The effects of walking on golf drive performance in two groups of golfers with different skill levels

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ANDREW GREEN MSC, CHLOE DAFKIN MSC, SAMANTHA KERR PHD AND WARRICK MCKINON PHD

Biomechanics Laboratory, School of Physiology, Faculty of Health Sciences, University of the Witwatersrand Medical School, 7 York Road, Parktown, 2193, South Africa.

ABSTRACT

Although walking is a fundamental part of the game of golf, the effects of walking on the golf shots outcome are largely overlooked. The purpose of the present study was to determine the effects of a hole-to-hole distance walk on the golf drive performance as well as possible physiological contributory factors were evaluated. Twenty-one volunteer golfers were recruited and divided into two groups based on their average round scores: More Competitive Golfer (MCG) ≤88 (n=13) and Irregular Social Golfer (ISG) ≥89 (n=8). Drive distance was directly measured. Balance and hand-eye coordination were assessed using a modified stork test and a customised three dimensional maze. Participants hit 10 golf balls and then walked 500m before repeating the tests. Heart rates of golfers before driving weren’t different between groups, but were elevated within the groups following walking. The MCG had longer drives following the walk (p=0.018). The change in the distance was correlated to the change in right leg balance with eyes closed (r=-0.619 p=0.003). Biomechanical changes were correlated to the change in drive distance (r=0.867 p=0.025). This study shows that an aerobic warm-up prior to a round or small amounts of walking early in a round may be beneficial to golfers of better ability.

Key Words: Golf, walking, balance, coordination, biomechanics
INTRODUCTION

Golfers seek to improve their game in many ways ranging from: undergoing strength and flexibility training programs (16) to purchasing the latest equipment. The game of golf involves highly complex biomechanical movements which, when well coordinated, result in the ball being struck over great distances (1). Health benefits of golf include an increase in aerobic capacity (19) (11) and improved balance in the elderly when compared to their non-golf playing counterparts (23).

An average golf game can take four hours to complete when walking the course (7). In 18 holes of golf an average player can take more than 10000 steps to complete their round. In addition they may take more than 85 shots (14). The effects of walking throughout the game of golf could contribute greatly to the outcomes of the intended shots (1). Although walking is a fundamental part of the game of golf, knowledge of the effects of walking on golf shots is lacking.

It has been suggested that fatigue in the latter stages of a golf game could lead to poor decision making, regarding either club or shot selection (21). Similarly, high intensity exercise has been shown to reduce tennis shot accuracy (3). Furthermore, an acute mild dehydration may reduce the distance and accuracy of the shot, along with the distance judgement (22).

The overall effects of walking on the golf drive have not been identified, especially on factors such as balance and hand-eye coordination which both affect the distance that a golfer can strike the ball. Anecdotal evidence would suggest that walking could negatively affect the performance of the amateur golfer. This could arise from the perception of increased mental fatigue or a decline in the golfer’s abilities to fully execute the needed shots. Despite this anecdotal suggestion, it is also possible that the physiological impact of walking may have positive effects on the golf swing where a minor aerobic warm-up may increase the alertness of the golfer or convey other benefits to the golfer.

Eye-hand-club coordination and the ability to balance are needed in the shot making phase of golf. Good balance assists in the weight transfer and is needed when the shot played is not on an even surface (9). The ability to control the movements and position of the hands from information received from the eyes is a highly complex task (17). Eye-hand-club coordination is the ability to control hand position based on the information received from the eyes. The control of the club is vital to the outcome of the shot (13) and the position at which the clubface strikes the ball is known to be a major contributor to the resulting flight of the ball (18).

Walking is a critical element when completing a game of golf however knowledge surrounding this essential component and its effects on the physiology of the golfer and the biomechanical action of the golf shot are largely unknown. In this study the effects of a hole-to-hole distance walk on the golf drive distance and
drive accuracy as well as possible contributory factors such as: eye-hand-club coordination, the ability to balance and the ability of a golfer to hit the “sweet spot” between club and ball were assessed.

MATERIAL AND METHODS

Twenty-one male golfers (age 37 ± 13 years, height 177 ± 7 cm, and weight 84 ± 14 kg) volunteered to take part in the study. The golfers were divided into two groups based on their recent golf round scores (similar to Sell et al., 2007 and Zheng et al., 2008): those with scores of 88 or less were classed as more competitive golfers (MCG, n=13) and those having scores of 89 or higher as irregular social golfers (ISG, n=8). Furthermore the separation of golfers was justified by the difference in annual rounds of golf played (MCG: 60 ± 25 golf games per year compared to ISG: 9 ± 3 golf games per year). Ethical approval for this study was obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M110424) and written informed consent was obtained from all participants.

Participants were allowed to warm-up in their own accustomed manner and further by hitting five practise balls under experimental conditions. A target was placed at one end of a flat grass outdoor driving range (260m from the tee, at the other end) towards which participants aimed their shots. Shot accuracy was defined as the distance perpendicular from the resting ball to the tee-target axis. Drive distances were determined as the intersection between the tee-target axis and the previously described accuracy measurement axis. All shots were hit from a standard tee and a small sheet of pressure sensitive paper was placed on the club face over the defined “sweet-spot”, and used to quantify the centeredness of hit for every shot. Resting heart rate was recorded using a heart rate monitor (Polar S610, Polar Electro Oy, Finland) prior to the start of testing. Balance was determined using the bilateral stork test repeated with the participant’s eyes closed. The time each participant could maintain his balance was recorded to the nearest second, with a cut off of 60 seconds. Participants wore their golf shoes during the balance and testing procedures.

Hand-eye coordination was determined as the ability for each subject to complete a three dimensional maze. The maze tested the subjects’ ability to manipulate a club through 360 degrees forwards and backwards in both the horizontal and vertical planes. Subjects moved a modified golf club through a predefined path in the approximate area of ball contact. Golfers were instructed to complete the maze in the shortest possible time making as few contacts between the driver shaft and maze as possible. Errors (contacts between club and maze) and timing
were tracked through an electric circuit which closed when an error was made. The maze circuit was connected to a Powerlab 26T system (26T, ADI instruments, Australia) which allowed errors and maze duration to be recorded. Hand-eye-club coordination was quantified as the number of errors divided by the time taken to complete the task. Participants were instructed to hold the club shaft with the same grip they would with a regular golf club. They were allowed to rotate their hands and move their arms and upper bodies while keeping their feet stationary.

After the participants hit ten golf balls they were instructed to walk to a marked 250m indicator, and back to the teeing ground (a total of 500m), at the pace they would normally walk on the golf course. Following this heart rate was recorded. All golfers then hit another ten golf balls followed by a repeat of the balance and hand eye coordination tests. The distance and accuracy of the golf drive was determined by the average over ten shots, for both before and after the 500m walk.

All the golf swing body movement data was captured biomechanically using six high speed Optitrack 250e (Natural Point NaturalPoint, Inc., OR, USA.) cameras recording at 250Hz. All biomechanical data was analysed in MatLab 7 (Mathworks, Natick, USA).

Retro-reflective markers were placed on the following anatomical landmarks: bilaterally on the first finger, acrominum process, calf, thigh, anterior superior iliac spine (ASIS), first toe and heel. Bilateral markers placed both medially and laterally on the ankles and knees and a marker on the sacrum. An additional marker was placed on the rubber tee, to determine when ball contact was made. Flexion angles of the knees were calculated as the angle between the thigh and calf vector lines, and the ankle flexion angles as the angle between calf and foot vector lines. Knee and ankle rotation angles were calculated using the vector lines from the middle of the joint to the lateral marker, and compared to the vector created from the toes in the address position on the xy plane. Shoulder and pelvis rotations were the angles created by translating the shoulder and pelvic vector lines to the mid-point of the vector line established by the feet markers in the address position on the xy plane. These biomechanical variables are graphically depicted in Figure 1.

Statistics: All data are presented as mean ± standard deviation. Paired t-tests were run to determine differences in any of the variables following the walking protocol. Pearson’s correlations were run on the change in values from before and after the walk. All statistics were run in GraphPad Prism 5 (San Diego, USA) with a significance level of α<0.05.
Fig. 1. Explanation of biomechanical variables: **A**: Shoulder rotation **B**: Pelvis rotation. **C**: Knee rotation **D**: Knee flexion angle. **E**: Ankle rotation **F**: Ankle flexion angle. Shaded area indicates the xy plane.

RESULTS

The change values noted in this study are the difference between the before walking values and the after walking values. The 21 golfers had a self reported average golf round score of 87±10 strokes, within the last three months. Significant differences were observed between the two groups in the amount of annual rounds of golf and their recent average scores (Table 1). Following the 500m walk heart rate was increased in both groups of golfers. (MCG 72±13 beats.min⁻¹ to 89±16 beats.min⁻¹ p=0.0004 and ISG 78±17 beats.min⁻¹ to 89±19 beats.min⁻¹ p=0.002). The MCG improved their drive distance by an average of 10m, with no significant change in drive distance in the ISG group (Table 2). The accuracy of the shots did not significantly improve following the walk, neither did the centeredness of ball strike on the club face. The combined group (MCG and ISG) of golfers’ ability to perform the hand-eye coordination task improved following the walk (p=0.046, paired t-test) (Table 2).
### Table 1.
The demographics, recent average scores and amount of annual rounds of golf for the two groups of male golfers.

<table>
<thead>
<tr>
<th></th>
<th>More Competitive Golfers (MCG)</th>
<th>Irregular Social Golfers (ISG)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>13</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>39.2 ± 14.6</td>
<td>34.1 ± 9.8</td>
<td>0.402</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.2 ± 8.2</td>
<td>176.4 ± 5.2</td>
<td>0.796</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>86.7 ± 14.3</td>
<td>79.9 ± 14.2</td>
<td>0.304</td>
</tr>
<tr>
<td>Average Score (strokes)*</td>
<td>81.5 ± 3.8</td>
<td>96.5 ± 8.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Annual golf rounds*</td>
<td>59.6 ± 25.0</td>
<td>8.7 ± 3.3</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

* p<0.05 (unpaired t-test)

### Table 2.
The effects of a 500m walk on two groups of golfers differentiated based on their average game scores.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MCG</td>
<td>ISG</td>
</tr>
<tr>
<td>Drive Distance (m) †</td>
<td>237.6 ± 29.0</td>
<td>195 ± 35.9</td>
</tr>
<tr>
<td>Drive Accuracy (m)</td>
<td>19.7 ± 5.2</td>
<td>20.9 ± 7.9</td>
</tr>
<tr>
<td>Distance from centre of golf club (mm)</td>
<td>29.7 ± 8.1</td>
<td>26.8 ± 4.9</td>
</tr>
<tr>
<td>Hand-eye Coordination task (errors/s) *</td>
<td>2.6 ± 1.2</td>
<td>3.0 ± 0.9</td>
</tr>
<tr>
<td>Balance Left Leg Eyes open (s)</td>
<td>50.9 ± 14.8</td>
<td>49.9 ± 18.8</td>
</tr>
<tr>
<td>Balance Right Leg Eyes open (s)</td>
<td>52 ± 17.8</td>
<td>48.6 ± 17.2</td>
</tr>
<tr>
<td>Balance Left Leg Eyes closed (s)</td>
<td>14.5 ± 16.9</td>
<td>12.6 ± 10.3</td>
</tr>
<tr>
<td>Balance Right Leg Eyes closed (s)</td>
<td>10.8 ± 9.4</td>
<td>18 ± 20.7</td>
</tr>
</tbody>
</table>

* significant difference between More Competitive Golfer (MCG) and Irregular Social Golfer before and after walk
† significant difference in More Competitive group between before and after walk
≈ significant difference between the More Competitive and Irregular Social groups
ISG = Irregular Social Group scores > 89. MCG = More Competitive Group scores ≤ 88.
The balance tests show that there were no significant differences in the amount of time the participants could maintain their balance following the walk. Changes in drive distance did not significantly correlate with changes in balance with eyes open, centeredness of strike or with changes in hand-eye coordination. However, changes in the ability to balance on the dominant leg with eyes closed was correlated to changes in drive distance (Figure 2A), with a stronger relationship in the ISG group (Figure 2B).

**Fig. 2 A and B.** (A) The correlation between the change in balance in the dominant leg with eyes closed (seconds) and the change in drive distance (m) in a group of 21 golfers. $R^2 = 0.383 \, r=-0.619 \, p=0.003$, and (B) in a group of 8 golfers with scores greater than 89 strokes. $R^2 = 0.650 \, r=-0.807 \, p=0.016$. 
A combined sub-group (samples from MCG and ISG) of golfers was assessed due to the limited nature of the biomechanical data. Assessing the biomechanical variables, we found that a change in drive distance was positively correlated to left knee angle change at backswing ($R^2 = 0.712\, r = 0.844\, p = 0.017$). In the contact position the change in right knee rotation angle also predicted the changes in drive distance (Table 3), but this same relationship is not seen at the level of the ankle. A significant reduction in the right ankle angle occurring in the contact position is evident following the walk ($p = 0.04, n = 4$). There was no correlations between the changes in right leg balance with eyes closed and any leg rotation angles or leg angles. The only relationship between movement variables describing the swing in our golfers (in a subgroup of six golfers where this analysis was possible) was where changes in right knee rotation angle from backswing to ball contact were significantly correlated to changes in pelvic rotation from backswing to ball contact ($r = 0.872\, R^2 = 0.930, p = 0.002$).

Table 3.
The change in biomechanical angles from backswing to contact position resulting from the 500m walk and the correlation with the change in the drive distance achieved.

<table>
<thead>
<tr>
<th>Angles (°)</th>
<th>n</th>
<th>Before</th>
<th>After</th>
<th>Change</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASIS rotation</td>
<td>7</td>
<td>-43.11 ± 43.75</td>
<td>-23.06 ± 21.97</td>
<td>20.05 ± 32.57</td>
<td>-0.115</td>
</tr>
<tr>
<td>Shoulder Rotation</td>
<td>7</td>
<td>-86.28 ± 33.47</td>
<td>-74.38 ± 19.46</td>
<td>11.90 ± 17.93</td>
<td>-0.325</td>
</tr>
<tr>
<td>Left Knee</td>
<td>7</td>
<td>30.77 ± 9.47</td>
<td>29.09 ± 8.76</td>
<td>-1.69 ± 7.17</td>
<td>-0.131</td>
</tr>
<tr>
<td>Right Knee</td>
<td>6</td>
<td>-5.40 ± 5.03</td>
<td>-6.65 ± 11.33</td>
<td>-0.98 ± 7.73</td>
<td>-0.577</td>
</tr>
<tr>
<td>Left Knee Rotation</td>
<td>7</td>
<td>22.41 ± 13.09</td>
<td>27.50 ± 26.38</td>
<td>5.08 ± 20.99</td>
<td>-0.510</td>
</tr>
<tr>
<td>Right Knee Rotation</td>
<td>6</td>
<td>16.19 ± 16.11</td>
<td>13.69 ± 21.28</td>
<td>-5.06 ± 10.85</td>
<td>0.872*</td>
</tr>
<tr>
<td>Left Ankle</td>
<td>6</td>
<td>-20.71 ± 15.31</td>
<td>-14.11 ± 14.63</td>
<td>7.02 ± 9.00</td>
<td>-0.500</td>
</tr>
<tr>
<td>Right Ankle</td>
<td>6</td>
<td>-11.70 ± 14.14</td>
<td>-13.68 ± 14.45</td>
<td>-1.97 ± 4.49</td>
<td>-0.167</td>
</tr>
<tr>
<td>Left Ankle Rotation</td>
<td>7</td>
<td>1.07 ± 9.57</td>
<td>-1.51 ± 3.72</td>
<td>-2.58 ± 11.63</td>
<td>0.140</td>
</tr>
<tr>
<td>Right Ankle Rotation</td>
<td>7</td>
<td>7.28 ± 20.13</td>
<td>4.76 ± 6.69</td>
<td>-2.51 ± 14.13</td>
<td>0.289</td>
</tr>
</tbody>
</table>

* $p < 0.05$
DISCUSSION

The results presented in this study would suggest that walking not only affects the physiology of the golfer, but can also affect the biomechanics of the golf swing. Walking during a game of golf has been shown (7) to elevate a golfers’ heart rate to an average of 95 ± 12 beats per min⁻¹, which is in line with the average post walking heart rates observed in this study (89 ± 16 beats per min⁻¹). Following a round of golf a change in mood states was shown to occur in senior players with a perceived increase in the level of fatigue (15), furthermore it was suggested that such fatigue might be associated with a possible decline in ability (22). However the increased heart rate in this current study would in no way indicate a fatigued state. It is interesting to note that the changes in heart rate were not significantly correlated to the changes in drive distance. This is likely due to the method used to measure heart rate. In this study heart rate was measured twice, once as resting and the other immediately after the walk. It is likely that a continuous measure of the heart’s activity would identify the golfers’ ability or lack of ability to reduce sympathetic tone prior to taking the shot.

The increase in drive distance seen in the group of More Competitive Golfers might be attributed to the effects of “warm-up” phenomenon. Such a phenomenon was attributed to an increase in club head speed in a group of golfers that underwent a full body aerobic warm-up (5). We would therefore propose that the addition of an aerobic warm up may be beneficial to the driving ability of golfers when incorporated into the pre-game preparation, particularly since many golfers do not warm up adequately prior to the first shot of the golf round (4).

The lack of a relationship between the changes of centeredness of ball strike on the clubface and changes in drive distance shown in this study could be testament to the advances in current golf club technology. We believe that caution should be exercised when considering our data of a golfers’ ability to perform the hand-eye coordination task. Our data may suggest that hand-eye coordination could have improved following the walk, however when the participant performed the task prior to the walk they were naïve to the fine motor skill needed to achieve minimal errors. It is possible that following the walk they were more aware of the necessary movements they had to fulfil to complete the task (a learning effect may have been evident). Segment coordination, and not hand-eye coordination, may have improved resulting in better ball striking and greater distances (13) (18) (12) through the summation of forces (6).

The correlation between the changes in drive distance and changes in the ability to balance on the dominant leg with eyes closed in the current study, may indicate the role that proprioception or vestibulocerebellar processing rather than (or in addition to) the contributions of visual information to the golf swing may con-
tribute to greater drive distance. The stronger relationship between changes in balance and changes in drive distance seen in our Irregular Social Golfers (compared to when all golfers were analysed) may suggest that in Irregular Social Golfers where proprioception or cerebellar processing for the golf drive may not be as refined as it is in more accomplished golfers, difference in proprioception may more clearly predict drive distance. Novice golfers may be unaware of which elements of their movement and swing are in error, a phenomenon which has previously been attributed to poor sensory-motor feedback (13). Balance is a multifaceted motor skill requiring integration of visual, vestibular and somatosensory information to produce postural actions (24). In a review regarding balance and sporting abilities, more proficient athletes are shown to have better balance than their less accomplished peers (9). The superior balance ability of more accomplished athletes was thought to be the consequence of a greater frequency of motion rehearsal and an enhanced ability to respond to proprioceptive and visual inputs (9). Furthermore better golfers have been shown to have better postural control at different phases of the swing (25).

The direct correlation between the change in left knee angle at total backswing and the change in drive distance agrees with current literature (8) which confirmed the relationship between their fatigue protocol and changes in left knee angle using pathway analysis. The left leg in backswing phase should bear very little weight as most of the weight in this part of the swing should be shifted to the right leg (26). The extension of the left knee should mediate a more pronounced transfer of weight to the right leg resulting in a greater distance.

The correlation between the change in drive distance and the change in right knee rotation angle at contact further emphasises the importance of weight being transferred during the swing sequence. Moreover the changes in the delta values, from the backswing to the contact, for the right knee rotation angle was correlated to the change in drive distance. The right knee rotation seems to act in a similar fashion to the rotation angle of the foot. When the right foot is abducted it allows for a greater pelvic rotation at full backswing (13) similarly the knee flexion facilitates the return of the pelvis (2). This greater pelvic rotation allows for more energy to be built up and stored, to be released later during the down swing (10).

Higdon and colleagues (2012) mention their study limitation regarding the amount of swing that each golfer took and the distance that they each walked. It is likely that the latter protocol could have induced an artificially high amount of fatigue that may not be observed in a normal game and separately that long term fatigue only takes effect later towards the end of the golf game. Despite this, there was a reduction in club head velocity and accuracy after extended simulated golf fatigue (8). There was no significant change in the direct accuracy measurement in this study. Additionally they mention that an indoor study further compounds the problem by occluding the environmental conditions. To overcome some of these
difficulties, the present study was conducted at an outdoor driving range, where distance and accuracy could be directly determined. The participants’ accuracy was determined by the perpendicular distance from the tee-target axis line, enabling the participants to select any shot (fade or draw) in attempting to reach the target. A golfer may need to adapt their swing in times of varying circumstances such as fatigue and the position of their feet on the playing surface (1).

It must be stressed that in this study we only simulated the effects of walking by making the participants walk 500m once, and not multiple shorter distances that would be experienced on the golf course. Furthermore the study only evaluated the use of one club, the driver. In reality the golfer would select the driver to attain maximal distance off the tee, and would rarely be used on consecutive shots. A further limitation is the exclusion of a control group who would not have been exposed to the 500m walk. Future studies should make use of a control group and identify the effects of walks of different distances and intensities.

CONCLUSION

In this study we have shown that an aerobic warm up may be beneficial to a group of More Competitive Golfers and that improving the proprioceptive ability of Irregular Social Golfers may improve their drive distances.

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Address for correspondence:

Andrew Green,
Biomechanics Laboratory,
School of Physiology,
Faculty of Health Sciences,
University of the Witwatersrand Medical School,
7 York Road, Parktown, 2193, South Africa.
Tel: +27(11) 717-2363
Fax: +27(11) 643-2765
Email: Andrew.Green@students.wits.ac.za