Static and Dynamic Balance Control in Older Golfers

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Purpose: To determine whether older golfers have better static and dynamic balance control than older but nongolfing healthy adults. Methods: Eleven golfers and 12 control participants (all male; 66.2 ± 6.8 and 71.3 ± 6.6 yr old, respectively) were recruited. Duration of static single-leg stance was timed. Control of body sway was assessed in single-leg stance during forward and backward platform perturbations. The lunge distance normalized with respect to each participant’s height was used to compare the 2 groups in a forward-lunge test. Results: Golfers maintained significantly longer duration in static single-leg stance. They achieved less anteroposterior body sway in perturbed single-leg stance and lunged significantly farther than did control participants. Conclusions: The better static and dynamic balance control exhibited by older golfers possibly reflects the effects of weight transfers from repeated golf swings during weight shift from 2-leg to predominantly 1-leg stance and from walking on uneven fairways.

Keywords: aging, golfing, falls, single-leg stance

Falls have been identified as one of the major causes of morbidity and mortality in older adults (Carter, Kannus, & Khan, 2001; Tinetti, Gordon, Sogolow, Lapin, & Bradley, 2006). In Western countries, 32% of community-dwelling older participants over the age of 75 were reported to have fallen at least once in the previous year (Tinetti, Speechley, & Ginter, 1988). In Hong Kong, Ho, Woo, Chan, Yuen, and Shan (1996) conducted a similar cross-sectional study among Chinese age 70 years and above to estimate the occurrence of falls. Of the 1,947 participants who could walk either independently or with aids, 18% reported at least one fall in the previous 12 months. Among these, 40% were multiple fallers. About one third of the falls resulted in soft-tissue injuries, with 4.6% of the falls in men and 8.5% in women resulting in fractures. In the United States, the cost of hip fractures attributable to falls in the older population was reported to be about $10 billion in 2001 (Carter et al.). The risk of bone fractures resulting from falls could become a major financial burden on society.

Among the various intrinsic and extrinsic causes of falls, impaired postural control has been identified as a major intrinsic factor in older adults (Berg & Kairy, 2002; Carter et al., 2001; Lin & Woollacott, 2002; Shumway-Cook, Ciol, Gruber, & Robinson, 2005). Golf is a posture-challenging sport that is popular among...
older people. A complete golf swing takes less than 2 s (Selicki & Segall, 1996). Hitting the ball in the right direction and to an accurate location requires golfers to develop a highly precise and efficient swing motion. With repeated practice, golfers aspire to be able to execute accurate shots in a reproducible and consistent manner. It is believed that poor trunk motion will affect the golf swing, shoulder turn, and weight shift, leading to inaccurate shots (Draovitch & Westcott, 1999). In other words, golf demands sensory, motor, and dynamic postural control with precise trunk motion and appropriate weight shifting from both legs to predominantly one leg during end-swing (Okuda, Armstrong, Tsunezumi, & Yoshiike, 2002).

In a previous study, we showed that older golfers (mean age 66.2 years) had significantly better knee-joint proprioception and limits of stability during double-leg stance than control participants similar in age, gender (male), and physical activity level. Of particular interest were our results showing that the acuity of their knee-joint proprioception, as well as the maximum excursion and the directional control of their normalized center of pressure during weight shifting within their base of support, was comparable to those of younger participants (mean age 20.3 years; Tsang & Hui-Chan, 2004a).

Falls seldom occur during double-leg stance, when the center of mass is well within the base of support. They often happen during walking, turning, or ascending or descending stairs (Nevitt, Cummings, & Hudes, 1991). Thus, any evaluation of balance control confined to double-leg stance alone may not reflect the functional performance required of older people in certain activities of daily living. A round of golf (18 holes) usually involves 8 km of walking and takes approximately 4 hr to play (Parkkari et al., 2000; Stauch, Liu, Giesler, & Lehmann, 1999). Because walking consists of double-leg and single-leg support phases, walking on the uneven golf fairway may enhance balance performance in single-leg stance.

In a review study, Horak, Henry, and Shumway-Cook (1997) reported that 35% of falls among older persons could result from inadequate responses to perturbations caused by external displacements of the body’s center of mass. They noted that balance control in response to environmental perturbations is important as part of effective postural control during functional activities. Indeed, the support surface is not always stationary when one conducts daily activities such as stepping onto a moving escalator or walking in a moving bus. Such daily activities demand greater balance control and could pose particular problems for older adults. Weight shifting from two legs to predominantly one leg while moving the trunk and arms in a precise golf swing is an activity that demands a high level of balance control. Extrinsic causes such as uneven ground and obstacles in the environment combined with intrinsic causes of poor balance in older adults may precipitate falls (Li et al., 2007). In addition, activities of daily living demand multidimensional complex tasks that require multijoint coordination, lower limb muscle strength, and single-leg-stance control. Golfing 18 holes often involves walking with double- and single-leg support up and down hills and sometimes through bunkers (hollows in the ground filled with sand; Parkkari et al., 2000; Stauch et al., 1999), activities that may promote balance control in both static and perturbed single-leg stance, as well as multidimensional balance tests. Therefore, the objective of the current study was to compare balance control between older golfers and healthy controls.
Methods

Participants

Eleven participants with a mean age of 70.8 years (± 4.0 years) were recruited in a pilot study to examine test–retest reliability. Of the 23 main study participants, 11 male golfers (mean age 66.2 ± 6.8 years) were recruited from local golf clubs and had practiced golf for a minimum of 1.5 hr/week for at least 3 years (mean golf experience 15.2 ± 13.4 years). The remaining 12 healthy male participants (mean age 71.3 ± 6.6 years) were recruited from community centers and had no previous experience in golf, although some took morning walks or did stretching exercises. All participants were independent in their activities of daily living, and none required walking aids. They were able to communicate and follow the testing procedures. Candidates with poorly controlled hypertension and those showing severe cognitive impairment (Mini Mental Status Examination score <24) or diagnosed with metastatic cancer, Parkinson’s disease, stroke, or any other neurologic disorder were excluded. Also excluded were people diagnosed with cardiovascular disease, symptomatic orthostatic hypotension, peripheral neuropathy of the lower extremities, or disabling arthritis that prevented them from completing the balance tests in the study. In addition, participants who reported a fall in the past 12 months, either injurious or noninjurious, were excluded.

Candidates were first interviewed using a general health questionnaire and a physical activity questionnaire. The validated Chinese version of the Mini-Mental Status Examination of Folstein et al. was then administered (Chiu, Lee, Chung, & Kwong, 1994), with a scale ranging from 0 to 30. A score below 24 was considered indicative of cognitive dysfunction, and such participants were excluded from the study. A modified version of the Minnesota Leisure Time Physical Activity Questionnaire (Tsang, Wong, Fu, & Hui-Chan, 2004; Tsang & Hui-Chan, 2003, 2004a) was used to compare the physical activity levels of the golfers with those of the control participants. This instrument evaluated the energy expended in leisure-time physical activities and household tasks (Van Heuvelen, Kempen, Ormel, & Rispe ns, 1998). The activities were categorized according to their metabolic equivalent (MET) status as either light (intensity ≤4.0 METs), moderate (>4.0–5.5 METs), or heavy activities (intensity >5.5 METs). This project was approved by the ethics committee of the Hong Kong Polytechnic University, and written informed consent was obtained from all participants before the study commenced.

Experimental Procedures

Three tests were conducted, namely, static single-leg stance, single-leg stance in response to external perturbations, and a forward-lunge test. This combination was more multidimensional than traditional balance tests and incorporated multijoint coordination and muscle strength.

Single-Leg Stance. Timed single-leg stance has frequently been employed as a clinical tool to assess balance control in patients with balance disorders. In a cross-sectional study, Hurvitz, Richardson, Werner, Ruhl, and Dixon (2000) found that participants (mean age 69.8 years) who had a history of falls showed significantly poorer results in timed single-leg stance than slightly younger participants (mean
age 63.2 years) without a history of falls. In the current study, participants performed a single-leg-stance test on their dominant leg while standing on a force platform (Kistler, model 9286AA, Switzerland) with their eyes open and arms by their sides. The leg used to kick a ball was defined as the dominant leg (found to be the trailing leg of all golfers who participated in this study). Participants were instructed to keep their nondominant leg off the ground and flexed 90° at the knee with the hip in a neutral position for a maximum of 30 s (Bohannon, 2006). A second force platform was used to record the duration of single-leg stance on the dominant leg (in seconds) by timing the moment when the nondominant leg landed on it. After familiarization, three trials were recorded. The mean standing duration was used to compare balance control in single-leg stance between the two groups.

Perturbed Single-Leg Stance. We detailed the test procedure in a previous article (Tsang & Hui-Chan, 2005) and therefore only summarize it here. Wearing a security harness, with their feet at shoulder width, participants stood without shoes on a computerized dynamic posturography machine with a movable platform (NeuroCom International Inc., type Smart EquiTest, Portland, OR). They were asked to stand still, with the same instructions as those in the static single-leg-stance test. They were told that the perturbation could start any time as soon as they flexed the nondominant knee. Participants were then perturbed with forward and backward platform translations in a random order. To minimize their anticipation, perturbations were initiated after a random delay of 2–7 s. The computerized dynamic posturography equipment scaled the platform translation amplitudes according to the participant’s height, to give a maximum anteroposterior body sway angle of 3.2° (NeuroCom, 2002). Translation lasted for 400 ms. The center of pressure was measured by four sensors mounted on the support surface. This was used to estimate the actual anteroposterior body sway angle of the participants during perturbations. The average of the maximum anteroposterior body-sway angles recorded over three trials was used to compare the balance control of the two groups for each perturbation direction (Tsang & Hui-Chan, 2005).

Forward-Lunge Test. The forward-lunge test has frequently been used to assess athletes’ fitness (Alkjær, Simonsen, Magnusson, Aagaard, & Dyhre-Poulsen, 2002). The test involves lunging one step forward using either the dominant or nondominant leg, to evaluate balance performance and lower limb coordination and joint stabilization as reflected by agonist–antagonist cocontraction (Mattacola, Jacobs, Rund, & Johnson, 2004). Participants were instructed to stand in an upright position on a rectangular force platform that consisted of two 9-in. by 60-in. footplates (NeuroCom International Inc., type Smart EquiTest, Portland, OR). They were instructed to perform a forward lunge by taking one step forward as far and as fast as they could. After landing on the force platform, participants flexed the knee of the lunged leg. They then extended that knee to move it back to the starting position as fast as possible (NeuroCom, 2002). Their arms were by their sides in the starting position and free to move to maintain balance if necessary during test. Practice trials were given to familiarize the participants with the testing procedure. Afterward, three trials were given for each leg, and the average distance of the forward lunge, expressed as a percentage of body height and termed the normalized lunge distance, was computed for comparison between the two groups (NeuroCom).
Data Recording and Analysis

The center of pressure, as measured by the four sensors attached to the force platform, was recorded and used to calculate the amount of body sway, termed body-sway angle, during the perturbed single-leg stance (Tsang & Hui-Chan, 2005). The latter was used in this study to compare the control of body sway between the two groups. Similar to our previous studies (Tsang, Wong, Fu, & Hui-Chan, 2004; Tsang & Hui-Chan, 2004a, 2004b, 2005), each participant’s body sway was first recorded for 2 s before any platform translation. The average value of the body-sway angle during these 2 s was computed and served as the baseline value. The maximum body-sway angle during perturbation was then estimated, and the difference from the baseline value, termed the perturbed body-sway angle, was calculated. Three trials were performed for each perturbation direction, and the average value was used to compare the two groups. If any participant fell during the platform perturbation, the theoretical anteroposterior-sway stability limit of 12.5° was treated as the perturbed body-sway angle (NeuroCom, 2002). A “fall” in the perturbed single-leg-stance test was recorded when the participant began to fall and touched the visual surround for support or gained support by using the nondominant leg (NeuroCom).

Statistical Analysis

Age, weight, and height were compared between the two groups using independent t tests. Because of the categorical nature of physical activity levels, a chi-square test was used for between-groups comparison. An intraclass correlation coefficient was applied to assess the test–retest reliability of single-leg-stance duration, body-sway angle during perturbed single-leg stance, and normalized lunge distance in the forward-lunge test. The ICC model 3, denoted by ICC(3,3), was used to assess intrarater reliability, with the latter 3 indicating the number of trials used in the balance tests. As shown in Table 1, the golfers were 5.1 years younger on average than control participants (p = .079). Although this difference was not statistically significant, age was treated as a covariate in the analysis of all balance tests. A univariate test with age as covariate was employed to compare the duration of single-leg stance between the older golfers and the control participants. Multivariate analysis of covariance was used to compare

| Table 1 Comparison of Age, Height, Body Weight, and Physical Activity Level Between Healthy Control Participants and Older Golfers |
|-----------------------------------------------|-----------------|-----------------|---|
| Control participants, n = 12 | Golfers, n = 11 | p               |
| Age, years            | 71.3 ± 6.6 | 66.2 ± 6.8 | .079 |
| Height, cm            | 160.0 ± 6.2 | 164.5 ± 7.7 | .135 |
| Body weight, kg       | 62.4 ± 8.6 | 65.7 ± 7.7 | .349 |
| Physical activity level, n (%) |               |                  | .269 |
| light, ≤4 METs        | 10 (83.3%) | 6 (54.5%) | |
| moderate, ≤5.5 METs   | 2 (16.7%) | 4 (36.4%) | |
| heavy, >5.5 METs      | 0 (0%) | 1 (9.1%) | |

Note: MET = metabolic equivalent.
the perturbed single-leg-stance and forward-lunge test results between the two groups. If statistically significant differences were found in the overall multivariate tests, a univariate test was conducted for each of the measures. A significance level (\(\alpha\)) of .05 was chosen for statistical comparisons.

## Results

### Participants

Independent \(t\) tests showed that there was no statistically significant difference in age, height, or weight between the golfers and control participants (\(p > .05\); Table 1). A chi-square test also found no statistically significant difference between the two groups in physical activity level (\(p = .269\); Table 1). The golfers and control participants were thus similar with respect to age, height, weight, gender, and physical activity levels.

### Test–Retest Reliability of Single-Leg-Stance, Perturbed Single-Leg-Stance, and Forward-Lunge Tests

The balance-control tests were readministered to participants in the pilot study 1 week after the first assessment. For single-leg stance, the ICC(3,3) value for stance duration was .99 (confidence intervals, or CI, .94-.99). For perturbed single-leg stance, the ICC(3,3) values for the maximum anteroposterior body-sway angles in forward translation and backward translation were, respectively, .81 (CI .51-.93) and .74 (CI .35-.90). The ICC(3,3) values for the lunge test in stepping forward onto the dominant and nondominant legs were, respectively, .90 (CI .58-.97) and .93 (CI .73-.98). The ICC values found in this study ranged from .74 to .99. Therefore, all the tests used in this study produced reliable measures. However, the confidence interval for backward translation of the perturbed single-leg-stance test was large (CI .35-.90). This might be a result of the small sample size in the reliability test (\(n = 11\)).

### Balance Tests

Results of the univariate analysis test of single-leg stance indicated that the golfers achieved significantly longer stance duration (average 28.1 ± 3.6 s) than the control participants (average, 17.1 ± 11.9 s; \(p = .020\); Figure 1). Multivariate test results of the perturbed single-leg stance indicated an overall statistically significant effect across the two measures between golfers and control participants (\(p = .023\)). Univariate tests showed that golfers had smaller body-sway angles during forward platform translation (mean 6.0° ± 2.7°) than control participants (mean 9.5° ± 3.1°; \(p = .005\); Figure 2), as well as during backward platform translation (means 6.1° ± 2.3° and 9.0° ± 3.4°, respectively; \(p = .041\)).

Multivariate tests on the forward-lunge results indicated an overall statistically significant difference across the two measures between golfers and control participants (\(p = .032\)). Univariate tests showed that the golfers performed larger normalized lunge distance onto both dominant (54.1% ± 4.5%) and nondominant legs (53.8% ± 4.8%) than did control participants (46.0% ± 9.1%, \(p = .014\), and 46.7% ± 10.0%, \(p = .043\), respectively; Figure 3).
Figure 1 — Comparison of single-leg-stance test results between healthy control participants and golfers, $M \pm SD$. *Significant difference at $p < .05$ using univariate test.

**Figure 2** — Comparison of perturbed single-leg-stance test results between healthy control participants and golfers, $M \pm SD$. **Significant difference at $p < .05$ and †$p < .01$ using univariate tests, after multivariate tests showing an overall statistically significant difference at $p = .023$.**
Discussion

Golf and Health Benefits

Shatil and Garland (2000) prescribed a therapeutic golf program for patients suffering from stroke. They suggested that therapeutic effects of golf training could include midline postural alignment, trunk rotation with large shoulder-girdle movement, weight shifting, and eye–hand coordination. However, they produced no data to demonstrate the effectiveness of such a program. Our previous findings showed that older golfers manifested greater limits of stability during double-leg stance when they were instructed to shift their weight to one of eight target positions, preselected in a random order, as quickly and smoothly as possible without moving their feet (Tsang & Hui-Chan, 2004a). In a well-executed golf swing, golfers must maintain good balance during weight shift between the two legs and precise control of the posture of the head and body in relation to space and to the limbs, as well as timely coordination of their muscle activities. These requirements might have promoted balance control with repeated golf practice over time (mean golf experience 15.2 years; Tsang & Hui-Chan, 2004a). In the current study, older golfers demonstrated significantly longer duration in single-leg stance, achieved...
less body sway in single-leg stance under perturbation, and lunged farther in the forward-lunge test than did the control participants (all \( p < .05 \); Figures 1–3). A question may arise as to why golfers had better balance performance during single-leg stance, seeing that golf mainly involves double-leg stance.

**Golf and Balance Control**

Parkkari et al. (2000) studied the health benefits of golf by recruiting 55 healthy male golfers, age 48–64 years, who stopped golfing for 7 months before the investigation. During the 20-week study period, these golfers played golf an average of 10 hr/week. The investigators found that the golfers improved significantly in treadmill walking time and static back-extension time when compared with age-matched sedentary controls without any intervention. They attributed the improvement observed in golfers to the regular walking on the golf course, estimated to be 20 km/week. Note that a usual gait cycle involves approximately 20–25% double-leg support for older adults, and the remainder of the cycle is spent on single-leg support (Oatis, 2004). Thus, walking could facilitate balance control on one leg and weight transfer to the other (Hurvitz et al., 2000). Consequently, prolonged walking, especially on uneven or hilly golf courses, could enhance balance control during single-leg stance. In this study, golfers achieved 64% longer single-leg-stance duration than control participants (Figure 1). Because older fallers (average age 69.8 years) had significantly shorter single-leg-stance duration (mean 9.6 s) than nonfallers (Hurvitz et al.), our findings imply that the improved single-leg stance in experienced golfers may reduce their risk of falling. Moreover, falls resulting from perturbations caused by external displacements of the body’s center of mass are not uncommon (Horak et al., 1997). In the current study, golfers demonstrated significantly less body sway than control participants in response to both forward (37% less, \( p = .005 \); Figure 2) and backward platform translations (32% less, \( p = .041 \)). Therefore, older golfers who are better able to maintain balance control in the face of perturbations could be expected to experience fewer falls. If so, golf could be a good balance-training approach for older adults.

The golfers’ balance performance in perturbed single-leg stance in this study was comparable to that of older Tai Chi practitioners (average age 69.3 years) reported in our previous study (Tsang & Hui-Chan, 2005). The Tai Chi participants in that study underwent the same assessment protocol and had average body-sway angles of 7.2° and 6.2° in response to forward and backward perturbations, respectively. Their performance was also significantly better than that of control participants similar in age and physical activity level. Note that Tai Chi requires constant weight shifting between double-leg and single-leg stances. In addition, the execution of various arm and leg movements in a coordinated manner during single-leg stance demands a high degree of balance control (Tsang & Hui-Chan, 2005). A round of golf usually involves 8 km of walking, often over uneven ground, up and down a hilly course, and sometimes through bunkers. These activities would provide good balance training for older people. In a previous study (Tsang & Hui-Chan, 2005), we demonstrated that body sway during single-leg stance in older participants subjected to forward and backward platform perturbations was negatively correlated with their balance confidence as measured by
the Activities-Specific Balance Confidence Scale. The better balance control in response to standing perturbations shown by the golfers may have given them better balance confidence. This might help them maintain their physical activity level and reduce their risk of falling as they age further.

In this study, golfers could lunge significantly farther than control participants, both when lunging onto their dominant leg (18% farther, \( p = .014 \); Figure 3) and when lunging onto their nondominant leg (15% farther, \( p = .043 \)). Lunging is commonly used in the sports field to assess lower extremity flexibility, muscle strength, and balance because the ability to quickly finish a lunge and return to a standing posture is important for success in sports such as squash, fencing, and basketball. Alkjær et al. (2002) conducted a study to determine the differences in movement pattern during a forward lunge as a result of anterior cruciate ligament deficiency (average participant age 29.4 years) using kinematic, kinetic, and electromyographic recordings. They found that the lunging knee reached an average of 80° flexion, followed by its extension’s being controlled by eccentric and concentric contractions of the quadriceps. The hamstrings were shown to be active during the lunging process both in the patients who could cope with their sporting activities and in healthy control participants. In contrast, the contraction of the hamstrings was significantly lower in those who could not participate in sports. The authors attributed the stability of the lunging knee joint to better cocontraction of the hamstrings.

What is the role of the support leg during the test? Pijnappels, Bobbert, and van Dieën (2005) investigated the contribution made by the support-leg muscles in maintaining postural control after tripping, one of the main causes of falls (Nevitt et al., 1991). Older adults and young participants were asked to walk over a platform, and the investigators tripped their swinging leg using an obstacle at different points in their gait cycle. They found that the magnitude and rate of development of muscle activity in the support leg were significantly lower in older participants, leading to inadequate recovery responses and falls. The better lunging performance of golfers may indicate better strength and motor control of both the lunging and the support leg. However, further research is needed.

Golfing requires coordinated trunk and arm movements and controlled weight shifting from two legs to predominantly one leg during precise golf swings, as well as prolonged walking comprising single- and double-leg support over uneven ground (Selicki & Segall, 1996). Okuda et al. (2002) conducted a biomechanical analysis of a professional golfer’s swing. Using the force platforms, they found that the weight distributions were similar, with 49% and 51% of body weight of the leading and trailing legs, respectively, at the starting position (address phase) of the golf swing. The weight varied from 21% to 142% of body weight from top-of-swing to impact phases for the leading leg, whereas values ranged from 85% to 32% from back-swing to follow-through phases of the trailing leg. All these requirements may contribute to the better single-leg-stance performance found in our current study. Rather than using a cart, older golf players should be encouraged to walk on the golf course, because it may enhance their balance control, as well as their cardiovascular system and muscle strength. With urbanization, older adults who reside in a city may no longer have much chance to walk on uneven and hilly ground. Golfing may provide an opportunity for people to exercise, not just in terms of the golf swing but also walking on the uneven
terrain of the fairway, carrying a bag, and pulling or pushing a bag cart. Because the metabolic demands of golfing are moderate (Ainsworth et al., 1993), it may provide an attractive outdoor exercise option for older people.

Limitations of the Study

There are several limitations of the current study. Because of its cross-sectional study design, a causal relation between golfing practice and balance control could not be established. Although the golfers showed significantly better performance in the static and perturbed single-leg-stance and forward-lunge tests (all $p < .05$), the sample size was relatively small. In addition, the participants were healthy men. This will limit the generalization of the current findings to older women and unhealthy men. The physical activity levels of the golfers and control participants were compared using a questionnaire and found to have a statistically insignificant difference. However, the higher number of golfers who achieved a moderate activity level (5 out of 11 participants) than control participants (2 out of 12) might have confounded the results. This is because more physical activity, not necessarily golfing per se, may lead to better balance control. To control these potential confounding factors, a prospective intervention design should be adopted next. In addition, such a design may differentiate the causal effect of motor actions of golf versus walking the golf course to improve balance control. The forward-lunge test, commonly employed to assess participants with sport injuries in the lower limbs, was used to assess more complex balance control involving lower limb coordination and muscle strength in this study. However, its relationship to more functional balance control such as gait and falls reduction has not been established. Therefore, the current findings should be interpreted with caution.

Conclusions

The improvements in static and perturbed single-leg-stance and forward-lunge tests, together with the improvement in knee-joint proprioception and in voluntary weight shifting in experienced golfers, reported in our current and previous studies (Tsang & Hui-Chan, 2004a) suggest that golfing may improve balance control in older participants. If so, the increasingly popular sport may have the potential to become part of a falls-prevention program. Toward these goals, a prospective study examining the effect of golf on balance control is warranted.

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