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The Difference of Bilateral Limbs Involvement During Trunk Bending and Reaching in Stroke Patients

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Abstract-**The purposes of this study were to investigate the effects of target locations on the demand of postural stability and to compare the involvement extent of bilateral lower limbs. The postural stability was measured by individual feet center of pressure (CoP). The proximal and distal end of the CoP line and the maximum CoP displacement in anterior-posterior direction were determined by custom-written Matlab programs and were expressed as percentage of foot length. Side of foot and target location interaction effects were significant only on CoP maximal anterior-posterior displacement (p = .008). The target location didn't affect the proximal end of the CoP line (p = .265) either did it affect the difference between feet as measured by the same parameter. The target location affected the distal end of the CoP line (p < .001) and the CoP maximal anterior-posterior displacement (p <.001) significantly, but only the later parameter showed the difference between feet when the targets were far/in the middle (p < .001) and on the paretic side (p = .008). The pedeography also show the target effects on CoP and different extent of bilateral limbs involvement. Change of target location can change the extent of the involvement of bilateral limbs and the parameters in this study were effective to show the effects. The relationship between CoP measures and neuromuscular control of the lower limb needs further investigations.**

I. MOTIVATION AND PURPOSES

Postural stability, or balance, is maintained through a complex interaction of various components of postural control systems including the vestibular, nervous, and musculoskeletal systems.[1] Both extrinsic and intrinsic factors can affect the ability to maintain stability. Extrinsic factors are those such as environmental constraints, while intrinsic factors are those such as aging process and neurological conditions.[2,3] Stroke is the most common neurological condition that affects postural stability and increases devastating risk of fall.[4,5] Understanding the control of postural stability during daily voluntary task is necessary for design of clinical training program. Trunk forward bending and reaching is common during daily living situations. The location of the target for reaching depends on the environmental constrains and also determines the required amount of center of mass (CoM) shift. As the required amount of CoM shift increases, the demands on the postural control systems to maintain stability increases concurrently. Therefore, the authors hypothesized that the location of the targets for reaching could induce graded postural control features. Previous studies[6,7] have shown that during forward and backward trunk bending movements, the body CoM is efficiently regulated with respect to the base of support (BoS). Most of the results of those studies suggested that the axial synergy, described as opposing displacements of the trunk and knee segments with those of the hips, acts to minimize the horizontal CoM displacement to prevent instability. Center of gravity (CoG) is the point application of ground reaction force of the CoM and the trajectory of the center of pressure (CoP), though different from the trajectory of CoG, is a reasonable approximation to the trajectory of CoG.[8,9] Therefore, the present study intended to investigate the postural control features during trunk bending and reaching for targets at various locations by measures of CoP trajectory.

Quantitative spatiotemporal variables of CoP have been repeatedly proven as robust indicators of the quality and functional balance ability during performance of voluntary movement,[8,10] but describe the outcome of the dysfunction rather than the origin. These measures also failed to describe a specific mechanism by which performance and function are increased after rehabilitation. We consider qualitative pattern of CoP to be an outcome of the underlying mechanistic processes. Researchers have used plantar pressure recording devices in various clinical populations to describe the features of posture and gait, but nothing as specific as foot CoP line under the individual feet has been reported during trunk forward bending and reaching. CoP under individual feet provides information specific to each lower extremity and the neuromotor fluctuations that are part of motor control. Mizelle et al.[11] predicted gait velocity by selected CoP measures under individual feet and they suggested that bilateral feet CoP measures not only index locomotor functions, but might also have the potential to provide information about the underlying control properties of the stroke-injured neuromuscular system.

The purposes of this study were: (1) to investigate the CoP pattern under the individual feet of stroke patients during trunk forward bending and reaching, (2) to examine the interactions effects of side of foot and target location and their main effects on individual feet CoP measures, (3) to examine the effects of target locations on CoP measures under the individual feet, (4) to investigate the correlations between feet of the CoP measures, (5) to identify specific individual feet CoP characteristics affected by the target locations. Both quantitative and qualitative characteristics of the individual feet CoP were analyzed.

II. RESEARCH METHODS

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Twenty-nine stroke patients signed informed consent form and made 2 bending-and-reaching trials for each of the 6 target locations at their self-selected pace. The target locations were constructed by the distance and direction in relation to the participants (Fig. 1).

Participants performed all trials while standing on a 0.5 m instrumented mat (Footscan, Rsscan pressure measurement system, Belgium). Pressure-sensitive sensors embedded in the mat were sampled at 100 Hz and transmitted data (the coordinates of the CoP under individual feet) that were processed into maximal displacement in anterior-posterior direction (MAP) /foot length ratio (MAP%FL), the proximal end of the CoP line (Start), and the distal end of the CoP line (Stop). (Fig. 2)

Qualitative descriptions of the CoP trajectories for each individual foot were plotted by a custom written Matlab program for each target location (Fig. 3) to show the effects of target locations on the CoP trajectory. The initial position (denoted as “A” in the figure) and the final position (denoted as “B ”) were indicated and the number 1 through 4 indicated the CoP movement sequence. The time interval between two consecutive numbers was 200 frames which was two seconds apart. The CoP coordinates was filtered with a forth order Butterworth filter with a cutoff frequency of 10 Hz.

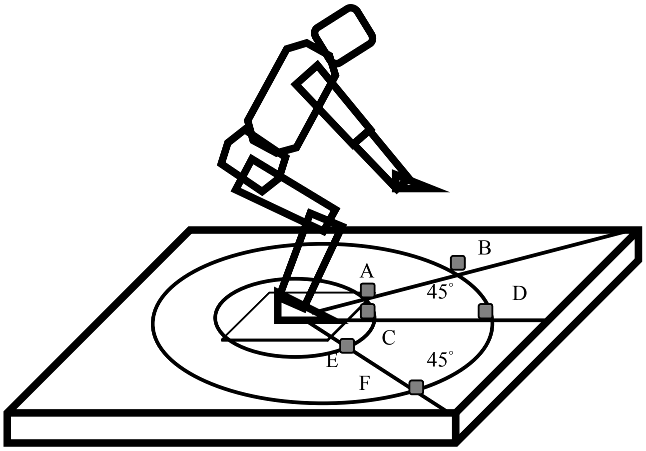


Fig.1 A~F indicated the six target locations for Whole Body Reach. A,C, and E are targets at near distance. B, D, and F are targets at far distance. A-B and E-F are targets deviated from the middle. C & D are targets in the middle. Line AB, CD, and EF originated from the same point which is in the middle of the tips of two great toes. The angle between line AB and line CD was 45 degrees, which was the same as the angle between line EF and line CD.

In order to show the CoP shift directions in relation to the initial CoP position, the following process was proceeded to plot the CoP shift in AP and ML direction separately (Fig. 4). The x and y coordinates along the time series were subtracted by the x and y coordinates of the initial CoP position before the bending and reaching movement began. The results of subtraction would be either positive or negative. The x coordinates are on the frontal plane and, therefore, the positive results indicate that the CoP locates at a position which is on the left side of the initial CoP position. The positive slope of the plot indicates that the CoP travels toward the left side, while the negative slope indicates that the CoP travels back and toward the right side. The negative results indicate that the CoP locates at a position which was at the right side of the initial CoP position. When the slop is negative and the x coordinates are negative, the CoP is at the right of the initial position and traveling all the way toward the right. When the slope is positive and the x coordinates are positive, the CoP is at the left of the initial position and traveling all the way toward the left. When the slope is negative and results are positive, the CoP is at the left of the initial position and traveling rightward toward the initial position of the CoP. When the slope is positive and the results are negative, the CoP is at the right of the initial position and traveling leftward toward the initial position of the CoP.

Two-way repeated-measure analysis of variance, paired-t test, one-way repeated-measure analysis of variance and Pearson correlation coefficients were used as appropriate. The statistical significant level was set at $\alpha = .05$

III. RESULTS AND DISCUSSIONS

The position of the proximal end of the CoP line (Start)

Non-significant foot and target location interaction effects were found (Table 1, *p* = .099), indicating that the difference between feet on the location of the Start point of the CoP line was not influenced by target locations. Either foot or target location main effects were significant (Table 1, *p* = .418 for foot main effects, *p* = .265 for target location main effects).

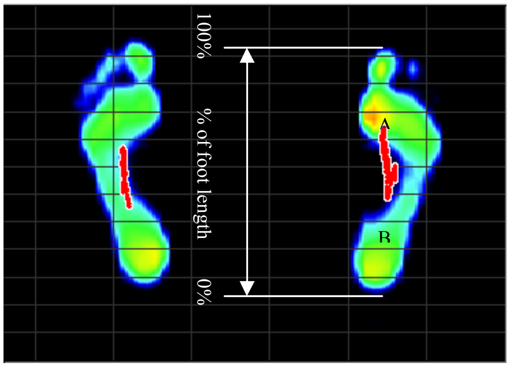
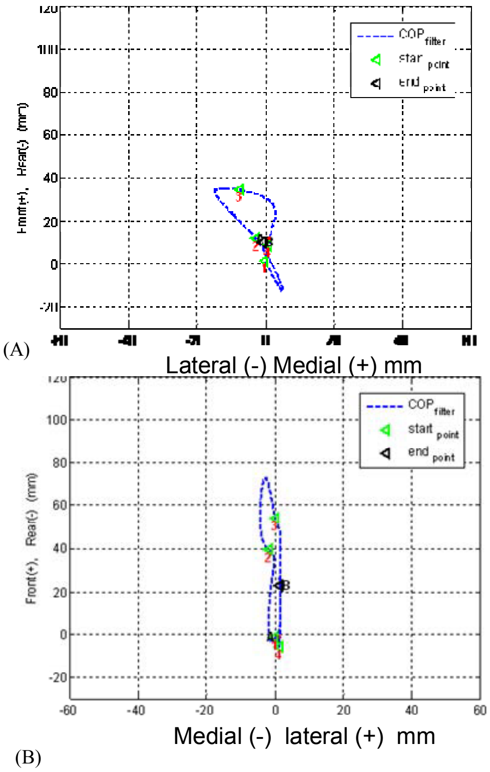


Fig. 2 The foot-print with CoP trajectory under the individual foot. The point A is the distal end of CoP and its position is designated as percent of foot length (Start). Point B is the proximal end of CoP and its position is designated as percent of foot length (Stop). The distance between point A and B is the maximum CoP displacement in AP direction and was designated as percent of foot length (MAP%FL).

The effects of target distance on the position of Start point were consistent across target directions and across feet (Fig. 5). Far targets moved the proximal end of the CoP line away from the heel compared to what the near targets did for both feet, indicating that the contact area of the paretic and non-paretic feet with the ground changed from the hindfoot to the midfoot area when the distance of the targets increased. The author hypothesized that the neuromuscular control of the ankle joint of both paretic and non-paretic limbs was changed by the target distance

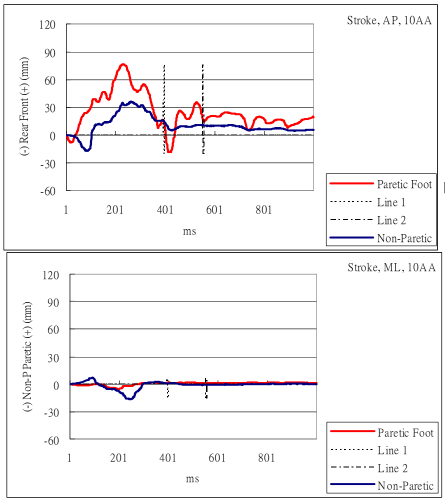


(A)

(B)

Fig. 3. CoP trajectory under the individual foot in a stroke patients with left hemiplegia. (A) CoP under the non-paretic (right) foot. (B) CoP under the paretic (left) foot. The initial position (the green triangle) and end position (the black triangle) of the CoP was indicated. Point A in the figure indicated the moment when the performer touched the targets on the floor while the point B indicated the moment when the performer resume erect standing after reaching. The number 1 through 4 indicate the trajectory of CoP shifting.

The effects of target directions on the proximal end of the CoP line (Stop) were not consistent across feet nor across target distances (Figure 5). For the paretic feet, the target distance seemed not to affect the location of the proximal end of the CoP line, indicating that the paretic feet did not change the neuromuscular control of the ankle according to the target directions no matter the targets were near or far. For the non-paretic feet, the effects of target directions on the location of the proximal end of the CoP line were more prominent when the targets were near than when the targets were far. But the trend of the effects of target directions on the location of the Start point of the CoP line was consistent across target distances. The targets on the paretic side tended to move the Start point away from the heel. On the other hand, the non-paretic feet were more capable of modulating the ankle joint control based on the demand of the target directions.



(A)

(B)

Fig. 4. The individual foot CoP shift direction in anterior-posterior (A) and medial-lateral (B) directions. The data was derived when a stroke patient with left hemiplegia was bending the trunk and reaching for a target at position A in Fig. 1.

The position of the distal end of the CoP trajectory (Stop).

Non-significant side of foot and target location interaction effects were found (Table 1, p = .076), indicating that the difference between feet in the location of the Stop point of the CoP line was not influenced by target locations. Non-significant foot main effects were found (Table 1, p =. 273). The descriptive data showed that the distal end of the CoP line of the individual feet located at the position of 60% to 80% foot length, which was within the metatarsal area of the foot (the forefoot area). The location of the distal end of the CoP line under the paretic feet was farther away from the tip of the toes than that under the non-paretic feet were when reaching for targets at all locations except when reaching for targets on the non-paretic side at both far and near distance (Fig. 6, 10SS and 30SS). This result suggested that the contact of the forefoot area of the paretic feet were increased but that of the non-paretic feet were decreased.

Combining the finding of the position of the proximal end of the CoP line with the finding of the position of the distal end of the CoP line, the CoP under the paretic and non-paretic feet was different in two ways: (1) the CoP under the paretic feet were in the midfoot to forefoot area and the CoP under the non-paretic feet was in the hindfoot to forefoot area, (2) the length of the CoP line under the paretic feet and was shorter than that under the non-paretic feet. Those results suggested that the extent of the involvement of the paretic and non-paretic feet during trunk forward bending and reaching were different. The difference might arise from the impaired neuromuscular control of the paretic limb, which decreased the degrees of the participation in weight shifting.

TABLE 1.

Repeated-measure ANOVA summary for analysis of the side of foot and target locations interaction effects.

Source	SS	DF	MS	F	p
Start					
Foot	.01	1	.01	.68	.418
Target	.02	5	.01	1.31	.265
Foot * target	.02	5	.01	2.15	.099
Stop					
Foot	.03	1	.03	1.27	.273
Target	.69	5	.14	27.83	.000*
Foot * target	.07	5	.03	2.59	.076
MAP%FL					
Foot	.08	1	.08	4.30	$.051^{\#}$
Target	.74	5	.15	22.83	.000*
Foot * target	.10	5	.02	3.21	.008*

*$p < .05$; Abbreviation notations: Start: proximal end of the CoP line under individual feet, Stop: distal end of the CoP line under individual feet; MAP%FL: maximal CoP displacement in anterior-posterior direction normalized to foot length.

Significant target location main effects on the position of the distal end of the CoP line were found (Table 1, $p < .001$). The post hoc pairwise comparison (Table 2) showed that the difference of the Stop across target locations was significant between all pairs of locations except between the following pairs of target location: 10M vs. 10SS ($p = .997$), 30M vs. 30AA ($p = .574$), 30M vs.30SS ($p = .263$), 10AA vs.10SS ($p = .100$), 30AA vs.30SS ($p = .623$). These results were not consistent clinical expectations. Clinicians expected that targets at different locations would induce graded amount of CoP shifts. The reason for this result might be due to the compensating movement strategies which inhibit the neuromuscular control of the paretic limb and subsequent CoP shift.

The effects of target distance on the location of the Stop point were consistent across target directions and across feet. Far targets tended to induce the distal end of the CoP line to move closer to the tip of the toes than near targets did (Figure 3) for both feet, indicating that both the paretic and non-paretic feet were able to increase the forefoot contact with the ground when reaching for far targets. Far targets might be able to facilitate the ankle plantar flexor activation.

The effects of target direction on the location of the distal end of the CoP line when reaching for near targets were consistent across feet. Both the paretic and non-paretic feet were able to increase the extent of the contact of the forefoot area with the ground when reaching for the targets that was near and in the paretic side (Fig. 6, 10AA). In another word, when the target distance remains constant, the targets on the paretic side might be able to induce more muscular activation of foot plantar flexor than targets in the middle and on the non-paretic side.

The effects of target direction on the location of the Stop point when reaching for far targets were not consistent across feet (Fig. 6). The descriptive data showed that the distal end of the CoP line of the paretic feet moved further ahead toward the tip of the toe when the participants were reaching for targets that were far and on the paretic side (Fig. 6, 30AA), while the distal end of the CoP line of the non-paretic feet moved further ahead toward the tip of the toe when the participants wee reaching for targets that were far and on the non-paretic side. This result indicated that the forefoot area of the paretic feet contacted with the ground in the greatest extent when targets were far and on the paretic side, while the forefoot area of the non-paretic foot contacted with ground in the greatest extent when the targets were far and on the non-paretic side. In another words, the forefoot area of the foot ipsilateral to the direction of the targets contacted with the ground in a greater extent than that the forefoot area of the foot contra-lateral to the direction of the targets. This is an important implication for the clinicians to induce the participation of the paretic limb by training the CoP shift of the stroke patients with trunk bending and reaching for targets that are far and on the paretic side.

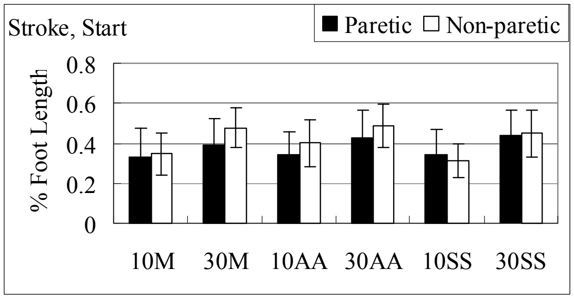


Figure 5. Differences between paretic and non-paretic foot on the position of the proximal end of the CoP in stroke patients. The labels of the x-axis represented the location of the target. "M" represents the targets in the middle and is corresponding to the position C/D in figure 1. "AA" represents the targets in the affected side and is corresponding to the position A/B or E/F depending on the side of paresis of the performer. "SS" represents the targets in the non-affected side and is corresponding to the position E/F or A/B depending on the side of non-paresis of the participants. "10" represent the near targets and "30" represents the far targets.

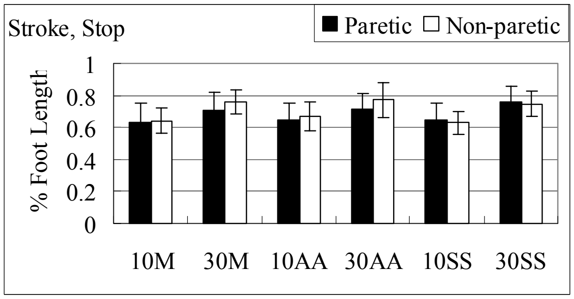


Fig. 6 Differences between paretic and non-paretic foot on the position of the distal end of the CoP in stroke patients. Please refer to Figure 5 for notation of the labels of the x-axis..

TABLE 2.
Post hoc pairwise comparison for the position of the distal end of CoP line (Stop).

Target Locations		Mean	SE	Sig.
10M	30M	-.10	.01	.000*
	10AA	-.02	.01	.030*
	30AA	-.11	.02	.000*
	10SS	.00	.02	.997
	30SS	-.11	.02	.000*
30M	10AA	.08	.01	.000*
	30AA	-.01	.02	.574
	10SS	.10	.02	.000*
	30SS	-.02	.02	.263
10AA	30AA	-.08	.01	.000*
	10SS	.02	.01	.100
	30SS	-.09	.02	.000*
30AA	10SS	.11	.02	.000*
	30SS	-.01	.02	.623
10SS	30SS	-.12	.01	.000*

*p < .05; Abbreviation notations: M: targets in the middle; AA: targets on the paretic side; SS: targets on the non-paretic side; 10: near targets; 30: far targets.

MAP/foot length ratio (MAP%FL)

Significant foot and target location interaction effects on MAP%FL were found (Table 1, $p = .008$) and significant foot simple main effects were found for targets that were far and in the middle (Fig.7, 30M) (Table 3, $p < .001$) and for targets that were far and on the paretic side (Fig. 7, 30AA) (Table 3, $p = .018$). The MAP%FL was always larger under the non-paretic feet than that under the paretic feet except when the targets were near and on the non-paretic side (Fig. 7, 10SS). Large MAP%FL indicated that the contact of the foot with the ground was larger comparing to small MAP%FL was. Therefore, the extent of the contact of the non-paretic feet with the ground was higher than the contact of the paretic feet with the ground. This result suggested that, although that some of the target locations might demand increased involvement of the paretic feet, the stroke patient still tended to avoid the participation of the paretic foot by other compensating movement strategies such as pelvis deviation. On the other hand, the targets that were near and on the non-paretic side might be a less challenging task for stroke patients. Therefore, they were confident and willing to increase the involvement of the paretic limbs. When the participant perceived the level of challenges is too high to manage, inhibition of participation might occur.

Significant target location simple main effects were found for both paretic and non-paretic feet (Table 4, $p < .001$). The post hoc pairwise comparison found that the significant target location effects were found between most of the pairs of target locations for both feet except the following pairs: 10M vs. 10SS (Fig. 7) (Table 5, $p = .650$; Table 6, $p = .164$), 30M vs. 30AA (Fig. 7) (Table 5, $p = .061$; Table 6, $p = .564$), 30M vs. 30SS (Fig. 7) (Table 5, $p = .146$; Table 6, $p = .295$), and 30AA vs. 30SS (Fig. 7) (Table 5, $p = .772$; Table 6, $p = .258$).

TABLE 3.
Paired-t test summary for analysis of the side of foot simple main effects on MAP/foot length ratio.

Target location	Mean	SD	SEM	t	DF	Sig. (2-tailed)
10M	-.02	.11	.02	-1.12	29	.272
30M	-.09	.07	.01	-6.64	27	.000*
10AA	-.04	.15	.03	-1.40	29	.172
30AA	-.06	.13	.02	-2.51	26	.018*
10SS	.02	.12	.02	.90	24	.378
30SS	-.02	.17	.03	-.55	23	.591

* p < .05; Please refer to Table 2 for abbreviation notations.

TABLE 4.
Target location simple main effects on MAP/foot length ratio.

	SS	DF	MS	F	Sig.
Paretic feet	.25	3.04	.08	8.00	.000*
Non-paretic feet foot	.60	2.76	.22	17.59	.000*

*p < .05

TABLE 5.
Post hoc pair-wise comparison for significant target locations simple main effects on MAP%FL of the paretic feet.

Target Locations		Mean	SE	Sig.
10M	-.06	.02	.003*	.000*
	-.01	.02	.650	.030*
	-.10	.02	.000*	.000*
	-.01	.02	.628	.997
	-.10	.03	.004*	.000*
30M	.05	.02	.020*	.000*
	-.04	.02	.061	.574
	.05	.02	.029*	.000*
	-.05	.03	.146	.263
10AA	-.09	.02	.001*	.000*
	-.00	.02	.950	.100
	-.10	.03	.002*	.000*
30AA	.09	.02	.000*	.000*
	-.01	.03	.772	.623
10SS	-.10	.03	.001*	.000*

*p < .05; Please refer to Table 2 for abbreviation notations.

The MAP%FL of the paretic feet seemed to be influenced by target distances more than by target directions (Fig. 4). The far targets increased the MAP%FL in both paretic and non-paretic feet no matter which direction the targets were at (Fig. 7). This result is consistent with the finding of the proximal and distal end of the CoP line. The direction effects on MAP%FL of both feet were consistent across target distance. For the paretic feet, the largest MAP%FL was induced by targets on the non-paretic side and the smallest MAP%FL was induced by the targets in the middle. For the non-paretic feet, targets on the paretic side induced the largest MAP%FL and targets in the non-paretic side always induced the smallest MAP%FL (Fig. 7). Clinical observation found that when the stroke patients were reaching for target in the paretic side, they usually adopted the pelvis strategy of lateral tilting toward the non-paretic side. The results of this pelvis strategy might induce the increased weight loaded over the non-paretic feet and therefore the magnitude of the MAP%FL of the non-paretic feet increased. On the contrary, the strategy of tilting the pelvis toward the paretic side when reaching for targets in the non-paretic side was not observed in the clinical settings. This is because that the targets on the paretic side possessed the potential to induce the involvement of the paretic feet but more guidance, such as verbal cues, might be needed for further facilitation. Obviously. the stroke patients in this study chose to inhibit the involvement of the paretic feet by avoiding pelvis lateral tilting

TABLE 6.

Post hoc pair-wise comparison for significant target locations simple main effects on MAP%FL of the non-paretic feet.

Target Locations		Mean	SE	Sig.
10M	-.06	.02	.003*	.000*
	-.01	.02	.650	.030*
	-.10	.02	.000*	.000*
	-.01	.02	.628	.997
	-.10	.03	.004*	.000*
30M	.05	.02	.020*	.000*
	-.04	.02	.061	.574
	.05	.02	.029*	.000*
	-.05	.03	.146	.263
10AA	-.09	.02	.001*	.000*
	-.00	.02	.950	.100
	-.10	.03	.002*	.000*
30AA	.09	.02	.000*	.000*
	-.01	.03	.772	.623
10SS	-.10	.03	.001*	.000*

*p < .05; Please refer to Table 2 for abbreviation notations.

Correlations between the paretic foot CoP measures and non-paretic foot CoP measures

Most of the correlations between paretic and non-paretic foot in stroke patients was positive and few was negative (Table 7). The negative correlation coefficients all failed to reach significant level. The positive correlation coefficients suggested synchronized CoP pattern of both feet. The mostly moderate coefficient also suggested that the level of synchronization between feet in stroke patients was low. This is another evidence which showed that the extent of involvement of bilateral limbs during dynamic activities is influenced by the asymmetry neuromuscular control in stroke patients.

As shown in Table 7, the target locations influenced bilateral limb synchronization prominently. The synchronization between limbs was the most prominent when the targets were far and in the middle (Table 7, r = .81). As the targets deviated away from the middle and toward either the paretic or non-paretic side, the level of synchronizations between limbs decreased. The CoP shift under both feet was in the same directions.

The correlations between limbs on MAP%FL was weak when reaching for targets that were far and on the non-paretic side (Table 7, r = .19) and moderate when the targets were far and on the paretic side (Table 7, r = .44). This result further suggested that targets that were far and in the paretic side tended to inhibit the participation of the paretic limb in this task. On the other hand when the targets were in the non-paretic side, more involvement of the non-paretic limb might be induced, and, therefore, the synchronization between limb decreased.

Qualitative analysis of the CoP trajectory

Fig. 8 showed the pedeobargraphy for each foot of a typical stroke patient with left hemiplegia. Fig. 3 is the posturography under the individual foot plotted by a custom-written program of the same patients. The results showed that the CoP under the non-paretic feet was smoother than the paretic feet and the position of the CoP under the non-paretic feet did not change its position within the foot across target location. The position of the CoP under the non-paretic feet was at the midfoot to forefoot area. On the other hand, the CoP under the paretic feet was jerky and affected by the target locations prominently. The position of the CoP under the paretic feet was within the midfoot area and seldom shifts into the forefoot area by with the target locations. The CoP shift in the ML direction under the paretic foot was prominent than under the non-paretic foot.

Fig.4(B) showed the CoP shift in ML direction of the same patients as in Fig. 3 and Fig. 8. The figure indicated that the fluctuation of the CoP under the paretic feet were less prominent than that under the non-paretic feet. Generally speaking, the CoP under the paretic feet moved straight ahead toward the target location and start to initiate return to the initial position before touched the targets on the floor. After finishing the tasks, the CoP under the paretic foot was able to return to the initial position without phase shift and resume a rather stable status quickly before the trunk return to erect status again. On the other hand, the CoP under the non-paretic feet usually move toward the non-paretic side with prominent forth-and-back fluctuations before the CoP arrived the most lateral position as with the target locations. The CoP under the non-paretic feet usually started to move back toward the initial position at the time when the performer touched the targets on the ground, which was later than the CoP under the paretic feet did. The CoP under the non-paretic feet needed more time to regain stability after finished the reaching process and the point of stability of the CoP under the non-paretic feet tended to shift toward the non-paretic side in relation to the initial position of the CoP. When the CoP shift direction of the paretic and non-paretic feet was plotted together in the frontal plane, the CoP shift direction under the paretic and non-paretic feet in the frontal plane was inverse, indicating that the movement strategies in both feet was reciprocal. The reason for these reciprocal movement strategies might be for equilibrium maintenance. The effects of target locations on the CoP shift directions were more prominent for the non-paretic foot than for the paretic foot but the effects was not consistent across target location.

The CoP shift direction of the paretic and non-paretic feet in the sagittal plane (Fig. 4B) indicated that the CoP under the paretic feet started with initial posterior shift while this initial posterior shift was not prominent by the CoP under the non-paretic feet. This result indicated that, although the reaching was a forward reaching in nature, the latency for the CoP of the paretic feet to shift anteriorly was observed as an instinct characteristic. The latency was not observed for the CoP under the non-paretic feet. The CoP under the paretic feet was able to return to the initial position without phase shift after finish the reaching process except when reaching for targets at that were far and on the paretic side (30AA), indicating that the location of 30AA might demand an exceptionally amount of CoP shift in anterior direction so that the CoP was not able to shift back to its initial position. The CoP seemed to prepare to recover back to the initial position before the targets were reached. And the CoP regains stability soon after the posture had return to erect standing. On the other hand, the paretic feet imitated shift without latency and traveled straightly anteriorly. The CoP under the non-paretic foot seemed to prepare to recover back to the initial position after the targets were touch. The phase shift of the final position of the CoP under the non-paretic feet was prominent and it fluctuated more than that under the paretic feet. When plot the CoP of both feet together, the CoP shift in AP direction of both feet was more synchronized than the CoP shift in ML direction but the extent of CoP shift in paretic feet was less than that in non-paretic foot as indicated by the quantitative analysis of CoP.

IV. CONCLUSIONS

The results of this study showed that the bilateral limb involvement during WBR was influenced by the target locations for stroke patients. The most sensitive parameters during reaching to show the difference between feet was MAP%FL.

The distance effects on stroke patients were more consistent across feet than the direction effects. Stroke patients were more capable to manage the increased demands on postural control based on the increased of targets distance than based on the changes of target directions. The correlations between feet were weak to moderate in stroke patients, indicating out-of-phase interlimb control in stroke patients. Far distance induced more interlimb control.

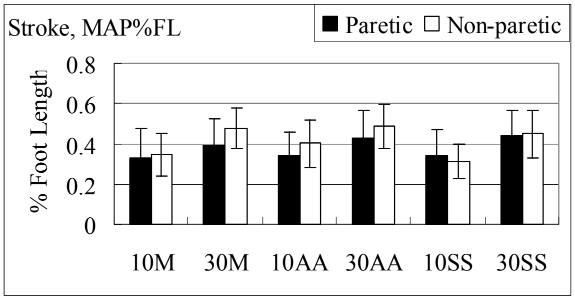


Fig. 7 Differences between paretic and non-paretic foot on MAP%FL in stroke patients. Please refer to Fig. 5 for the notations for the labels of the x-axis.

TABLE 7

Correlation coefficients between paretic and non-paretic foot when reaching for targets at different locations.

	10AA	30AA	10M	30M	10SS	30SS
Start	-.02	.12	.01	**.46**	.13	**.43**
Stop	-.23	-.04	.33	**.43**	.16	.26
MAP%FL	**.54**	**.44**	**.63**	**.81**	**.59**	.19

The bold numbers indicated significant correlations with $p < .05$.

Please refer to Table 2 for abbreviation notations.

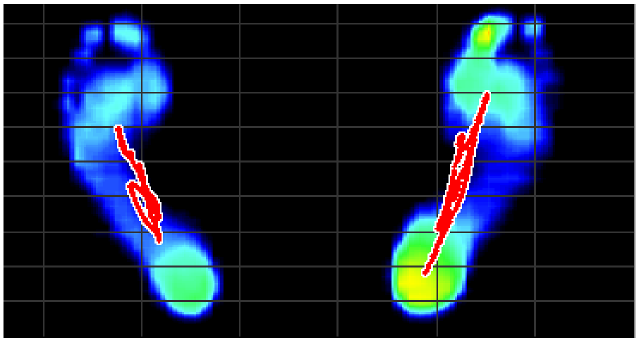


Fig. 8 Pedeography for the individual foot during forward bending and reaching in stroke patients. This is a stroke patient with a left hemiplegia and the subject was reaching for a target that located at the "B" position as indicated in Fig. 1.

Finally, the CoP under the individual foot is valuable and sensitive in revealing the involvement of the bilateral limb in daily task performance and could be important parameter for evaluation of functional improvement.

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