Effects of 8 weeks of balance or weight training for the independently living elderly on the outcomes of induced slips

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The study was conducted to evaluate whether the balance or weight training could alter gait characteristics of elderly contributing to a reduction in the likelihood of slip-induced falls. A total of 18 elderly were evaluated for the study. The results indicated decreases in heel contact velocities and the friction demand characteristics after 8 weeks of training, although fundamental gait characteristics, such as walking velocity and step length, were not changed. The results also indicated an increase in transitional acceleration of the whole body center of mass. The number of falls after 8 weeks was reduced in training groups. These findings were found in conjunction with the improvements in knee flexor muscle and plantarflexor muscle strength. In conclusion, after training, elderly were less likely to initiate slips and more likely to recover from slips.

Im Rahmen der vorliegenden Studie soll ermittelt werden, ob ein Gleichgewichts- oder Krafttraining die Gangeigenschaften von älteren Personen ändern und somit zu einer geringeren Wahrscheinlichkeit von Stolper-, Rutsch- und Sturzunfällen beitragen könnte. Für die Studie wurden insgesamt 18 ältere Personen evaluiert. Die Ergebnisse deuteten nach einem 8-wöchigen Training auf verminderte Fersenkontakt-Geschwindigkeiten und auf verminderte Reibungseigenschaften hin, wobei jedoch fundamentale Gangeigenschaften wie Gehgeschwindigkeit und Schrittlänge nicht geändert wurden. Die Ergebnisse deuteten ferner auf eine Steigerung der vorübergehenden Beschleunigung des Massenmittelpunkts des gesamten Körpers hin. Die Zahl der Stürze war in den Trainingsgruppen nach 8 Wochen gesunken. Diese Ergebnisse wurden mit den Verbesserungen der Stärke des Beugemuskels im Knie und des plantaren Zehenbeugers in Verbindung gebracht. Zusammenfassend lässt sich sagen, dass ältere Personen nach dem Training seltener ausrutschten und sich eher von Rutschunfällen erholten.

El objetivo de este estudio fue determinar si los ejercicios de entrenamiento destinados a mejorar el equilibrio y el peso corporal podrían causar cambios en las características de la marcha y, por ello, contribuir a la reducción de las probabilidades de que ocurran caídas por resbalamiento. En el estudio participaron un total de 18 ancianos. Los resultados revelaron una disminución de las velocidades de contacto del talón y de las características de la demanda de fricción tras 8 semanas de entrenamiento, aunque no se hallaron cambios en las características fundamentales de la marcha, como la velocidad de la marcha y la amplitud del paso. Los resultados revelaron, además, un aumento en la aceleración de transición del centro de masa de todo el cuerpo. La cantidad de caídas tras 8 semanas de entrenamiento se redujo en los grupos que participaron en ello. Estos resultados se acompañaron de mejoría en la fuerza muscular del músculo flexor de la rodilla y del flexor plantar. En conclusión, después del entrenamiento, los ancianos fueron menos propensos a sufrir resbalones y más propensos a reincorporarse a una postura normal inmediatamente después de un resbalón.

L'étude a été menée afin d'évaluer si les exercices d'équilibre ou de levée de poids pouvaient modifier les caractéristiques de la démarche des personnes âgées et contribuer à une réduction des risques de chutes résultant de glissades. Un total de 18 personnes âgées a été évalué pendant l'étude. Les résultats ont indiqué des diminutions au niveau des vitesses de contact du talon et des caractéristiques de besoin de friction après 8 semaines d'exercices, bien que les caractéristiques fondamentales de la démarche, telles que la vitesse de marche et la longueur du pas, soient restées inchangées. Les résultats indiquent également une augmentation transitoire de l'accélération de l'ensemble du centre de masse du corps. Le nombre de chutes après 8 semaines d'exercice avait diminué pour le groupe ayant suivi le programme d'exercices. Ces résultats se sont également accompagnés d'améliorations dans la force des muscles fléchisseurs du genou et de la voûte plantaire. En conclusion, après le programme d'exercices, les personnes âgées étaient moins susceptibles de glisser et mieux capables de retrouver l'équilibre en cas de glissade. *International Journal of Rehabilitation Research* **33:49–55 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Slip-induced falls were most likely to occur when the required coefficient of friction (RCOF) at the shoe–floor interface exceeded the available coefficient of friction of the floor (Irvine, 1986; Hanson *et al.*, 1999). The RCOF was determined by a ratio of F_h (horizontal force) to F_v (vertical force) (Hanson *et al.*, 1999). Modifications in either F_h or F_v could result in higher or lower RCOF. The RCOF was suggested to increase as heel contact velocity (HCV) increased or transitional acceleration of the whole body center of mass (TA COM) decreased because of their effects on the variation in horizontal ground reaction force while walking (Soames and Richardson, 1985; Lockhart *et al.*, 2003). Therefore, inability to reduce HCV during the heel contact phase of the gait cycle could result in higher horizontal foot force leading to higher RCOF, contributing to the risk of slip-induced falls. Activation of hamstring muscles, tibialis anterior muscles, and gluteus maximus and minimus muscles was a functionally important indicator for horizontal HCV, as one major role of these muscles was to decelerate the forward leg momentum during the heel contact phase of the gait cycle (Hashimoto *et al.*, 2000).

Two other main factors that could influence the RCOF were step length (SL) and TA COM. RCOF (F_h/F_v) increased if the resistance (horizontal) force (F_h) increased or normal (vertical) force (F_v) decreased. Ankle strength during the push-off (i.e. plantarflexion) phase and hamstring strength during the heel contact phase of the gait cycle were important indicators for TA COM and HCV, as the roles of the muscles were to either accelerate forward body momentum after the heel contact or to decelerate forward leg momentum before the heel contact (Chen *et al.*, 1997; DeVita and Hortobagyi, 2000; Khuvasanont and Lockhart, 2002).

Earlier studies (Jones *et al.*, 1989; Gardner *et al.*, 2002; Aagaard *et al.*, 2002; Barnett *et al.*, 2003; Mador *et al.*, 2004; Woo *et al.*, 2007) suggested that a strength or balance training program could have a profound effect on reducing risk for falls, which could result in fewer injuries or even death. However, earlier studies have not measured whether training, would transform gait characteristics, resulting in a reduction in the likelihood of slip-induced falls. This study evaluated whether training would benefit particular aging gait characteristics that would contribute to the likelihood of slips and falls among elderly. Specifically, it was hypothesized that strengthening lower extremity muscles among elderly had an influence on speeding the forward progression of COM resulting in a decreased RCOF, and on decelerating the forward leg momentum resulted in a decreased HCV. In contrast, strength training would improve gait characteristics such that elderly' risks for dangerous slips would be lessened.

Table 1 Variable definitions

Variables	Definitions
RCOF	Peak 3 (vertical GRF/horizontal GRF) as defined by Perkins (1978) (Fig. 1)
Right HCV	The instantaneous horizontal HCV was calculated utilizing the heel position in horizontal direction at the foot displacement of 1/120 s before and after the heel contact phase of the gait cycle using the instantaneous heel velocity formula: $HV = [X(i+1) - X(i-1)]/2\Delta t$ Heel contact was defined when the vertical force exceeded more than 7 N after the heel contacted the ground
The whole body COM velocity (i.e.WV)	The COM was calculated by averaging all the COMs from the 14 segments (left and right feet, left and right shanks, left and right thighs, trunk, left and right hands, left and right lower arms, left and right upper arms, and head). The COM velocity of all the participants was calculated using the formula: COM velocity $= [X(i+1) - X(i-1)]/2\Delta t$, where X = COM Then, all COG velocities from left heel contact to right heel contact were averaged
SL	The linear distance was measured in the direction of progression between successive points of foot-to-floor contact of left foot ($X1$, $Y1$) and right foot ($X2$, $Y2$). SL was calculated from the distance between consecutive positions of the heel contacting the floor
SDI	Slip distance was divided into SDI and SDII. SDI was measured to provide information concerning the severity of slip initiation. Slip-start point was defined as the point where nonrearward positive acceleration of the heel after heel contact, equivalently where the first minimum of the horizontal heel velocity after the heel contact (Fig. 2). The slip-stop point for SDI was defined as the point where peak horizontal heel acceleration occurred after the slip-start point (mid slip in Fig. 2). SDI was obtained using the heel coordinates between slip-start and slip-stop point on the vinyl floor surface (Fig. 2)
SDII	SDII provided the information with regard to the slip behavior after the initiation of slips. The start point for the SDII was defined from SDI slip-stop point (peak heel acceleration 'mid slip' in Fig. 2) to the end of slip (Lockhart *et al.*, 2002, 2003). The end of the slip was estimated as the time where the first maximum of the horizontal heel velocity after slip-start point occurred (Fig. 2). SDII was calculated from the heel coordinates using the distance between the two points as with SDI (Fig. 2)
PSHV	The PSHV after slip-start point (Fig. 2) was measured while slipping. This measure was used to predict slip severity in addition to slip distances
Frequency of actual falls	A fall was identified through visual inspections of video recordings of the actual fall trials. A slipping event was identified as a fall, if participants were aided by the fall arresting rig when attempting to recover from the slipping

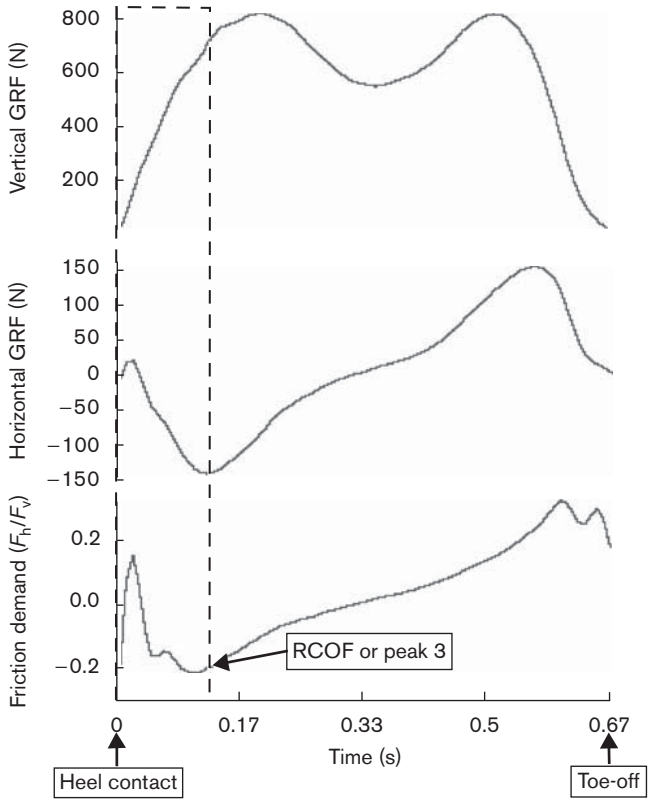
COG, center of gravity; COM, center of mass; GRF, ground reaction force; HCV, heel contact velocity; PSHV, peak sliding heel velocity; RCOF, required coefficient of friction; SDI, initial slip distance or slip distance I; SDII, slip distance II; SL, step length; WV, walking velocity.

Methods

Participants

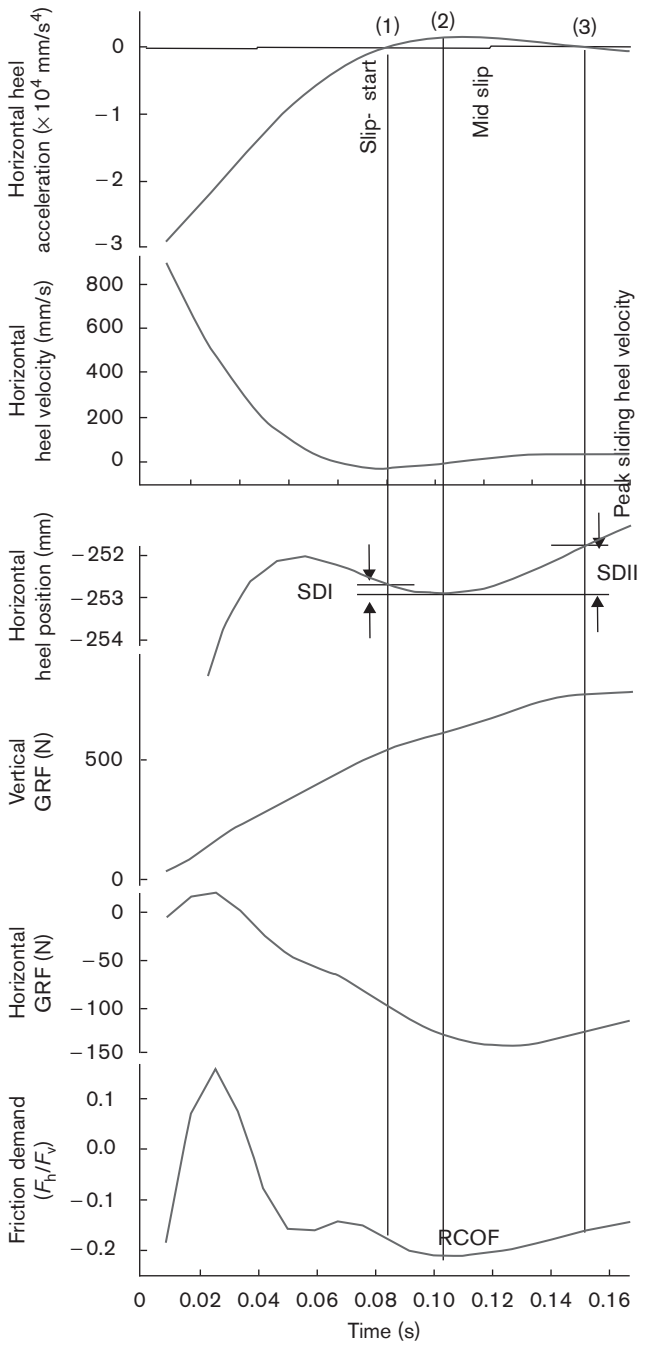
Eighteen individuals, who were examined, were divided into three groups (weight, balance, and control groups) of six individuals each. The volunteers were recruited from Montgomery County, Virginia.The Department of Park and Recreation for Montgomery County contacted all individuals (65 years or older) from their directory and asked whether they volunteered to participate in the study. Each volunteer was randomly assigned to one of the three groups. Each participant completed a written consent form approved by the Virginia Tech Internal Review Board and listened to verbal explanations from graduate students as well. Participants were excluded

Fig. 1



Composite view of the F_h (horizontal force), F_v (vertical force), and required coefficient of friction (RCOF; friction demand, the ratio of F_h to F_v) during a typical normal walking on dry surface. GRF, ground reaction force.

Fig. 2



Composite view of the heel dynamics (kinetics and kinematics) during a typical normal walking on dry surface. Heel dynamics during the first 0.16 s of stance phase. (Lockhart and Kim, 2006). F_h, horizontal force; F_v, vertical force; GRF, ground reaction force; RCOF, required coefficient of friction; SDI, initial slip distance or slip distance I; SDII, slip distance II.

from the study, if they indicated any physical problems (i.e. hip, knee, ankle problems); a written questionnaire and a verbal interview were used as an initial screening tool (for more details, see Kim *et al.*, in press).

Balance and weight training

During the first week, all the participants performed exercises on a hard surface floor to be familiar with the balance exercise routines, which is provided in the instructional manual of the Stability Trainer (Thera-Band, Akron, Ohio, USA). During the second week, all volunteers were tested to see whether they could perform the exercises on a green stability trainer (intermediate challenge level) with no assistance. If an individual could not perform the exercises safely on the stability trainer, his or her exercise routines continued on firm surface until he or she was able to perform the exercises safely on the green stability trainer. In addition, blue stability trainers (advanced challenge level) were introduced, if an individual performed exercises perfectly and confidently on the green stability trainer. Among the six volunteers, only two progressed to perform the exercises on the blue stability trainer. They met three times a week.

Periodized strength training was implemented as it proved to be more effective in gaining strength than nonperiodized strength training (Fleck, 1999). Two different hypertrophy phases were introduced for 5 weeks; three sets of 10 repetitions with 50% of maximum

exertion for 2 weeks and three sets of 10 repetitions for 70% of maximum exertion for 3 weeks. Strength phase lasted for the last 3 weeks; three sets of seven repetitions with 85% of maximum exertion (for details on exercise regimen, see Kim *et al.*, in press).

Procedure and gait analysis

Peak isokinetic ankle and knee strengths at 30, 90, and 120° were evaluated using Biodex System 3 (Biodex Medical Systems Inc., Shirley, New York, USA). For the ankle strength test, participants were seated with their right foot on a footplate attached to Biodex System 3. For the knee strength test, participants were seated with their right ankle strapped to a knee attachment fixed to Biodex System 3. The ankle and knee strength tests were performed as recommended in the Biodex 3 Instructional Manual (Biodex Medical Systems Inc.). Three trials for each measurement were collected and averaged to be used for statistical analysis.

Walking trials, including the slipping and falling trials, were conducted on a walking track (20 m), which was elevated 15 cm above the floor surface (Lockhart and Kim, 2006; Kim and Lockhart, 2008). Kinematic and kinetic data (for variable definitions, see Table 1; Figs 1 and 2) were evaluated using six cameras and two force platforms (Kim *et al.*, 2005). The entire walking track was covered with vinyl tiles. For slippery conditions, the vinyl tile surface was covered with a soap and water mixture (2 : 3) to reduce COF of the floor surface. The dynamic coefficient of friction of the soapy and dry vinyl floors was 0.07 and 1.80, respectively (Lockhart and Kim, 2006). The camera was calibrated before every experiment and the force plates were calibrated and zeroed before every trial.

Descriptive and inferential statistical analyses were performed by utilizing the JMP statistical packages (SAS Institute Inc., Cary, North Carolina, USA). Repeated-measure analysis of variance, 2×3 (time; pretraining and posttraining, group; weight, balance and control) was performed to evaluate the effects of training on the risk of slip-induced falls. In addition, 2×2 (floor; slippery and nonslippery, time; pretraining and posttraining) within-subject analysis of variance was performed on right HCV and SL to evaluate consistent gait patterns between normal walking trials and slippery walking trials to see whether there was an order effect; data during dry surface condition were collected before wet surface, as people's gait characteristics changed after they walked over the slippery surface. The results were considered statistically significant when $P \leq 0.05$. To maintain consistency in the coefficient of friction between the wet floor surface and the experimental shoes, the available coefficient of the wet floor surface was tested daily and the same brand of experimental shoes were used for every trial.

Table 2 ANOVA summary of right HCV and step length (floor × time)

	Right HCV		Step length	
Source	F	*P*	F	*P*
Floor	1.66	0.20	0.24	0.62
Time	0.16	0.68	0.60	0.43
Floor × Time	0.02	0.88	0.006	0.93

ANOVA, analysis of variance; HCV, heel contact velocity.

Results

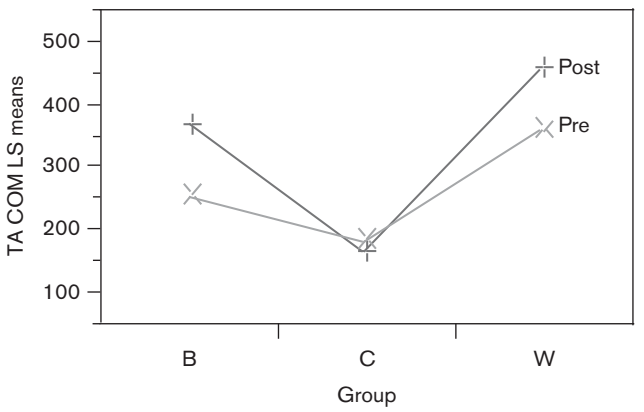
Gait characteristics (floor × time)

Table 2 suggested that there was no difference in the HCV and SL while walking on the different floor surfaces. These results suggested that participants did not notice the slippery surface while approaching the slippery area.

Slip vulnerability (time × group)

The data were collected during walking on the slippery surface. The results indicated that the risk of slips for all groups did not change after 8 weeks.

Fig. 3



Interaction of time × group for transitional acceleration of the whole body center of mass (TA COM). B, balance group; C, control group; LS means, least square means; Post, posttraining; Pre, pretraining; W, weight group.

Table 3 ANOVA summary of HCV, COM velocity, TA COM, and step length (time × group)

	HCV		COM velocity		TA COM		Step length	
Source	F ratio	*P*	F ratio	*P*	F ratio	*P*	F ratio	*P*
Group	9.41	0.002	6.69	0.008	11.64	0.0009	7.01	0.007
Time	11.45	0.004	2.09	0.168	12.57	0.002	2.17	0.16
Time × Group	7.96	0.004	0.15	0.857	4.82	0.02	0.34	0.71

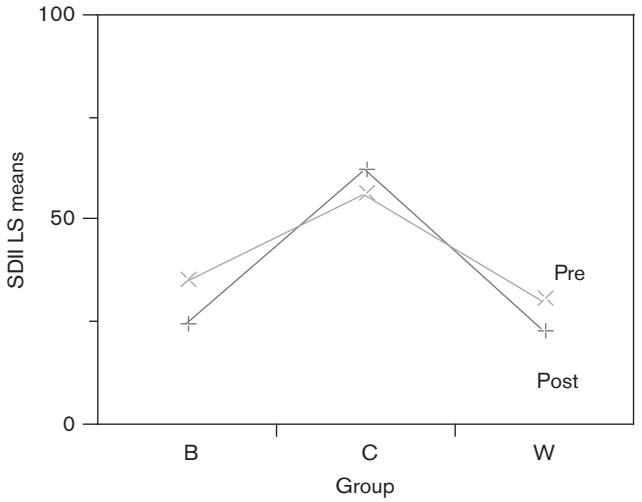
ANOVA, analysis of variance; COM, center of mass; HCV, heel contact velocity; TA COM, transitional acceleration of whole body COM.

Table 4 ANOVA summary of RCOF, SDI, SDII, and PSHV (time × group)

	RCOF		SDI		SDII		PSHV	
Source	F ratio	*P*	F ratio	*P*	F ratio	*P*	F ratio	*P*
Group	0.96	0.40	0.004	0.99	1.53	0.24	3.55	0.05
Time	5.75	0.03	0.035	0.85	5.95	0.02	0.96	0.34
Time × Group	13.41	0.0005	0.593	0.56	11.19	0.001	0.37	0.69

ANOVA, analysis of variance; PSHV, peak sliding heel velocity; RCOF, required coefficient of friction; SDI, initial slip distance or slip distance I; SDII, slip distance II.

Fig. 4



Interaction of time × group for slip distance II (SDII). B, balance group; C, control group; LS means, least square means; Post, posttraining; Pre, pretraining; W, weight group.

Table 5 ANOVA of isokinetic ankle plantarflexion and knee extension strengths at various speeds

	Weight ($n=6$)	Balance ($n=6$)	Control ($n=6$)	*P* (time)	*P* (group × time)
A 30° Px					
Pre	38.3 ± 17.5	34.5 ± 8.5	22.7 ± 7.6	0.003	0.003
Post	48.0 ± 9.2	45.7 ± 12.1	23.7 ± 6.0		
A 90° Px					
Pre	27.3 ± 17.3	30 ± 9.2	17.5 ± 6.9	0.01	0.05
Post	40.2 ± 8.1	35.5 ± 11.8	17.0 ± 4.3		
A 120° Px					
Pre	25.7 ± 16.0	29.0 ± 10.0	16.7 ± 6.6	0.001	0.02
Post	35.0 ± 8.0	33.3 ± 9.8	16.7 ± 5.2		
K 30° Ex					
Pre	68 ± 5.9	63.7 ± 12.7	53.5 ± 9.9	0.0001	0.001
Post	79.3 ± 13.9	73.3 ± 18.8	52.5 ± 10.3		
K 90° Ex					
Pre	52.3 ± 7.0	48.3 ± 14.5	40.7 ± 8.7	0.001	0.006
Post	59.5 ± 7.6	56.0 ± 13.7	38.8 ± 10.8		
K 120° Ex					
Pre	47 ± 7.6	45.2 ± 16.2	36.2 ± 6.9	0.0001	0.0004
Post	53.5 ± 8.1	48.2 ± 12.2	34.3 ± 7.2		

A, right ankle; ANOVA, analysis of variance; Ex, knee extension; K, right knee; Post, post-training; Pre, pre-training; Px, ankle plantarflexion.

Heel contact velocity

Table 3 (Time, $P = 0.004$) indicated that HCV was decreased at the post-training stage. In addition, Table 3 (time × group, $P = 0.004$), and Student's *t*-test (not provided) showed that HCV was decreased only in the training group.

Center of mass velocity (walking velocity)

Table 3 indicated that there was no significant main or interaction effect.

Transitional acceleration of the whole body center of mass

Table 3 and Fig. 3 indicated that after 8 weeks, individuals in training groups walked with faster TA COM during the heel contact phase of the gait cycle, whereas individuals in control group showed no change in the TA COM (time × group, $P = 0.02$).

Step length

Table 3 indicates that there was no significant main or interaction effect.

Required coefficient of friction (friction demand)

Table 4 (time, $P = 0.03$) indicated that the RCOF was reduced after training. Furthermore, the Student's *t*-test suggested that the reduction in the RCOF was seen only in training groups.

Slip severity

Table 4 indicated that that there was no significant main or interaction effect in initial slip distance or slip distance I (SDI) and peak sliding heel velocity. However, Table 4 and Fig. 4 indicate that after 8 weeks, training groups showed a reduction in slip distance II (SDII), whereas the control group showed no change in SDII (time × group, $P = 0.001$).

Isokinetic ankle and knee strength

Table 5 indicates that ankle plantarflexion and knee extension strengths improved only in the two exercise groups.

Fall frequency

In balance training group or weight training group, four individuals in each group who fell in the pretraining stage recovered from slips and two individuals in each group who recovered from slips in the pretraining stage recovered from slips. In the control group, five individuals who fell in the pretraining stage fell again and one

individual who recovered from a slip again recovered. These results with consistent gait characteristics suggested that elderly with training showed more chance to recover from slips.

Discussion

After 8 weeks of training, elderly' HCV and TA COM besides walking velocity (WV) and SL were altered in training groups. These results were similar to earlier literatures (Sipila *et al.*, 1996; Schlicht *et al.*, 2001), although some studies indicated an unclear relationship between strength gain and gait characteristics (Buchner *et al.*, 1997; Singh *et al.*, 1997). In contrast, these earlier studies did not attempt to examine whether the changes in gait characteristics influenced the likelihood of slips or falls (i.e. RCOF).

As a result of neuromusculoskeletal degradation, elderly could not develop rapid torque at the knee (Ferri *et al.*, 2002) or ankle joints (Thelen *et al.*, 1998; Connelly and Vandervoort, 2000), or could not generate explosive forces (Lexell, 1995; Hook *et al.*, 1999). Lockhart and Kim (2006) reported that the ability to generate an adequate neural response in hamstring muscle could be a factor for a reduction in heel contact forces (i.e. horizontal shear force). In this study, strength improvements in knee flexors could play a role in reducing the forward leg momentum in agreement with the study by Lockhart and Kim (2006), and strength improvements in ankle plantar–flexor muscles played a role in pushing off the whole body COM in forward direction after the heel contact in agreement with the study by Khuvasanont and Lockhart (2002). Reducing forward leg momentum and accelerating the whole body in a forward direction were critical components in avoiding dangerous slips (Gronqvist *et al.*, 1989; Lockhart *et al.*, 2003). Individuals in training groups were capable of reducing HCV and increasing TA COM and, thus lessening the RCOF. Moreover, it was noteworthy to see improvements in slip propensity (i.e. slower HCV and faster TA COM) among elderly in training groups without exhibiting alterations in fundamental gait characteristics, such as WV and SL. In addition, WV and SL (Lockhart and Kim, 2006) were suggested to influence the likelihood of slips because of their mechanical effects on an increase in horizontal shear force component at the heel contact phase of the gait cycle. It was generally suggested that elderly exhibited slower gait and shorter SL because they wanted to maintain safer gait characteristics. However, elderly fell more (Lockhart *et al.*, 2002; Lockhart and Kim, 2006) than their younger counterparts. These findings perhaps indicate that slower gait and shorter SL should not be referred as a safer gait. It could be more proper to refer slower gait and shorter SL as an aging gait or a pathological gait. This study suggested that elderly with neuromusculoskeletal training were able to walk normally, but were able to reduce the likelihood of slip by altering only HCV and TA COM.

In this study, slip severity evaluated by SDII were decreased after 8 weeks in only training groups although SDI and peak sliding heel velocity were not different after 8 weeks among all the three groups. These results suggested that participants in the training group were able to recover from the initial slip (e.g. no difference in SDI, but, significant reductions in SDII) suggesting that exercise training would influence recovery mechanisms (e.g. they attempted to retract their foot earlier to recover from the initial slip). This could result in small SDII in training groups. Furthermore, a TA COM difference observed in this study further supported the effect of training on recovery mechanism. Earlier studies (Lockhart *et al.*, 2002; Lockhart and Kim, 2006) reported that younger adults exhibited more severe slips than elderly; but, younger adults fell less frequently than elderly. Those studies suggested that fewer falls in younger adults were because they exhibited faster TA COM than elderly. Faster TA COM may have helped individuals to retract their slipping foot or to progress their COM forward closer to their slipping foot; two main techniques to recover from the slips were to retract their foot closer to their center of body or to progress their COM forward closer to the slipping foot. This study also found a similar result that participants in training groups recovered more frequently and exhibited enhancements in TA COM. These results suggested that training played a role in improving mechanisms contributing to the forward progression of the whole body COM during double stance phase. Authors in this study found that all fallers at the pretraining stage fell backward – upper body (i.e. head, trunk, and arms) twisting backward, whereas the lower body (i.e. slipping foot) was continuously moving forward as slipping. However, nonfallers who did not fall at the pretraining stage exhibited their upper body in forward progressing motion while slipping. These video analyses further emphasized the impacts of faster TA COM in recovering from slipping.

There were some limitations to this study. The number of participants in each group was six. The experimenter had no choice but to start the program, immediately with available participants as the experimenter could not postpone the program to wait for the preferred number of participants to join. In fact, most participants would have dropped out if the training was postponed for additional participants. Sex was not balanced out across the groups because of the circumstance explained already. Therefore, it was not possible to evaluate the sex effect. This could cause problems when generalizing the results of this study to all female and male adults above 65 years of age. In addition, the experimenter assumed that all individuals were comparable with each other, and that all

individuals may respond similarly to the programs. Descriptive statistics (i.e. mean and standard deviation) suggested that height, weight, and age across the three groups were not significantly different. These similarities in physical figures minimized the threat to internal validity. Yet, their education level, attitude, personality, motor ability, and mental ability were not statistically evaluated to indicate whether those groups were comparable. These factors may influence measures while walking or slipping and responding to questionnaires. Ideally, in the future, more comparable individuals should be tested to minimize the selection bias. The experimenters were challenged to monitor each individual's activities throughout 8 weeks. However, it was not possible to monitor their every minute lives that may have consisted of performing heavy housework, gardening, or home improvement projects.

This study concluded that for the elderly to recover effectively or efficiently from dangerous slipping, it was advantageous to have the whole body COM progressed forward enough after heel contact was made. In addition, improvements in the ankle plantarflexor and knee flexor strengths accounted for improvements in transitional acceleration of COM and for the reduction in HCV, respectively. As a result, training played a critical role in reducing slip-propensity among elderly.

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