



Effects of Orthotic Intervention and Nine Holes of Simulated Golf on Club-Head Velocity in Experienced Golfers

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ABSTRACT

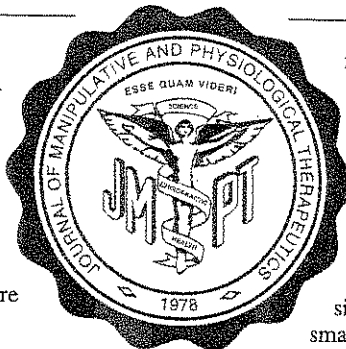
Objective: This study was an initial investigation evaluating the effects of orthotic intervention on club-head velocity (CHV) among a group of experienced golfers before and after 9 holes of simulated golf.

Setting: Northwestern College of Chiropractic, Bloomington, Minnesota.

Participants: Twelve experienced golfers were included in the study.

Method: CHV was measured with a device used by many Professional Golf Association and Ladies Professional Golf Association teaching professionals before and after wearing orthotics and before and after completing 9 holes of simulated golf. Subjects wore custom-made, flexible orthotics daily for 6 weeks and then were retested with the same objective measurement parameters.

Outcome Measure: CHV (swing speed in miles per hour) was measured in all subjects before and after wearing custom-fit,



flexible orthotics for 6 weeks and before and after completing 9 holes of simulated golf.

Results: There was an approximate increase in CHV of between 3 and 5 mph, or a relative increase in CHV by up to 7%, after subjects had worn custom-made, weight-bearing, flexible orthotics daily for 6 weeks. A 5-mph increase in CHV is equivalent to an approximate increase in golf ball travel distance of 15 yards, a significant increase for the tour player for whom small increases in performance can reflect large position changes on the roster board. In addition, the use of these custom orthoses eliminated the effects of fatigue associated with playing 9 holes of golf (relative to CHV) and therefore may improve the likelihood for more consistent golf performance.

Conclusion: The use of the custom-fit, flexible orthotics in this study had a positive influence on CHV in experienced golfers. (*J Manipulative Physiol Ther* 2000;23:168-74)

Key Indexing Terms: Biomechanics; Orthotic Devices; Golf; Sports

INTRODUCTION

The lower extremity and the spine represent a closed kinetic chain in the upright posture. Furthermore, the function of one region can influence the function of another region.¹⁻³ The foot and ankle, as part of this kinetic chain, have considerable potential for influencing the function of the rest of the kinetic chain. Stude and Brink⁴ found that in subjects who wore custom-made, flexible orthotics, proprioception improved, and the effects of fatigue were reduced in a population of experienced golfers. Evidence suggests that shoe selection affects balance performance,⁵ indicating that foot function can influence whole-person activity. In golfers, the pedal foundation, or sole, has a greater effect on lower extremity biomechanics and thus overall performance than the upper construction of the shoe.⁵ Subsequently, golf shoe design modifications and the use of custom orthotics to address individual differences have been recommended by Williams and Cavanagh.⁶

Wren⁷ identified 5 factors that influence golf ball flight: club head speed, club angle of approach, club face position, centerness of contact, and golf fundamentals (eg, stance, grip, swing position, and posture). The golf industry has made many innovations in golf club design to address these factors, including but not limited to oversized club heads and larger "sweet spots" to improve the point of contact. In addition, changes have been made in club shaft design and materials (steel vs graphite shafts), which have influenced changes in shaft flexibility and torque. All these club changes have caused some changes in golf performance,^{8,9} although average overall scores do not seem to have improved during this time of technologic advances in equipment.

Exercise programs have been designed and developed to improve golf swing and to reduce the likelihood for injuries.¹⁰⁻¹² It has been assumed that by strengthening the muscles used during the golf swing, more power will be generated and club-head velocity (CHV) will subsequently increase. However, research has not been conducted to address this assumption.

One premise in this study is that improved pedogenic function improves balance, which may influence the function of the rest of the closed kinetic chain during the golf swing and subsequently increase CHV.

Evidence supports a relation between changes in physical status/ability and subsequent performance potential on the golf course. Adlington¹³ observed that a stable base of sup-

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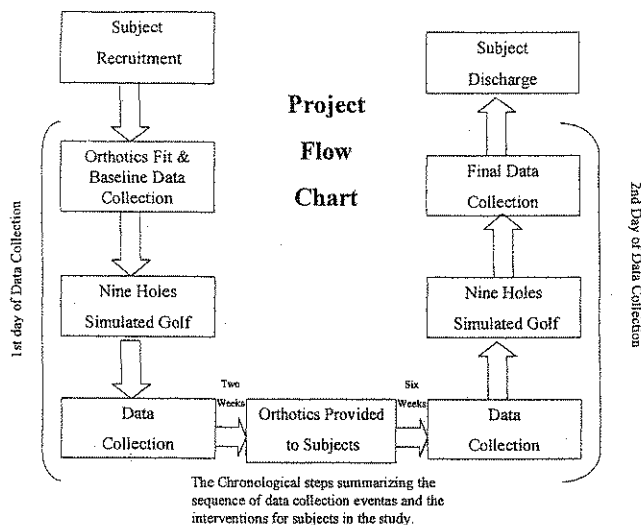


Fig 1. Project flow chart.

port will allow a player to generate more acceleration during the downswing, with a subsequent increase in CHV and greater flight distance. He has also noted that many players with poor balance have less consistency in properly contacting the ball, thus negatively affecting flight distance.

McTeigue et al¹⁴ showed that the majority of tour players initiate the downswing with hip rotation. In addition, Robinson¹⁵ found that the angular velocity of the hips positively influences CHV. Therefore the main purpose of this study was to investigate if improved function of the pedal foundation and subsequent improvements in balance and the rest of the closed kinetic chain promote greater efficiency during the golf swing (eg, lower extremity and pelvic function) and in this way influence subsequent CHV.

METHODS AND MATERIALS

Subject Recruitment: Demographics and Attrition

Potential subjects were recruited for the study by advertising at an annual golf exposition held at the Metrodome in the Minneapolis-St. Paul area, by word of mouth through students at Northwestern College of Chiropractic (NWCC), and on the "Dr Golf" radio talk show on AM 1500 in the community. Only experienced golfers with a reported handicap ≤ 10 were allowed to participate. Some of these golfers were teaching or touring professionals. This subject population was chosen to reduce the learning curve that is associated with golf performance—experienced golfers tend to have a more consistent golf swing. A standard telephone interview script was prepared. Interested subjects were excluded if any of the following criteria were identified:

1. Use of any form of custom-fit orthotic within the past 2 years
2. Allopathic health care within the 6 months before the study for any reason
3. Chiropractic health care within the 6 months before the study for any reason
4. Musculoskeletal pain, including back, knee, shoulder, or wrist pain

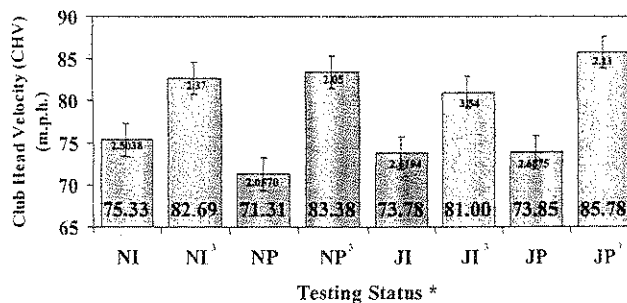


Fig 2. CHV values measured during all stages of testing. Superscripted abbreviations reflect a recorded value based on the indicated number swing attempt only; unsuperscripted abbreviations reflect a recorded value based on the overall average CHV after completing 3 trials. N, Before wearing orthotics; I, after completing 9 holes of golf; J, after wearing orthotics for 6 weeks; P, after completing 9 holes of golf.

5. History of stroke, heart attack, or angina
6. A handicap (subjectively reported) ≤ 10

Of the 12 subjects (11 men and 1 woman) tested on the first day, 9 returned for data collection 2 months later. One subject did not return because of a golf tournament, one because of an acute fracture, and the last because of a job conflict.

Informed Consent

All subjects were required to sign a consent form before participating in data collection. Subjects were informed that the study would examine the biomechanics of golf performance. This study was approved by the Human Subjects Committee on the campus of NWCC.

Instrumentation

Subjects were tested with a Bel-Tronics Swing Mate (Bel-Tronics, Inc, Mississauga, Ontario), an electronic device that measures the speed of the club head as the golfer swings, which offers several options for the golfer, such as club selection, distance, club head speed, and average speed for up to 10 swings. This device has an operating frequency of 10.525 GHz (X band) with a nominal measurement range from 40 to 135 mph and is used by numerous Professional Golf Association and Ladies Professional Golf Association teaching professionals.

Testing Protocols

Before beginning 9 holes of simulated golf, each subject was instructed to hit 10 golf balls as a warm-up. The participants were also instructed to warm up by stretching. The participants were then instructed to take 2 practice shots at the tee and then a final shot. All 3 shots were measured for CHV. The participants were then led through the course by a research assistant. On each hole, participants took 2 practice swings before their final shot. At the end of the 9 holes of simulated golf, the participants were then instructed to stretch and take 2 practice shots and a final third shot.

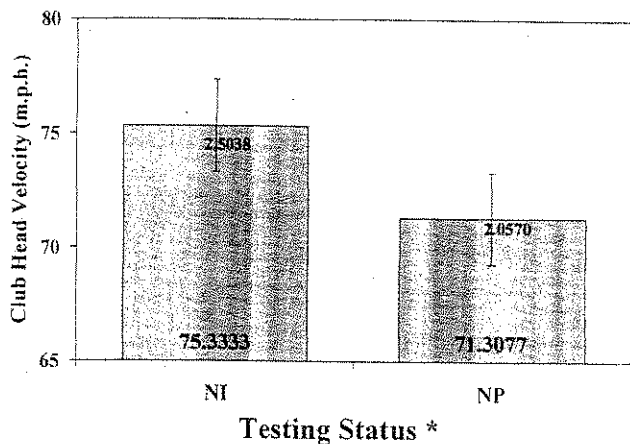


Fig 3. Difference in CHV before and after completing 9 holes of simulated golf before wearing custom orthotics ($P < .001$).

Nine Holes of Simulated Golf

Fatigue was simulated with a 9-hole round of golf in this study. This required the subjects to walk 9 holes of golf and to wait for those ahead of them, typical of real course situations.⁴

Various golf courses in the Minneapolis-St. Paul area were assessed for distance and difficulty; an on-campus course at NWCC was designed with the averages of these courses. Each subject was required to wear golf shoes without spikes or with soft spikes and to carry his or her own bag. The number of clubs and balls carried was consistent among all participants; however, each participant was allowed to use his or her own clubs and bag.

Each hole was assigned a specific par and total distance from the red and white tees. This provided different distances for the male and female participants. Subjects were given a distance for each shot consistent with their sex, and they were then instructed to choose the club based on the distance. Each subject was limited to the same number of shots per hole as all other subjects.

Supervisors were in charge of each group of golfers (with a maximum of 4 subjects per group) to lead them through the course and to ensure subject compliance. Each supervisor completed a comprehensive checklist on each hole to ensure subject compliance.

Orthotics

The custom-made, flexible orthotics used in this study were provided by Foot Levelers, Inc (Roanoke, Va). Two specific types of orthotics were provided for the subjects; the subjects were given 1 full length and 1 three quarter length design. The full-length design was for use in recreational shoes (ie, golf shoes) and the three quarter length design was for use in dress or oxford-style shoes. The men received a pair of full-length Firmflex Plus and a pair of Sir Energy Plus orthotics. The woman received a pair of full-length Firmflex Plus and a pair of Ms Energy Plus orthotics. These orthotics were manufactured with functional materials in multiple layers, including a closed-cell polymer inserted in the heel for shock attenuation.

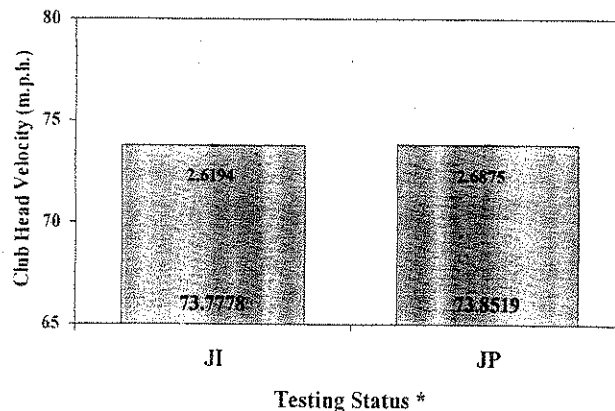


Fig 4. Difference in CHV after wearing custom orthotics for 6 w before and after 9 holes of simulated golf ($P =$ not significant).

Weight-Bearing Casting Procedure

The weight-bearing casting procedure was performed by a chiropractic physician and certified orthotic technician on the initial date of data collection. The weight-bearing casting procedure followed the manufacturer's protocol (Foot Levelers, Inc).

Timeline and Wear Protocol

Casts were made for the custom-made orthotics on the initial date of data collection. Subjects returned to NWCC 2 weeks later to receive their orthotics and written and verbal instructions from the manufacturer's guidelines. The subjects were required to wear their orthotics daily for 6 weeks and then were retested. Fig 1 summarizes the chronologic steps relevant to data collection in the study.

Compliance and Subjective Feedback

Telephone contact was established with all the subjects between the initial and final date of data collection to promote wear compliance. On the last day of data collection, each subject completed an Orthotic Fit and Initial Response Questionnaire to give feedback about the subject's experience with his or her orthotics.

Statistical Analysis

The data were analyzed with a paired Student t test, controlling for individual characteristics and modeling the effect of treatment before and after 9 holes of simulated golf and before and after orthotic intervention. The paired Student t statistic assessed each subject's change in CHV from before to after the test and indicated whether the average change for all subjects was greater than 0. The Student t statistic is the quotient of the mean change for all subjects divided by the standard error of the mean difference. The Student t value, if large enough, indicates that the average change for the subjects is significantly greater than 0, the value that would have occurred by chance.

In addition, a mathematic correction was made (the Bonferroni adjustment, also known as the Dunn test) for the

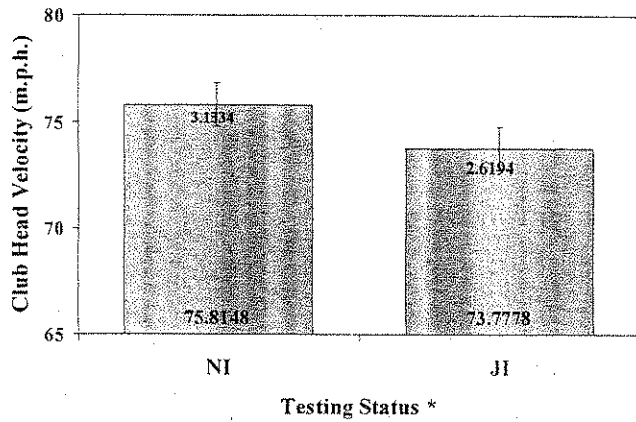


Fig 5. Difference in CHV before and after use of custom orthotics for 6 w before completing 9 holes of simulated golf ($P =$ not significant).

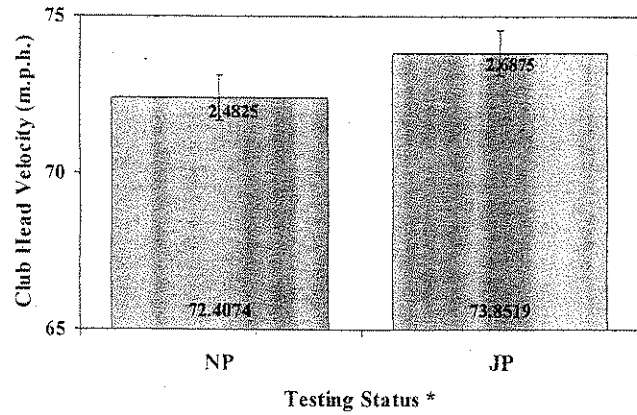


Fig 6. Difference in CHV before and after wearing custom orthotics for 6 w after completing 9 holes of simulated golf ($P < .001$).

number of statistical tests conducted in this research study.⁴ This strategy was introduced to decrease the likelihood that a result would seem statistically significant when it may have occurred as a result of chance. Because the number of statistical group comparisons was 32, the usual significance criterion for a single test, $P < .05$, was divided by 32. As a result, the new threshold for reaching statistical significance became a more conservative $P < .002$.

Statistical analysis was performed by establishing a preliminary data set with Alpha 4 (Alpha Software Corp, Burlington, Mass) and then conducting mean and group calculations with the SPSS statistical software (SPSS, Chicago, Ill).

RESULTS

Fig 2 summarizes the mean values and standard error mean (standard deviation divided by the number of subjects participating) for all objective evaluations performed in this study that involved CHV relative to the use of custom orthotics and 9 holes of simulated golf. CHV was consistently much higher when only the third swing (ie, the "real" swing after a 2-swing warm-up) was used for analysis compared with a 3-swing average.

There was a decrease in CHV (3-swing average values were used) associated with completing 9 holes of golf when no orthotics were used (Fig 3). However, this fatigue, specifically as it affected CHV, was not observed after subjects wore orthotics for 6 weeks (Fig 4). Although CHV decreases slightly after wearing orthotics and before completing 9 holes of golf, the change in CHV was not statistically significant (3-swing average values were used) (Fig 4).

After wearing custom orthotics and completing 9 holes of golf, not only was the fatigue factor eliminated, but CHV actually increased (with statistical significance) (Fig 6).

When only the third swing was used to calculate CHV (Fig 7), subjects demonstrated no change in CHV associated with fatigue (orthotics not used).

The effect of fatigue on CHV after wearing custom orthotics for 6 weeks before and after completing 9 holes of golf calculated with the third swing to record CHV was not statistically significant (Fig 8), demonstrating that CHV val-

ues remain relatively consistent for orthotic users, regardless of whether they have completed 9 holes of golf or are physically rested.

CHV did not change appreciably before and after wearing orthotics before completing 9 holes of golf (calculated with only the third swing to record CHV values) (Fig 9). As long as golfers were physically rested, CHV values were relatively the same whether or not they were wearing the custom orthotics. CHV was greater for subjects who did not wear orthotics after wearing custom orthotics and completing 9 holes of golf (using only the third swing). This difference was statistically significant (Fig 10), demonstrating that the use of orthotics eliminated the effects of fatigue and resulted in increased CHV values compared with that measured when golfers were physically rested.

DISCUSSION

In the subjects tested, custom-fit orthoses worn for 6 weeks increased CHV. Fatigue may likely reduce a player's CHV after playing 9 holes of golf under normal conditions. This assumption is consistent with the data in Fig 3, which shows a significant decrease in the average CHV after completing 9 holes of simulated golf without orthotic intervention. The average CHV did not decrease significantly for golfers who wore orthotics and played 9 holes of simulated golf (Fig 4), indicating that orthotic intervention reduces the effect of fatigue associated with playing 9 holes of golf. This fatigue-associated benefit is supported by the data in Fig 6, which compares the average CHV of golfers after playing 9 holes of golf before and after orthotic intervention. The difference in average CHV with orthotics versus without orthotics was statistically significant, with a higher average CHV after orthotic intervention.

During the course of the study, each participant was instructed to take 2 practice shots and then a final shot; the CHV of each swing was then recorded. Data demonstrated that the CHV of the final (third) shot was higher than the 3-shot average. It was assumed that the participants placed a greater emphasis on the final shot, which resulted in a relatively greater CHV. Even when evaluating the effect of

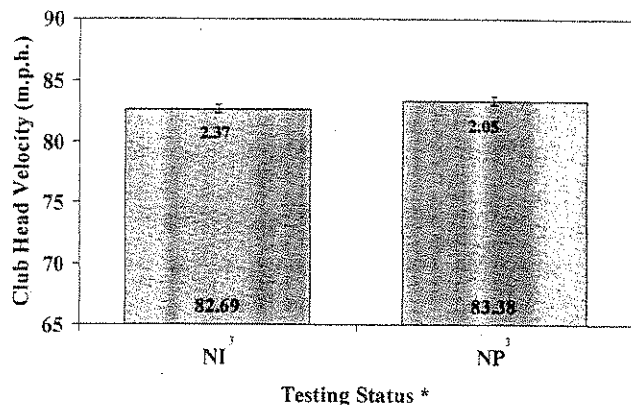


Fig 7. Difference in CHV before and after completing 9 holes of simulated golf before wearing custom orthotics using only the third swing/attempt to measure CHV ($P < .563$, not significant).

orthotics on CHV associated with only the third shot, a statistically significant difference was still present, with greater CHV measured after orthotic intervention and completion of 9 holes of golf.

This specific study design did not include a standard control group to address the possibility that the objective changes observed in CHV could have occurred as a result of chance alone and not a result of having worn custom-fit orthotics on a daily basis for 6 weeks. Larger studies involving more subjects and control groups should be undertaken to address this question. It was assumed that having each subject serve as his or her own control (each subject measured before and after orthotic use) would actually better establish relative conclusions because of the possibility of functional differences between groups, which would be difficult to account for objectively.

Another assumption made during this study was that the Swing Mate, the instrument used to record CHV in miles per hour, was an accurate and reliable measurement tool. Although the value recorded for CHV was not compared with a standard benchmark, the primary assumption was that the relative changes in CHV were accurate. This study focused on the changes between CHV before and after orthotic intervention and before and after subjects completed 9 holes of golf. These relative changes were considered appropriate for addressing the primary question in this study.

There was no observable difference in CHV when fatigue was not considered. However, when fatigue was included as a variable, there was an approximate (3 mph) change in CHV (Fig 1, NP vs JP). There was an approximate (5 mph) increase in CHV when the relative effects of fatigue were considered in subjects who had worn orthotics for 6 weeks (Fig 8, 81.00 mph vs 85.78 mph). This relation was true whether the CHVs of all 3 swings were averaged or whether only the third swing was used to calculate average CHV values (Fig 10, 81.78 mph vs 85.78 mph). This statistical pattern indicates that CHV will increase when custom-fit orthotics are used. However, this study addresses a specific population and specific orthoses. There may be a variety of

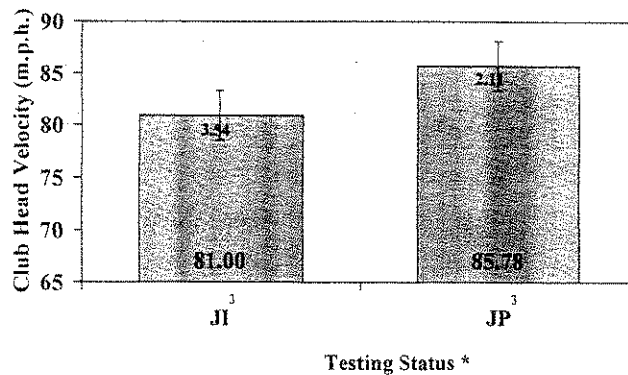


Fig 8. Difference in CHV after wearing custom orthotics for 6 weeks before and after completing 9 holes of simulated golf using only the third swing/attempt to record CHV values ($P =$ not significant).

different physical effects of orthotics. Therefore the trends identified here are reserved for only orthotics that were actually tested in this study, namely, custom-made (vs standard stock), weight-bearing, casted, flexible (vs nonflexible and non-weight-bearing) orthotics.

Standard mathematic principles support a relation between CHV and subsequent golf ball travel distance. First, the relation between CHV (mph) and golf ball velocity (GBV) (in feet per second) is represented by a formula showing a proportional relation between CHV and subsequent GBV:

$$\text{After Impact, } \frac{1}{2}M(\text{CHV})^2 = \frac{1}{2}m(\text{GBV})^2$$

where M is mass of the club head (a MacGregor Tourney #1 driver [MacGregor Golf, Albany, Ga] weighs approximately 350 g and club head mass is approximately 210 g) and m is mass of the golf ball (a Titleist DT wound 90 compression ball weighs approximately 30 g).

Another way to express this formula is

$$\text{GBV} = \sqrt{\frac{M}{m}} \times \text{CHV} \quad \text{where } \sqrt{\frac{M}{m}} = \sqrt{11.67} \text{ or } 3.4$$

Assuming an approximate 50% energy transfer from club head to golf ball at the time of impact,

$$\sqrt{\frac{M}{m}} = (3.4)(50\%) = 1.7$$

Equation of motion: force = mass \times acceleration or

$$m\ddot{x} = -k\dot{x} \quad \text{where } -k\dot{x} = \text{air resistance drag proportional to the velocity, } \dot{x}, \text{ and } m\ddot{x} = \text{mass} \times \text{acceleration}$$

Golf ball distance, traveled horizontally, can be estimated by the formula:

$$x(t) = \frac{\dot{x}_0}{\alpha}(1 - e^{-\alpha t}), \text{ where } \alpha = \frac{k}{m}, \text{ and } k = \text{constant of proportionality}$$

where air resistance is proportional to golf ball velocity, m is golf ball mass, \dot{x} is horizontal distance traveled, e is Euler constant [2.718], t is the time the golf ball travels, and \dot{x}_0 is the initial velocity of the golfball in x direction immediately after impact with golf club head. Initial horizontal speed of golf ball immediately after impact is $3.4 \times \text{CHV} \times \cos \theta$.

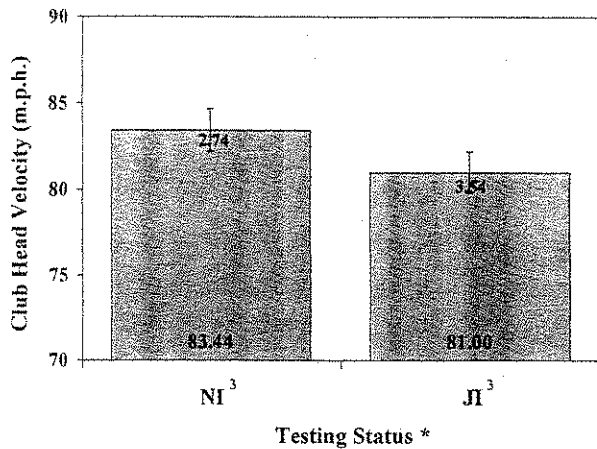


Fig 9. Difference in CHV before and after wearing custom orthotics for 6 w before completing 9 holes of simulated golf using only the third swing/attempt to record the CHV values (P = not significant).

The Titleist DT wound 90 compression ball, a frequently used ball, was used in this study.

The vertical golf ball distance traveled can be estimated by:

$$y(t) = \frac{v_0}{\alpha} (1 - e^{-\alpha t}) - \frac{g}{\alpha^2} (e^{-\alpha t} + \alpha t - 1)$$

where g is the gravitational pull on the golf ball and α is the steady, downward terminal velocity (constant, approximately 200 mph with the influence of gravity and air resistance).

In summary, a CHV of 100 mph would be responsible for a drive of approximately 300 yards with a 30% drive angle and no additional wind influence present (except the air drag constant), calculated with the principles described earlier and assuming an approximate 50% transfer of energy from the club head to the golf ball. This would take approximately 6.3 seconds from impact to the golf ball making contact with the ground. Additional yardage associated with the drive through continued movement of the golf ball would occur, depending on terrain features/variables. In addition, a 1-mph increase in CHV is associated with an increase in golf ball travel distance of approximately 2.77 yards, or 3.0 yards, rounded to the nearest yard.

Research at the United States Golf Association Technical Department also demonstrates an approximate 1:3 relation (2.5-yd increase in air travel of the golf ball for every 1-mph increase in CHV) between increases in CHV and subsequent driving distance (rounded to the nearest yard). All balls have slightly different characteristics. The one referred to in this instance weighed 45.93 g.

This relation suggests that for every 1-mph increase in CHV, there is a subsequent 3-yd increase in air travel distance. This relation is potentially useful for the competitive golfer, where minimal increases in driving distance mean the difference between winning and losing in a competitive environment. In this study, an increase of up to 5 mph in CHV was demonstrated, which, translated in the relation described earlier, indicates an increase in air driving distance of 15 yd. The great golf legend Harvey Pennick often

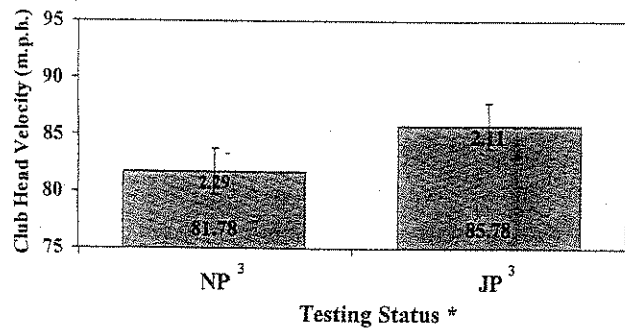


Fig 10. Difference in CHV before and after wearing orthotics for 6 w after completing 9 holes of simulated golf using only the third swing/attempt to measure CHV (P < .005).

noted, "It's not the fiddle, it's the fiddler," implying that the human body has the most impact on golf performance, not which kind of club is used.¹⁶ The use of a custom orthotic like those tested in this study may have a positive influence on human performance that accounts for the changes described.

As cited earlier, Adlington¹³ has suggested that golfers with poor balance make positive contact with the ball less consistently, suggesting that methods to improve balance ability may also have a positive influence on a golfer's ability to hit the sweet spot consistently. It was assumed that fatigue associated with golf-related activities during play will influence muscle strength and balance ability, therefore serving as an influential factor in golf performance and, specifically, golf swing mechanics and subsequent CHV. Reducing the effects associated with fatigue may also have a positive influence on outcomes associated with consistent golf performance.

CONCLUSION

The use of the custom-fit, flexible orthotics in this study had a positive influence on CHV in experienced golfers. Specifically, an approximate increase in CHV between 3 and 5 mph, or a relative increase in CHV up to 7%, was observed after subjects had worn custom-made, weight-bearing, flexible orthotics daily for 6 weeks. A 5-mph increase in CHV is equivalent to an approximate increase in ball air distance of 15 yards, a significant increase for the tour player where small increases in performance can reflect large position changes on the roster board. In addition, the use of these custom orthoses eliminated the effects of fatigue associated with playing 9 holes of golf (relative to CHV) and thus may improve the likelihood for more consistent golf performance.

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