Steering Accuracy and Sitting Symmetry During Simulated Driving in Drivers with Chronic Stroke

Hwa-Kyung Shin [1*], Young Uk Ryu [2], Ho-Cheol Lee[3]
[1,2] *Department of Physical Therapy, College of Bio and medical science, Daegu Catholic University,Gyeongsan, Korea*
[3] *School of Mechanical and Automotive Engineering, Daegu Catholic University*
[1] *hkshin1@cu.ac.kr;* [2]*ryu3091@cu.ac.kr,* [3] *hclee21@cu.ac.kr*

Abstract : The steering while sitting in the driver's seat is one of the most basic and important driving performances. The purpose of this study was to investigate the characteristics of sitting symmetry and steering accuracy of stroke drivers compared to healthy drivers, and to examine the correlation between them.Fifteen stroke drivers and fifteen healthy drivers participated in this study. Both group performed the large and small s-curve driving during five minute. Accuracy index (AI) was measured by comparing the performance line that drove along large s-curve and small s-curve (target line). Symmetry index (SI) was calculated by difference of right and left seat pressure.The steering AI of stroke drivers was significantly lower than that of healthy adult drivers (p <0.05), and the AI of small S-curves was significantly lower than that of large S-curves (p <0.05). The sitting SI of stroke drivers was significantly greater than that of healthy driver (p <0.05). Also, AI of stroke driver showed significant correlation with SI in both S-curve. However, healthy drivers had no significant correlation between SI and AI (p> 0.05). SI and AI are valid variables for evaluating the stroke driver's driving ability in off-road environment.

Key Words: driver, evaluation, rehabilitation, stroke.

1. INTRODUCTION :

Driving is essential for physically, socially and economically independent living. Driving is a complex task that requires the integration of visual, motor, cognitive and perceptual skills. Therefore, the driver must constantly check, anticipate and make decisions in response to the changing driving environment. Despite advances in automotive technology, all vehicle control depends on human behavior. Among them, steering operation while sitting in the driver's seat is one of the most basic and important driver operations.

After a stroke, most drivers want to drive again as before. Stroke is a lesion of the upper motor neuron, and has difficulty in functional activity due to hemiplegia, muscle weakness, decreased sensory and motor control, and asymmetric posture control. In particular, more than 69% of hemiplegic patients experience the disability of the upper extremity, and suffer from difficulty in driving as well as activity of daily living due to impaired motor control. Therefore, it is necessary to study about the qualitative evaluation of upper limb function in order to expect positive results for the driving performance of stroke drivers.

Mainly used methods to evaluate the driving performance include the on-road evaluation conducted on a real road or a limited course, and the off-road evaluation with driving simulator that simulates a real environment(Betz et al., 2014)(Mazer et al., 2015). On-road evaluation is an accurate and scientific evaluation method for evaluating driving performance, but it is difficult to use widely because of time, cost, and accident risk(George and Perrelle, 2017). However, the off-road evaluation, such as the driving simulator evaluation, can predict the results of the on-road evaluation and was used as an appropriate alternative for evaluating the driving performance of stroke patients for reasons of low cost and safety(Green, 2015). The goal of driver rehabilitation is to determine whether or not driving is possible through an evaluation of driving performance including motor and cognitive functions, and then to help the driver to drive safely through a multi-dimensional driver rehabilitation program if driving is possible(King, 2018; Lowe et al., 2014).

Research using off-road evaluation using a driving simulator has been recently conducted. However, studies on the evaluation of driving ability reflecting the pathological characteristics of stroke are insufficient, and in particular, studies on the characteristics of asymmetric posture control and steering and the correlation between them are very rare. The purpose of this study was to investigate the characteristics of sitting symmetry and steering accuracy of stroke drivers compared to healthy drivers, and to examine the correlation between them.

2. METHODS

Participants

This study was conducted for stroke drivers (n=15) and healthy drivers (n=15) who have a driver's license and have more than 3 years of driving experience. The healthy driver group was selected as those without neurological and musculoskeletal disorders and those without hearing and vision disorders. The stroke driver was selected as those diagnosed with a stroke, those passed more than 6 months after the stroke, those has a score of 24 or higher on the Korean Mini-mental State Examination-Korean Version (MMSE-K) score, and those is no pathological problem to the visual and vestibular systems. All subjects received sufficient explanation about the experiment process before voluntarily experimenting and voluntarily agreed to participate in the experiment. The general characteristics of the subjects are shown in Table 1. The ethical committee of Daegu Catholic University has approved this study (CUIRB-2019-0023).

Experimental equipment and procedures

Steering Accuracy

Driving simulator equipment was used to evaluate driving performance(Figure 1A). The driving simulator equipment consists of a display unit, a control unit, a mode selecting unit, a steering wheel, a acceleration pedal, and a brake. The target waveform of the S-curve appears on the monitor, and the experimenter tracks the target waveform by operating the steering wheel. Large and small waveforms built according to the amplitude of the s-curve are stored in the computer. When the experiment is started, a target waveform is drawn on a computer monitor, which is called a target line. The line that appears when the drivers is steering along the target line is called a performance line.

The target line and the performance line compared according to the accuracy index (AI) introduced and proven by Carey et al. (2002) (Carey et al., 2002). E is the root mean square error between the target line and the performance line. P is the root mean square difference between the target line and the center line (the line separating the upper and lower parts of the target line). The size of P is determined by the scale of the y-axis, which is the moving distance along the road width. Therefore, AI showed the difference in performance among subjects by normalizing the moving distance of each subject. The maximum AI score is 100%. The larger the AI, the higher the steering accuracy.

$$AI = \frac{100\ (P-\ E)}{P}$$

Before the experiment, the researcher explained the overall experiment process to the subject. The subject adapted to the driving scenario before the experiment through a simulation for 2 minutes, and after resting for 5 minutes, the target tracking evaluation of the driving simulation was performed. The total experiment time was 5 minutes.

Seating Symmetry

Force Sensitive Application (FSA) 4.0 software was used to measure the sitting pressure (Figure 1B). The FSA is a flexible pressure sensitive mat that is connected to a computer and contains 256 sensors (thickness 0.36 ㎜,). The sampling rate of FSA data was 5 Hz. Pressure data were collected while the subject was driving for 5 minutes with both hands in a comfortable sitting position in the driver's seat of an FSA mated with driving simulator.

The representative value of the left and right peak pressures was obtained by averagingthe values of 4X4 sensors around the highest value. In 5 minutes driving, the first 5 seconds and the last 5 seconds were excluded from the analysis. To quantify the sitting symmetry, the absolute value of the symmetry index (SI) was used(Au-Yeung, 2003). The SI can be seen that the closer to 0, the higher the left-right symmetry of the sitting position(Won-Jin and Moonyoung, 2013).

Symmetry Index (%) = |Variables (non-paretic side)-Variables (paretic side)/Variables (non-paretic side)+Variables (paretic side)| × 2 × 100

Statistical Analysis

For statistical analysis, SPSS version 19.0 was used. Descriptive statistics were used to analyze the general characteristics of the subjects. The steering AI was analyzed using theone way repeated ANOVA. The SI of seat pressure was analyzed using an independent sample t-test. Pearson correlation analysis was used to correlate steering AI and sitting SI.The significance level was set at 0.05.

3. RESULTS

15 stroke drivers (8 left hemiplegic, 7 right hemiplegic) and 15 healthy adults participated in the experiment. The average age of the subjects was 49.5 ± 9.5 years old for stroke drivers and 50.05 ± 9.9 years for stroke drivers. The average height was 169.1 ± 4.04 cm for stroke drivers and 171.9 ± 4.07 cm for healthy drivers. The average weight was 69.5 ± 5.82 kg for stroke drivers and 71.3 ± 6.45 kg for healthy drivers. The average duration of stroke onset was 28.1 ± 13.08 months, the mean MMSE score was 28.1 points / 30 points, the modified Ashworth scale was G0, and there was no joint contracture

The steering AI of stroke drivers was significantly lower than that of healthy adult drivers ($p <0.05$), and the AI of small S-curves was significantly lower than that of large S-curves ($p <0.05$)(Figure 2). In addition, the difference in AI between the large S-curve and the small S-curve was significantly greater in stroke drivers than in healthy drivers ($p <0.05$)(Figure 2). The sitting SI of stroke drivers was significantly greater than that of healthy driver ($p <0.05$)(Figure 3). This means that stroke drivers have poor sitting symmetry compared to healthy drivers. As a result of correlation analysis between steering AI and sitting SI, AI of

ISSN 2515-8260 Volume 07, Issue 01, 2020

stroke driver showed significant negative correlation with SI in both S-curve. However, healthy drivers had no significant correlation between SI and AI ($p > 0.05$).

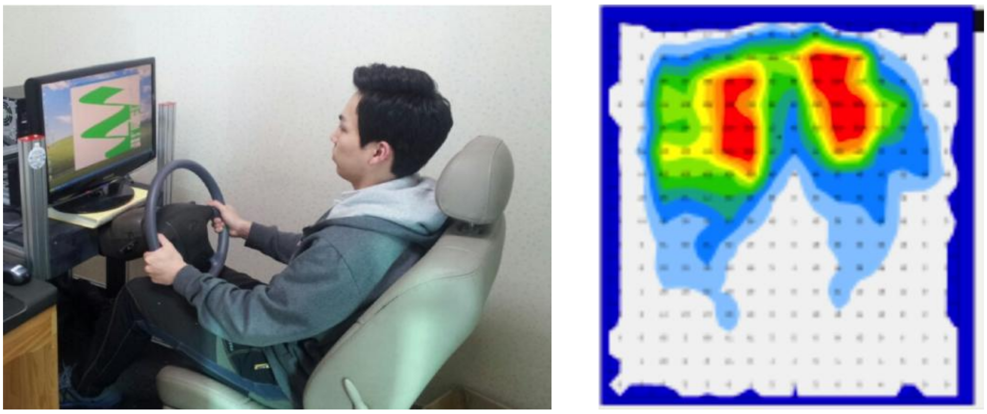

Fig 1. Experimental equipment A. driving simulator for steering accuracy, B. Result of Force Sensitive Matrix array for seating symmetry

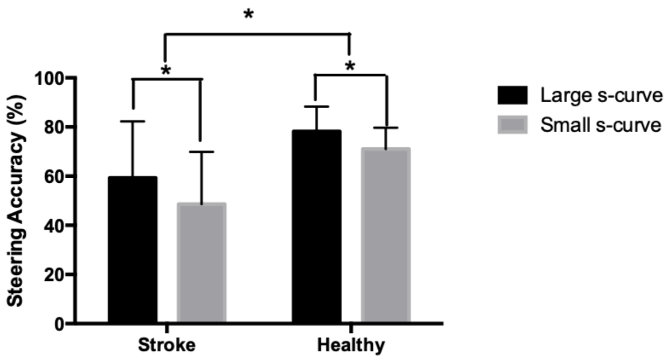

Fig 2. Comparison of steering accuracy on speed between stroke driver and healthy driver P<0.05

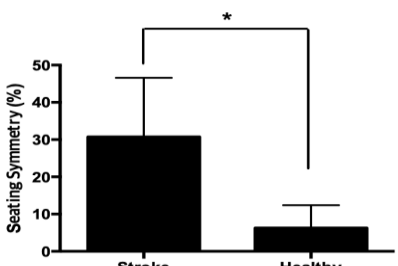

Fig 3. Comparison of seating Symmetry between stroke driver and healthy driver
$P<0.05$

4. DISCUSSION

The main purpose of the present study was to investigate the characteristics of sitting symmetry and steering accuracy of stroke drivers compared to healthy drivers, and to examine the correlation between them.

The steering AI of the stroke driver was significantly lower than that of the healthy driver, and the AI difference between the large s-curve and the small s-curve was significantly higher in the stroke driver than in the healthy driver. The results of this study showed that stroke drivers are more affected by the driving environment than healthy drivers. The small s-curve has a relatively small amplitude and a short travel distance. It is assumed that the accuracy of a small s-curve is lower in stroke patients because the smaller the range of delicate movements, the more difficult it is to control movement. In an aiming task, Fitts' law predicts a linear relationship between movement time and spatial accuracy, because the human motor control system requires more time to move effectors for spatial accuracy(Fitts). Visuomotor tracking studies have demonstrated that a slow and fine movement causes an increased non-smoothness of movement. The degree of the non-smoothness of the movement is dependent on the utilization of feedback information that becomes outstanding when a closed-loop feedback control is required to track an external signal(Shin et al., 2008). During increased closed-loop control, motor control systems require frequent updating of the limb's movements, acting to external events, in order to reduce tracking error. In the present study, the slower small s-curve condition required increased closed-loop control with frequent updating of the limb's movements. Importantly, patients with stroke have impaired proprioception that results in decreased ability in the sensorimotor feedback loops. Therefore, it is suggested that training fast and large s-curves and then training slow and small s- curves is effective in improving the steering ability(Shin et al., 2008).

The sitting SI of stroke drivers was significantly greater than that of healthy drivers. It was possible to estimate the asymmetry of the driving posture due to hemiplegia, and further the possibility of asymmetric driving performance. Therefore, it can be considered that the asymmetry of stroke patients affects the seat pressure during driving and thus decreases the driving performance. A recent study reported that wheelchair posture training improved sitting balance and reduced back pain, thus increased patient satisfaction(Pomeroy et al., 2003)(Kilincsoy et al., 2016). Therefore, the improvement of sitting balance by increasing the symmetry of seat pressure may be effective in driving rehabilitation of stroke patients, and is similar to the results of this study(Kim and Chang, 2013).

Steering accuracy and sitting symmetry was significantly correlated in stroke drivers. However, healthy drivers did not show a significant correlation. This means that the steering ability of stroke drivers has a greater effect on stroke drivers with posture asymmetry than healthy adults.In particular, the correlation was high in small s-curve requiring precise, delicate and high visuomotor coordination. This means that a more stable sitting balance is required when driving on a relatively difficult road(Pellerito, 2005). Therefore, if you intend to improve the steering ability in driver rehabilitation, you should first make a treatment plan to increase sitting balance, and it may be efficient to practice large s-curves first than small s-curves.

The stage of driver rehabilitation proceeds in the order of clinical assessment, on-road driving evaluation, vehicle modification, driving education and training, total fitting and operation assessment. Since on-road driving assessment includes accident-related risk factors, it is effective to first accurately screening whether or not driving is possible at the stage of off-road clinical assessment(Aufman et al., 2013). In addition, both quantitative and qualitative evaluations should be conducted for off-road assessments, and evaluation items should be further diversified and subdivided.

The limitation of this study is that it is difficult to generalize the results of the study due to the small number of subjects, and the diversity of applied roads is insufficient.Therefore, future studies will need to increase the number of subjects and compare the characteristics of the steering ability according to the brain injury area. It is necessary to evaluate various steering abilities by adding regular or irregular, low or high frequency driving modes to driving scenarios.

5. REFERENCES

[1] Au-Yeung SSY. Does weight-shifting exercise improve postural symmetry in sitting in people with hemiplegia? Brain Inj. 2003;17(9):789-797.

[2] Aufman EL, Bland MD, Barco PP, Carr DB, Lang CE. Predictors of return to driving after stroke. Am J Phys Med Rehabil. 2013;92(7):627-634.

[3] Betz ME, Dickerson A, Coolman T, Schold Davis E, Jones J, Schwartz R. Driving rehabilitation programs for older drivers in the united states. Occup Ther Health Care. 2014;28(3):306-317.

[4] Carey JR, Kimberley TJ, Lewis SM, Auerbach EJ, Dorsey L, Rundquist P, Ugurbil K, Carey JR, Kimberley TJ, Lewis SM, Auerbach EJ, Dorsey L, Rundquist P, Ugurbil K. Analysis of fMRI and finger tracking training in subjects with chronic stroke. Brain: A Journal of Neurology. 2002;125(4):773-788.

[5] Fitts PM. The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol. 1954;47:381-389.

[6] George S, Perrelle N. Simulator-based occupational therapy driving intervention can reduce driving errors on a simulator-based driving assessment in combat veterans with polytrauma. Aust Occup Ther J. 2017;64(6):512-513.

[7] Green E. Driver rehabilitation services and their role in the care plan. Journal of Nurse Life Care Planning. 2015;15(2):862-867.

[8] Kilincsoy U, Wagnera A, Vink P, Bubb H. Application of ideal pressure distribution in development process of automobile seats. Work. 2016;54(4):895-904.

[9] Kim WJ, Chang M. A comparison of the average sitting pressures and symmetry indexes between air-adjustable and foam cushions. J Phys Ther Sci. 2013;25(9):1185-1187.

[10] King L. Advances in vehicle technology and their implications for life care planning: The perspective of a driver rehabilitation specialist. Journal of Life Care Planning. 2018;16(3):35-39

[11] Lowe E, Drouin N, Venhovens PJ, Brooks JO. Understanding the needs of hand control users, driver rehabilitation specialists, and dealers/installers. Occup Ther Health Care. 2014;28(4):394-409.

[12] Mazer B, Gélinas I, Duquette J, Vanier M, Rainville C, Chilingaryan G. A randomized clinical trial to determine effectiveness of driving simulator retraining on the driving performance of clients with neurological impairment. Br J Occup Ther. 2015;78(6):369-376.
[13] Pellerito J. Driver rehabilitation and community mobility: Principles & practice. Mosby, 2005.
[14] Pomeroy VM, Mickelborough J, Hill E, Rodgers P, Giakas G, Barrett JA. A hypothesis: Self-propulsion in a wheelchair early after stroke might not be harmful. Clin Rehabil. 2003;17(2):174-180.
[15] Shin HK, Cho SH, Jeon HS, Lee YH, Song JC, Jang SH, Lee CH, Kwon YH. Cortical effect and functional recovery by the electromyography-triggered neuromuscular stimulation in chronic stroke patients. Neurosci Lett. 2008;442(3):174-179.
[16] Won-Jin K, Moonyoung C. A comparison of the average sitting pressures and symmetry indexes between air-adjustable and foam cushions. Journal of Physical Therapy Science. 2013;25(9):1185-1187.