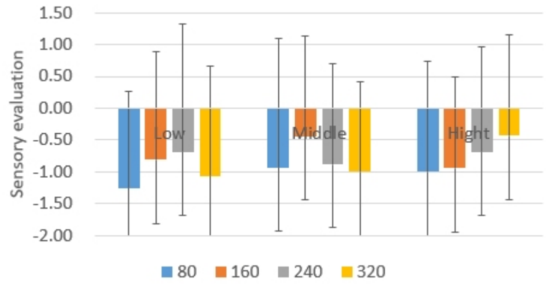


Figure 9: Sensory evaluation of seating comfort based on differences in running speed.

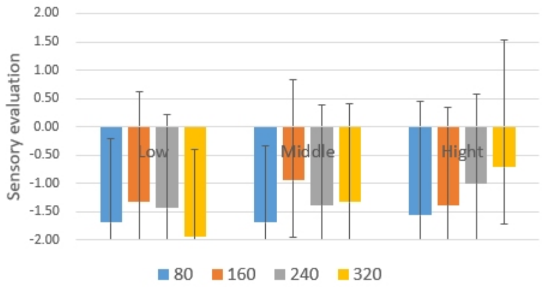


Figure 10: Sensory evaluation of feeling of security based on differences in running speed.

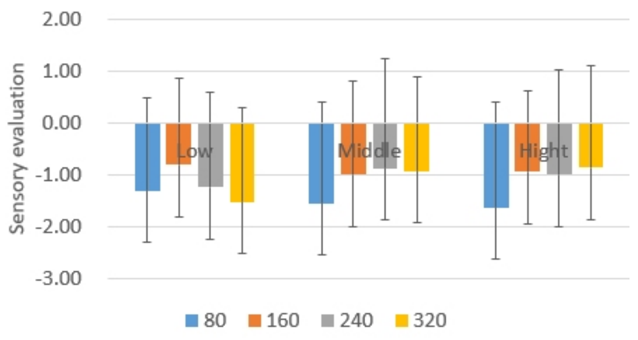


Figure 11: Sensory evaluation of comfort in buttocks based on differences in running speed.

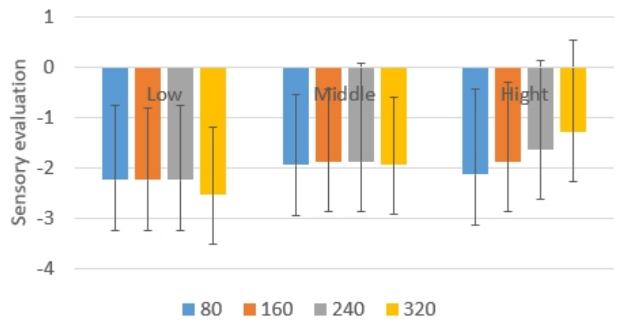


Figure 12: Sensory evaluation of swing strength based on differences in running speed.

DISCUSSION OF EXPERIMENTAL RESULTS

The experiment highlighted variations in sensitivity assessments influenced by driving speed and tire air pressure. However, the limited number of participants (16) during the dynamic phase of the experiment only allowed the identification of general trends. However, in vibration analysis using FFT, the strength of vibration is stronger at higher speeds, but this trend was not observed in sensory evaluation. The resonant frequency of the human body is said to be around 5Hz in the vertical direction. The running speed this time was 4.4Hz at low speed, 8.8Hz at medium speed, and 13.3Hz at high speed, and it can be seen that the low speed is close to the resonant frequency of the human body. This is presumed to be one of the reasons. In addition to this, another possible cause is that the running distance is constant at 6m. It is thought that the longer the running time, the worse the sensory evaluation becomes. It may be necessary to consider such matters.

In this experiment, linear blocks designed for the visually impaired were used to simulate a basic uneven road surface for measurement. It is important to note that real-world conditions often present more complex challenges, including various step sizes and irregular, shorter-period vibrations. In light of these findings, future experiments should be conducted. This will involve a larger cohort of elderly individuals and people with disabilities, utilizing the SD method for sensory evaluations. The aim is to further elucidate the relationship between the tire pressure and vibration.

CONCLUSION

In this study, a manual attendant-controlled wheelchair was equipped with an air pressure indicator suitable for English-style valves to measure vibrations at different running speeds under controlled conditions. The results indicated that vibrations tended to increase with higher tire pressures, leading to decreased ride comfort. Conversely, lower tire pressures require greater effort to push the wheelchair. Future research should focus on determining the optimal tire pressure that balances the comfort and ease of use for caregivers and assistants in various operational scenarios.

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