DEVELOPMENT OF CURLING BRUSH FOR MEASURING FORCE EXERTED DURING SWEEPING

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The purpose of this study was to examine the validity of the forces exerted on the curling brush devised with strain gauges and angular velocity sensors. Force data obtained from the devised brush were compared with data obtained from the force plates. Mean values of the vertical forces during the sweeping were 185 N for the brush and 187 N for the force plates, respectively, and there were no significant differences between them. The horizontal forces were 38 N for the brush and 37 N for the force plate, respectively, and there were no differences between them. There were significant correlations ($p<0.001$) between the forces exerted on the brush and the ground reaction forces. In this study, more valid force data during the sweeping were obtained by using the device compared to our previous study.

KEY WORDS: curling, sweeping, brush, force measurement, angular velocity sensor.

INTRODUCTION: Curling is a game where two teams of four players each slide stones down a sheet of ice toward a target at the far end. Each team tries to get more of its stones closer to the center of the target circle than the other team. Curlers often strongly sweep the ice in front of the sliding stone in order to correct the speed or the trajectory of the stone thrown in the games of curling (Weeks, 2006). Buckingham et al. (2006) reported an instrumented curling brush as a sweeping ergometer for measuring the forces exerted on the ice. So far we have advanced development of a simple and different type of device for measuring the forces exerted on the brush during the sweeping using strain gauges on the brush shaft. Although the shaft angle between the brush shaft and the ice surface was detected by using a goniometer for force calculation in our previous study, it was found that the horizontal force was less valid (Yanagi, Miyakoshi, Nakajima, Yamamoto, & Isaka, 2008). Therefore, we attempted to detect more valid force data during the sweeping using strain gauges and angular velocity sensors for the shaft angle measurement in the present study. The purpose of this study was to compare the forces exerted on the brush with the ground reaction forces during the sweeping to examine the validity of the devised brush.

METHODS: Three subjects volunteered to participate in the laboratory test. One was a five-year experienced curler and the others were beginners. The mean (and standard deviation, *SD*) of their heights, weights, and ages were 1.75 ±0.02 m, 80 ±14 kg, and 23 ±1 y, respectively. They received an explanation of the experimental protocol and provided an informed consent prior to testing.
A commercially available curling brush (Tapered Ultra-Light Carbon Fiber Brush, BalancePlus) was used to develop the device in the study. It consists of a head and a shaft with a joint combined to it. Eight strain gauges (N11-MA-10-1000-11, SHOWA) were attached to the shaft 200 mm away from the joint center to detect the loads in the direction of the shaft axis and in the direction perpendicular to it. Two angular velocity sensors (CRS07-02S, Silicon Sensing) were attached to the shaft to detect the shaft angle between the shaft and the ice surface and the roll angle about the shaft axis. The amplified signals from the strain gauges and the output signals from the angular velocity were digitized and sampled by the A/D converter at the rate of 200 Hz. The angles of the brush were calculated by using time integration of the angular velocities measured. The forces on the brush were calculated as the forces applied to the ice surface vertically (FV_{brush}) and horizontally (FH_{brush}) based on the output from the strain gauges and the angles. The vertical (FV_{fp}) and the horizontal

ground reaction forces (FH_{fp}) on the force plates (KYOWA) were also recorded at the rate of 200Hz during the sweeping simultaneously.

Subjects swept the force plates covered with a polypropylene sheet using the brush in place three times. They were instructed to sweep with maximum efforts for approximately 10 sec at a time after picking up the brush placed on the floor.

Force data for each trial were averaged for 5 sec from the time at which the first peak of the vertical force exerted on the brush appeared. The force exerted on the brush and the ground reaction force were expressed as the mean and standard deviation (*SD*). Paired t-test was used to determine significant differences between force exerted on the brush and the ground reaction force. A correlation coefficient was calculated from the samples of the force data obtained for 5 sec to examine the relationship between the force exerted on the brush and the ground reaction force during the sweeping for each trial. The *p*-value was considered significant when it was found to be less than the usual level of significance 0.05.

RESULTS AND DISCUSSION: Figure 1 shows sample data of the vertical forces and the horizontal forces exerted while the subjects were sweeping the force plate with the devised brush. Force curves obtained from the devised brush seemed to be almost fit to those from the force plates in each graph. Peaks of the vertical forces appeared to be higher in the experienced curler than the beginner and those of the horizontal forces slightly higher. From these data, it can be said that the vertical force data obtained during the sweeping is useful for understanding the individual sweeping performance. Coaches can objectively evaluate curlers' sweeping performance with the device and provide more effective advice to improve their performance to them.

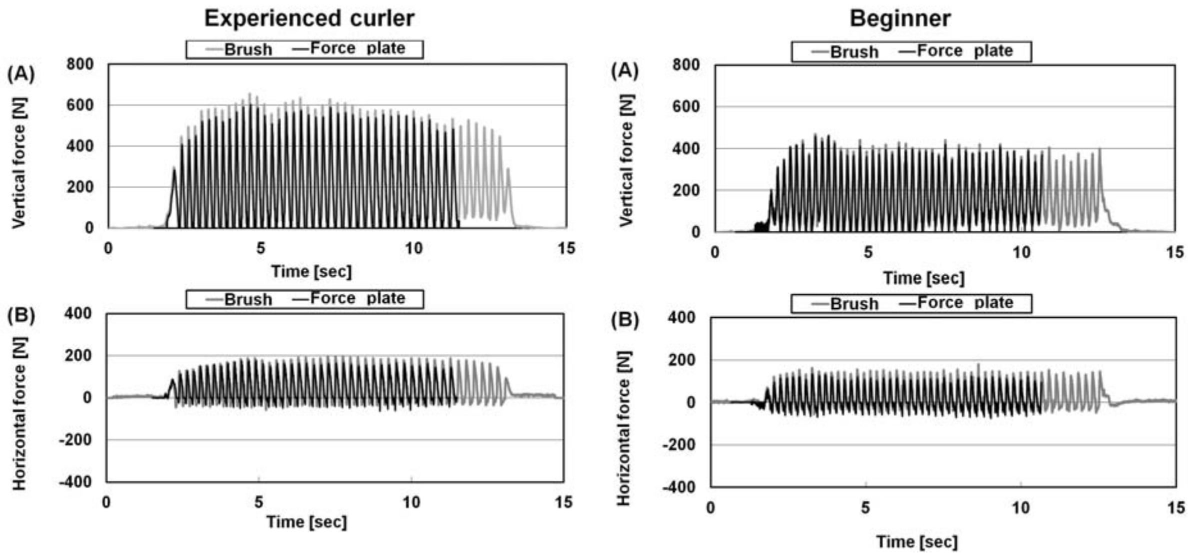

Figure 1: Samples of the vertical force (A) and horizontal force (B) exerted during the sweeping (left: experienced curler, right: beginner).

Table 1 shows the 5-sec averaged force data and the correlation coefficients between forces exerted on the brush and the ground reaction forces during the sweeping. The mean (and *SD*) of the vertical forces during the sweeping were 185 (38) N for the brush ($F_{V\,brush}$) and 187 N (37) for the force plates ($F_{V\,fp}$), respectively, and there were no significant differences between them. The horizontal forces were 38 (12) N for the brush ($F_{H\,brush}$) and 37 (21) N for the force plate ($F_{H\,fp}$), respectively, and there were no differences between them. There were significant correlations ($p<0.001$) between $F_{V\,brush}$ and $F_{V\,fp}$ and between $F_{H\,brush}$ and $F_{H\,fp}$. These results indicated that force data obtained from the devised brush were more valid compared to the data of our previous study (Yanagi et al., 2008).

Table 1: Mean and SD of the force data and correlation coefficients between the force exerted on the brush and the ground reaction force during the sweeping.

	$F_{V\ brush}$ (N)	$F_{V\ fp}$ (N)	$F_{H\ brush}$ (N)	$F_{H\ fp}$ (N)
Mean (*SD*)	185 (38)	187 (37)	38 (12)	37 (21)
Correlation coefficients	0.985-0.995 *		0.912-0.968 *	

* indicates p<0.001.

In this study, the device was composed of the curling brush and the sensors with a cable connecting with the recorder. The cable and the sensors restricted the curlers' activities when they were sweeping with the device. Wireless system and downsized sensors would be necessary to improve the usability of the device when curlers are sweeping on the ice.

CONCLUSIONS: These results demonstrated that the simple device with the strain gauges and the angular velocity sensors enables the force measurement during the sweeping in curling. The device can provide useful information for evaluating sweeping performance in curling. In this study, more valid force data during the sweeping were obtained by using the device compared to our previous study. Wireless system and downsized sensors would be necessary to improve the usability of the device when curlers are sweeping on the ice.

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