BIOMECHANICAL ANALYSIS OF WHEELCHAIR WHEELIE PERFORMANCE

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Abstract- Wheelchair wheelie is an advanced manual wheelchair skill which is useful for negotiating obstacles in the activities of daily living. The main aim of this study was to investigate the biomechanics of wheelchair wheelie. We performed kinematic and kinetic analyses of a wheelie activity. Results showed that the center of mass (COM) of human-wheelchair unit was located in front of the base of support (BOS) of rear wheels during a wheelie. A certain COM-BOS boundary with small fore-aft posture sway was maintained to keep a stationary wheelie. In order to learn how to do a wheelie effectively, it was suggested that the training programs should start with the feeling of balance point without unnecessary rear-wheel displacement. Afterward, a forward-backward-forward technique can be taught as a useful skill to pop a wheelie.

Keyword- wheelie, COM, posture sway

INTRODUCTION

Wheelchair wheelie is an advanced manual wheelchair skill which can be used to elevate the caster wheels. A wheelie is executed when the user pops the front casters off the ground and balances on the rear wheels. The wheelie is a useful mobility skill in various situations, for instance, when an individual has to climb a curb, turn in confined spaces, or negotiate uneven terrain. However, for fear of losing balance and falling backward, many wheelchair users do not learn this skill. Wheelchair-related injuries caused by tips and falls are common and often serious[1, 2]. If an individual tips the wheelchair too far backward, his/her head might hit the ground thereby causing serious head injuries. Therefore, the wheelchair users' fear of tipping over backward is the most difficult obstacle to overcome when teaching a wheelie. In addition to safety concerns, many therapists cannot perform the skill themselves and many, therefore, lack the confidence to teach it. Also, there is little in the literature regarding wheelie skill acquisition [3].

Static balance in the wheelie position is nearly difficult because of the wheelchair's relatively small base of support (BOS) on rear wheels. If a wheelchair user is maintaining a stationary wheelie and experiences unanticipated external perturbation, the user need to exert a balance strategy to restore balance. Previous studies had identified two strategies: first, reactive balance strategy (RBS); secondly, proactive balance strategy (PBS) [4]. However, no matter how RBS or PBS was used to maintain balance during a wheelie, these strategies were concluded based on a small number of formal studies. Some studies only based on kinematic measurement, no detailed relationship between BOS and center of mass (COM) was built and discussed [5-7]. Much further research is needed to better understand the biomechanical nature of the wheelie, especially a combination of kinetic and kinematic measurements. Improvements in our understanding of the biomechanics of wheelies will hold promise for the learning and teaching of this particular skill. Therefore, the purpose of this study was to investigate the relationship between BOS and COM during initiation and balance phases of a wheelie. The effect of trunk motion on the pitch angle and posture sway was also studied.

METHOD

Twenty unimpaired people (16 male and 4 female provided informed consent prior to participation in the study. Their mean age, height, weight and years of learning wheelie skill were 24.4 $\pm$ 4.1 years old, 166.8$\pm$7.3 centimeters, 63.2 $\pm$ 10.2 Kg, and 2.12 $\pm$ 2.20 years respectively. Participants were instructed to pop and maintain a stationary wheelie for at least 10 seconds while remaining in an area 90

× 90 cm. 31 reflective markers were placed on the participant's upper extremity, trunk and low extremity at the bony landmarks to create body coordinate positions in a global reference frame. Three-dimensional marker trajectory data then were measured using a six-camera motion analysis system (Qualisys Medical AB, Göteborg, Sweden) at a sampling rate of 120 Hz. A custom force plate (90 cm X 90 cm, Rehabdevice Co. Ltd, Kaohsiung, Taiwan) was placed on a level surface to measure the center of pressure (COP) at a sampling rate of 120 Hz. Four additional markers were placed on each corner of the force plate to define the position of the force plate in a global reference frame.

In order to determine the COM of the human-wheelchair unit during a wheelie, the COM of the human body and the COM of the wheelchair had been calculated respectively. Based on our previous study, we had identified the COM of a wheelchair (COM_w) [8]. It was located 13.7 cm in front of the midpoint between the right and left rear hubs. For the COM of human (COM_h), a 12-body-segment model of the human body with the head-neck, trunk, upper arms, forearm-hands, thighs, shanks and feet modeled as rigid bodies was used. The position of the COM of the human body (COM_h) was calculated as:

$$COM_w = \frac{\sum_{i=1}^{12} m_i \vec{c}_i}{BM} \quad (1)$$

where mi and ci were the mass and position of the COM of the ith body segment calculated using marker data and Dempster's coefficients [9]. BM was the total body mass of the subject. Afterwards, the whole COM of the human-wheelchair unit can be estimated as:

$$COM_{h+w} = \frac{BW \times COM_h + WM \times COM_w}{BM + WM} \quad (2)$$

where WM was the weight of the wheelchair. The BOS during a wheelie was defined as the projection line of the rear hub positions on the force plate in a global reference frame. The distance between the projection line of the COM and BOS was used to measure the COM–BOS boundary. The pitch angle was defined as the angle between the line connecting two markers on the wheelchair frame with respect to their locations at the beginning of the trials when all four wheels were on the force plate. Trunk angle was defined as the angle between the thigh and trunk (Figure 1), and trunk forward angle was estimated as the differences of the trunk angle between during the balance phase and at the beginning of the trial. Furthermore, in order to quantify the posture sway, we calculated the standard deviation of the fore-aft (AP) direction and mediolateral (ML) direction of the COP durin g the balance phase of a wheelie.

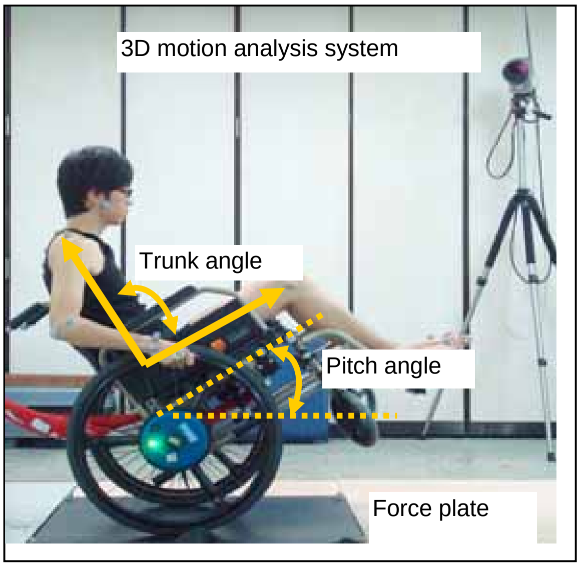

Figure 1. Experimental settings

Statistical analysis:

Since a Shapiro-Wilk test showed that all variables were normally distributed, Pearson correlation coefficients were calculated to examine the relationships between trunk motion, pitch angle, and posture sway. Statistical analyses were completed using SPSS 11.0 software (SPSS Inc., Chicago, IL), and the significance level was set at a = .05.

RESULT

Table 1 shows the biomechanical variables during a wheelie. We observed that the COM of the human-wheelchair unit during balance phase was located in front of the BOS (Figure 2). A certain COM-BOS boundary (mean value: 4.9±1.2 cm) was maintained to keep a stationary wheelie. There was a significant positive correlation between trunk forward angles and pitch angles ($r=0.51$, $p=0.02$). The larger trunk forward movement was, the higher pitch angle was. Furthermore, there was also a

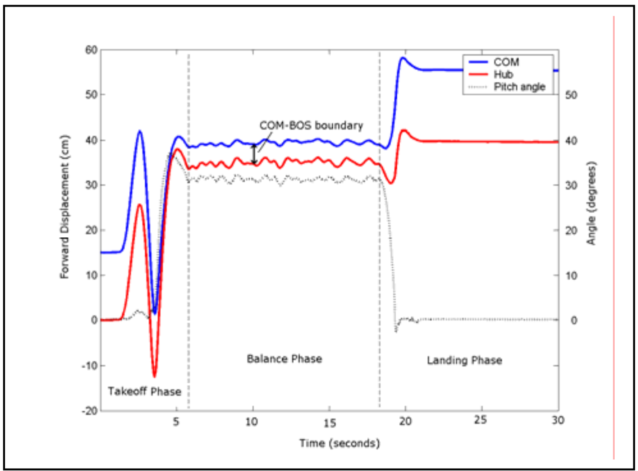

Figure2. The displacement of COM of the human-wheelchair unit(in cm, top trace), rear-hubs displacement (in cm, middle trace) and pitch angle (in degrees, bottom trace) plotted against time (in seconds) during a stationary wheelie.

significant positive correlation between trunk forward angles and COM–BOS boundary (r=0.44, p=0.05). When participants leaned their trunk more forward during a wheelie, the COM–BOS boundary was increased. However, there was no significant correlation between trunk forward angles and AP posture sway(r=0.27, p=0.24). No correlation was found between COM–BOS boundary and AP posture sway(r=0.32, p=0.17).

We also observed that participants lifted the wheelchair's casters off the ground by using one of three distinct wheelie take-off patterns defined in the study by Bonaparte et al.[6] Fourteen-twentieth (70%) of participants used a forward-backward-forward pattern, Five-twentieth (25%) used a backward-forward, and one-twentieth (5%) used a forward only pattern.

Table 1: Biomechanical variables during the balance phase in a wheelie

Pitch angle (deg)	Trunk angle (deg)	Trunk forward angle (deg)	COM-BOS boundary (cm)	AP posture sway (cm)	ML posture sway (cm)
29.2±2.3	96.1±10.6	6.9±8.1	4.9±1.1	2.2±0.8	0.2±0.1

DISCUSSION

In the earlier study by Bonaparte et al, they defined three distinct phases (takeoff, balance and landing) during a wheelie[4]. During the takeoff phase, we found that the forward-backward-forward pattern was the most strategy used to lift the casters. This finding was consistence with the previous study [6].

During the balance phase, a person might need to use any reactive strategy when the projection line from the COM of the human-wheelchair unit falls outside the BOS. We found that the COM fell in front of the BOS, and maintained a certain COM–BOS boundary throughout the whole balance phase. It looks like that a person shall fall forward under this circumstance. However, our participants still were able to keep a stationary wheelie without falls. A possible explanation may be that participants grasped and pushed the handrim during a wheelie. Therefore, any reaction force from pushing down would be directed upward along with the upper extremities to avoid fells. We also found that participants could lean their trunk more forward to increase the pitch angle and the COM–BOS boundary. A forward trunk leaning movement would cause the COM to move forward, thereby increasing the COM–BOS boundary. However, the wheelchair must then tipped further backward with larger pitch angle to bring COM back and kept the COM–BOS relationship within the constant boundary. Therefore, if a user popped a wheelie with larger pitch angle, he/she might overshoot the balance point. Trunk forward flexion movement can be used as a compensatory strategy to move the COM back within the COM-BOS boundary.

Furthermore, our results showed that there was a very small postural sway in the mediolateral direction during wheelie performance. It was consistence with the previous study [6]. Movement in the mediolateral direction was negligible. During the balance phase, participant oscillated within a small range (mean value: 2.2±0.8 cm) around the point of balance in fore-aft direction. Since maintenance of wheelie balance is an example of metastability, any small deviation from the equilibrium point could cause the wheelchair to fall. Our participants tended to maintain a stationary posture without any unnecessary motion including moving the wheelchair, or trunk movement. Therefore, if a wheelchair user wishes to learn a wheelie by moving the rear wheels forward or backward to correct the loss of balance, it might be getting harder and harder to find the point of balance. Kirby et al. had showed that using high rolling resistance on rear wheels was effective technique to learn a wheelie skill [10]. Therefore, it was suggested that the wheelie training programs should be focused on finding the point of balance (e.g. COM–BOS boundary) firstly by lifting off the casters without unnecessary rear-wheel displacement.

CONCLUSION

Our study showed that a forward-backward-forward technique was the most strategy used to pop a wheelie. During the balance phase in a wheelie, the COM of the human-wheelchair unit was located in front of the BOS. A certain COM–BOS boundary was maintained to keep a stationary wheelie. The increase of trunk forward flexion movement was accompanied with larger pitch angles. Since there was a small fore-aft posture sway during the balance phase, future wheelie training programs should start with the feeling of balance point.

ACKNOWLEDGEMENTS

This study was funded by the National Science Council, Taiwan (NSC 98-2320-B-037-006-MY3)

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