# Development of Modified Motorcycle Simulator Assessment and Training System for the Spinal Cord Injury Patients

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## Abstract

*Independence of locomotion is vital to the disables activities of daily living (ADL) and social activities. The key functional deficit of spinal cord injuries (SCI) that usually decreases the SCI patients' performance in locomotion is poor sitting balance. Modified motorcycles are the most popular transportation by SCI patients in Taiwan. Virtual reality (VR) has the potential to provide a more safe and interesting way to teach skills of practical relevance, but there is no research documenting the applications on modified motorcycle. Therefore, the purpose of this pilot study is to investigate the feasibility of assessment and training with a modified motorcycle simulator for the spinal cord injury patients. We designed the pilot study to analysis how participants react in VR environment and in the real world and what elements might be sensitive. We compared the performance of the normal participant and the SCI participant in VR environment, and compared the performance of the SCI participant in VR environment and in the real world. This is a first step toward the following studies in the future aimed at determining what elements should be used to analysis the performance and the potential of using VR system to evaluate and train SCI patients who are in the rehabilitation.*

## 1. Introduction

Spinal cord injuries usually damage to the central or peripheral nervous systems that cause problems of sensory and motor functions. The key functional deficit of spinal cord injuries (SCI) is poor balance and it usually makes the patients' performance of activities of daily living decrease and influences their quality of life [1]. In Taiwan, there are 1,200 new spinal cord injury patients every year, and the main cause is car accidents (50%), the mean age is 44.45 years old, 80.5% are male, and most cases are young adults[2]. They had economic and social live needs. But the limitation of transportation result in their participation of social activity decreased. And, transportation was one important factor for SCI patients' quality of life, too [3]. Moreover, owning the modified vehicle can affect the employee status and the sense of freedom and independence [4]. But only 20% of SCI patients used modified vehicles including 15% modified motorcycles and 5% modified cars. One major reason why they do not used modified vehicles is because the shadow of a car accident is still in their mind. A transport tool, motorized scooter, Helen Hoenig et al. indicated that the biggest risk factor was the accident [5]. This reveals assessment and training is necessary before riding modified motorcycle on road.

Virtual reality (VR) is a new high technology developed in recent years and has been used in many areas, such as aviation, military, or medical operation training. Now it is used in the patients' rehabilitation. Training with VR has many advantages, such as more safety, interesting, and users have less discouragement [1]. The most important advantage is that it allows participants make decisions under potentially dangerous environment. Although there are many studies about the motorcycle simulator designing and development, but there is no research documenting the applications on patients' rehabilitation.

Kim et al. found improvement in cycling velocity and a decrease in the deviation from the path after virtual cycling training with normal people [6]. Some studies showed that fear of driving decreased after the experience in the driving simulator [7]. The driving skills were also improved after training courses. These results revealed that training with VR systems is possible. In our previous study, we have found similar body reaction could be induced in VR environment by less acceleration than in the real world [9] and significant performance difference of center of pressure (COP) between normal and SCI patients [8-9]. But to date, the report of the performance evaluation in the real world after training with VR systems is still very limited. Therefore, the purpose of this pilot study is to investigate the feasibility of assessment and training with a modified motorcycle simulator for the spinal cord injury patients.

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## 2. Experiment

### 2.1. Subjects:

This pilot study included two participants. One is normal male, aged 23 years old and one is SCI patient with ASIA impairment scale at the level of T9, aged 71. Both of them had abundant of experiences on motorcycles. The SCI patient has been riding modified motorcycle since he was 30 years old.

### 2.2. Materials and Method:

In the VR environment, we designed a modified motorcycle simulator with a single axis platform, which could tilt forward and backward, and a pressure board under the sitting cushion. A three-axis accelerometer was fixed in the chest of the participant to record the motion of the trunk during the experiment. Both participants rode in the VR scene designed base on the urban road. There are several different situations in the scene, including straight line with flat road, roadblock, roadblock and barriers, up-hill and down-hill. The speed, break, accelerator, steering, total time, and tract of COP were record to evaluate the performance of riding.

In the real world, we used the SCI participants modified motorcycle that the user with wheelchair can ride on straightly, as shown in figure 1, to do an U shaped route on road test. Only the SCI patient participated in this on road test, and three three-axis accelerometer were be used. One was fixed on the single axis platform floor, one was on the steering, and one was fixed in the chest of the SCI rider to record the motion on the human body and the vehicle. Total time was also recorded as the performance index of riding.

## 3. Result

The performance comparison between two participants in the VR environment is presented in table 1. Response time is defined as the time from the body sway started after the platform tilting to the body sway stopped. The response time for the normal person was 386.6 seconds, and 561.1 seconds for the SCI. We found that in a steady situation, like the straight line, the normal person participant's total displacement of COP is smaller than the SCI participant, but in unsteady situation, such as riding over the roadblock or up-hill, the normal person participant's total displacement of COP is larger than the SCI participant.

The average speed of normal person is higher in all VR environment situations and but the reaction time is shorter than the SCI patient. And the most interesting thing is the normal participant didn't use the brake in all situations.

In the on road test, we captured and compared the acceleration recorded from the SCI participant in the VR environment and on road test, as presented in table 2.


**Figure 1: The modified motorcycle**

The acceleration in the VR environment was much smaller than the acceleration in the real.

Figure 2 and 3 displayed the acceleration on the steering and floor of forward and backward direction of the modified motorcycle during the on road test.

| | Distance (M) | Time(S) | Speed(m/s) | Acceleration (g) (average ± SD) | Total Acceleration (g) |
|---|---|---|---|---|---|
| Straight line | 18.39 | 3.75 | 23.56 | 0.0250 ± 0.0026 | 11.7764 |
| On road test | 18.39 | 7.00 | 2.60 | 0.0698 ± 0.01736 | 61.0259 |

**Table 2: The acceleration in VR environment and on road test**

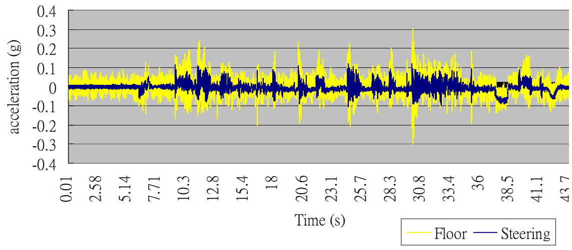


**Figure 2: The acceleration of on road test**

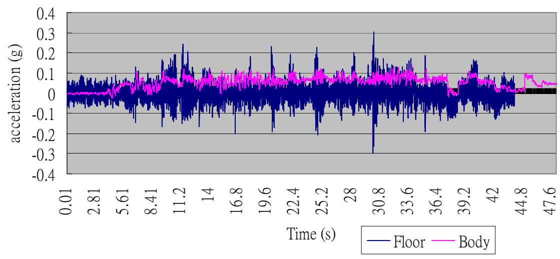


**Figure 3: The acceleration of on road test**

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| | Straight line | | Roadblock | | Roadblock before barriers | | Roadblock between barriers | | Up-hill | | Down-hill | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCI | Normal | SCI | Normal | SCI | Normal | SCI | Normal | SCI | Normal | SCI | Normal |
| **Total displacement of COP of X-axis (cm)** | 3.43 | 2.31 | 25.26 | 17.18 | 29.94 | 17.03 | 13.16 | 21.12 | 24.46 | 23.26 | 20.77 | 21.10 |
| **Total displacement of COP of Y-axis (cm)** | 4.42 | 2.62 | 70.30 | 89.49 | 65.74 | 74.10 | 45.63 | 103.01 | 38.27 | 82.42 | 45.17 | 91.58 |
| **Total displacement of COP (cm)** | 6.19 | 4.00 | 79.49 | 93.73 | 79.16 | 78.23 | 49.76 | 107.52 | 50.60 | 90.27 | 55.28 | 97.59 |
| **Average speed (km/hr)** | 26.38 | 49.10 | 9.83 | 44.68 | 20.11 | 50.63 | 15.70 | 38.50 | 25.98 | 48.69 | 34.13 | 47.85 |
| **Steering %** | 0.33 | -0.13 | -3.34 | 0.84 | 0.15 | 0.95 | -0.08 | 0.60 | -0.91 | 0.04 | 0.19 | 0.68 |
| **Accelerator %** | 22.92 | 47.25 | 16.81 | 41.96 | 23.30 | 47.60 | 18.96 | 26.51 | 25.57 | 42.42 | 32.22 | 46.33 |
| **Break %** | 1.44 | 0.00 | 6.73 | 0.00 | 1.99 | 0.00 | 0.64 | 0.00 | 1.78 | 0.00 | 1.03 | 0.00 |
| **Response Time (s)** | — | — | 6.44 | 5.38 | 4.44 | 3.88 | 5.81 | 6.50 | 6.38 | 6.13 | 5.69 | 5.46 |

**Table 1: The results of two participants in VR environment**

## 4. Discussions

In our previous study [9], 12 normal people and 5 SCI patients were included, we recorded the COP and the three-axis accelerometer which was fixed in their chest information during they rode over the roadblock in the VR environment to see their performance. The result showed that the COP displacement of Y-axis of normal people was bigger than SCI patients. In figure 4, we can see that when participants rode over the roadblock, the tendency of COP movement was similar, but the normal participant's displacement magnitude was higher than SCI participants. Normal people have better lower extremity control and balance ability, so they can bear more COP changes.

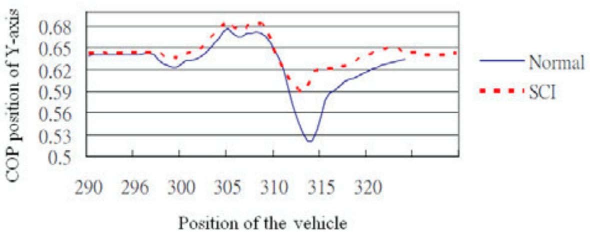


**Figure 4: The reactions of Normal and SCI subjects**

This pilot study showed very similar results. The normal participant's COP displacement is bigger than the SCI participant and in Y-axis has the most obvious trend. So, it may indicate the displacement of COP of Y-axis, in segmental plan, is a sensitive index to evaluation the balance ability [8]. And the shorter response time with more displacement may stand for a better balance ability.

In addition, in the previous study, the accelerometer information also was collected by the accelerometer information during these normal participants riding over the roadblock in the real world and compared with the data in VR environment. They rode over the roadblock with three different speeds including 20 km/hr, 30km/hr, and 40 km/hr. The comparison between the road test and the VR simulation are presented in figure 5 and 6.

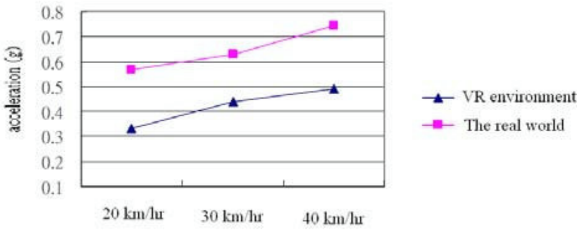


**Figure 5: The acceleration of riding over the roadblock in VR environment and the real world**

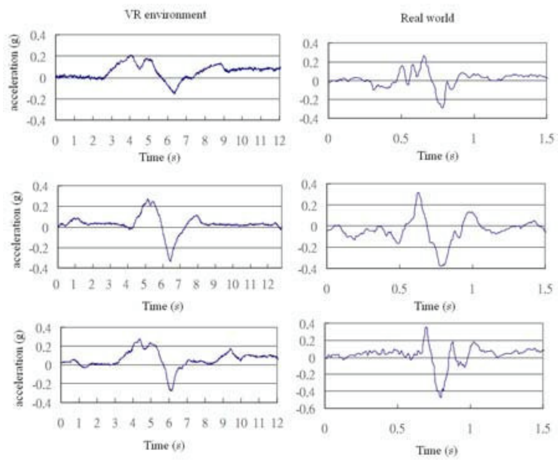


**Figure 6: The acceleration of riding over the roadblock in VR environment.**

The result reveals that although the acceleration in VR environment is smaller than in the real world, the human

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body reaction is similar. In this pilot study, we found that the reaction of SCI participant during riding on the flat road in VR environment and on road test had similar tendency. The result showed in figure 7. The variation of the acceleration in the on road test is bigger than in VR environment. Perhaps it's due to the acceleration caused by the rider speed up or down. In our VR environment, the acceleration of speed up or down in flat road couldn't be simulated.

When the rider speeded up, speeded down or made turns, these movements would produce the acceleration on the floor, steering and the body. It can stand for the rider's control of accelerator, brake, and steering. So, we could use these data to analysis the rider's behaviors in the real world.

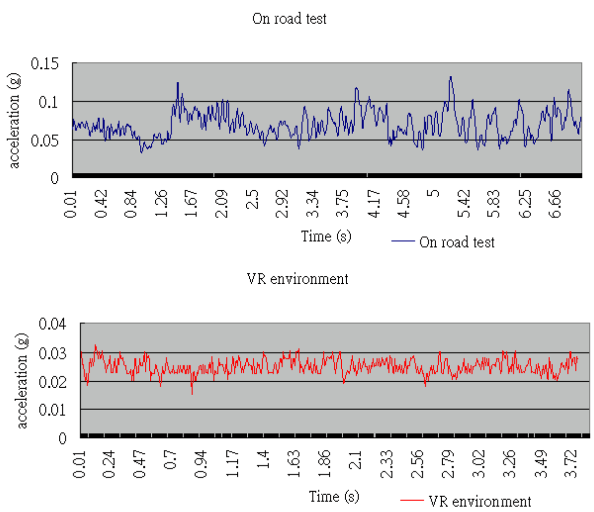


**Figure7: The acceleration of SCI participant riding on a flat road in straight line in VR environment and on road test.**

## 5. Conclusion

Although the VR systems can't 100% simulate the real world, it could induce similar human body reaction and movements. Normal people's body reaction is similar as the SCI patients in VR environment and the real world. It means we may assessment and training by a safer way with a less impact to participants in VR. There is a potential of VR for some patients who need assessment and training but have higher risk. Through the VR system, we can get many detail objective and precise data which hardly to get from the real world to evaluate the performance. It seems using modified motorcycle simulator to do assessment and training is feasible. The COP displacement, and response time may be good elements to evaluate the balance ability. And the acceleration detected form the trunk maybe can be used to evaluate the performance of on road test and compared the data, before and after training with VR system to investigate if the training effect can be transfer to the real world. Because the relative researches are still limited, more studies are needed.

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