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The Effects of Orthotic Intervention and 9 Holes of Simulated Golf on Gait in Experienced Golfers

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ABSTRACT

Background: This investigation evaluated the effects of orthotic intervention on gait patterns and fatigue associated with 9 holes of simulated golf among a group of experienced golfers.

Setting: Northwestern Health Sciences University, Bloomington, Minn.

Participants: Twelve experienced golfers.

Method: By means of video freeze-frame analysis, gait was assessed in each subject before and after 9 holes of simulated golf. Subjects wore custom-made, flexible orthotics daily for 6 weeks, and gait was then reassessed through use of the same objective measurement parameters. Fatigue was introduced by having participants complete 9-hole rounds of simulated golf before and after wearing custom-made, flexible orthotics for 6 weeks.

Main Outcome Measure: Parameters associated with gait (ie, stride length and pelvic rotation) were measured in all subjects before and after they used custom-fit, flexible orthotics for 6 weeks and before and after they completed 9 holes of simulated golf.

Results: The data indicate that for experienced golfers, wearing the custom-fit, flexible orthotics used in this study for 6 weeks influenced the parameters associated with gait and reduced the effects of fatigue associated with 9 holes of simulated golf.

Conclusion: The use of custom-fit, flexible orthotics in this study had a significant influence on the elements of gait measured in the investigation—specifically, pelvic rotation and stride length. There was an average increase in pelvic rotation of between 29% and 36%, and there were concomitant changes in stride length after subjects had used the orthotics for 6 weeks. In addition, use of these custom orthoses reduced the effects of fatigue associated with playing 9 holes of simulated golf; they could thus improve the likelihood of more consistent performance, possibly as a result of a more efficient gait pattern. (J Manipulative Physiol Ther 2001;24:279-87)

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

INTRODUCTION

The lower extremity and the spine represent a closed kinetic chain in the upright posture. The premise that the function of one region of the body can influence the function of another region has been supported.[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 Brink[4] 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. There is also evidence that shoe selection affects balance performance,[5] suggesting that foot function can influence whole-person activities. In golfers, the pedal foundation (ie, sole) has a greater effect on lower extremity biomechanics, and thus on 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.[6]

Previously, 5 factors have been cited as having an influence on golf ball flight.[7] These are (1) club head speed, (2) club angle of approach, (3) club face position, (4) centeredness of contact, or "sweet spot," and (5) golf fundamentals. The golf industry has made numerous innovations in golf club design to address some of these factors, including (but not limited to) oversized club heads and larger "sweet spots" to improve the centeredness of contact. In addition, changes that have been made in club shaft design and materials (ie, from steel to graphite) have brought about changes in shaft flexibility and torque. All of these changes might have led to some changes in golf performance,[8,9] though overall scores, on the average, have not improved significantly during this time of technologic advances in equipment.

Exercise programs have been designed and developed to help improve the golf swing and to reduce the liklihood of injury.[10-12] It has been assumed that as a result of strengthening the muscles used during the golf swing, more power

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could be generated and club head velocity (CHV) would subsequently increase. However, no research has yet been conducted to address this premise.

There is evidence to support a relationship between changes in physical status/ability and performance on the golf course. It has been observed that a stable base of support will allow a player to generate more acceleration during the downswing, with a subsequent increase in CHV and subsequent greater ball flight distance.[13] This research has indicated that many players who have poor balance show less consistency in properly contacting the ball, which negatively affects golf ball flight. One premise that might help account for this is that progressively accumulating fatigue during a period of golf-related activity can influence the level of consistency relative to overall golf performance. Currently, most professional tour players initiate the downswing with hip rotation.[14] The angular velocity of the hips also positively influences CHV.[15]

Proposed questions for this research include the following:

1. Can improved pedogenic function resulting from the use of custom-fit, flexible orthotics influence patterns and also influence the function of the rest of the closed kinetic chain while one is walking and standing on the golf course?
2. Can these changes subsequently influence overall performance by reducing the effects of fatigue associated with golf-related activities (ie, preserving the objective performance ability in a golfer, as this is measured before he or she completes 9 holes of golf)?

METHODS AND MATERIALS

Subject Recruitment: Demographics and Attrition

Research participants were recruited through advertising at an annual golf exposition held at the Metrodome in the Twin Cities (Minnesota), by word of mouth among students at Northwestern Health Sciences University (NWHSU), and through informational announcements on a radio talk show. Only experienced golfers with reported handicaps of 10 or less (some of them teaching or touring professionals) were included in the sample. This sample was chosen to control for the effects of experience and skill as much as possible (an experienced golfer tends to have a more consistent golf swing). A standard telephone interview script was prepared in advance, and 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 (for any reason) during the 6 months before the study
3. Chiropractic health care (for any reason) during the 6 months before the study
4. Current musculoskeletal pain (of any kind)—eg, back, knee, shoulder, or wrist pain
5. History of stroke, heart attack, or angina
6. Golf handicap (subjectively reported) of more than 10.

Of the 12 participants (11 men and 1 woman) present on the first day of data collection, 9 were able to return for subsequent data collection 2 months later. The other participants were unable to return—1 because of an out-of-state golf tournament, 1 because of an acute fracture, and 1 because of a job conflict.

Informed Consent

After questions about the study had been answered, each participant was oriented about the nature of the research and what would be expected of the subjects; he or she then signed a consent form before participating in data collection. The subjects were informed that the investigators would be examining the biomechanics of golf performance. The study was approved by the Institutional Review Board of NWHSU.

Instrumentation and Outcome Measures

Gait was assessed while the subject walked on a Star Trac 3000 commercial treadmill (Tustin, Calif) with programmable, adjustable height options, though no incline demands were introduced during the course of the study. To reflect an average walking speed, a treadmill velocity of 3.2 mph was programmed for all subjects for both warm-up maneuvers and gait assessment.

Initially, each subject did 2 minutes of walking on the treadmill as a warm-up maneuver, after which his or her gait was assessed for 2 minutes through use of video analysis. In this analysis, colored fluorescent markings were placed on the subject's anterior superior iliac spine as primary measurement landmarks for assessing changes in hip rotation during gait analysis. So that the anterior superior iliac spine markings could be easily seen for analysis, one video camera was placed on the floor 6 feet anterior to the subject and with an upward projection. Another video camera was placed 10 feet lateral to the subject while he or she walked; this camera, mounted on a tripod approximately at the level of the subject's hip joint (this could only be approximated inasmuch as the subjects varied in height), was used to assess stride length while the subject walked on the treadmill.

Each subject was videotaped while walking on the treadmill for 2 minutes after a 2-minute warm-up. Two trained assistants assumed responsibility for the videotape measurements. Measures included hip rotation, which was assessed through use of the video freeze-frame feature from measurement of the distance between the medial edges of the fluorescent markings at the time of each heel strike. Each measurement was obtained at one of 3 different instances of heel strike, the average value being used for analysis for each subject. Stride length, also assessed objectively through use of the video freeze-frame feature, was the average value of 3 measurements obtained at 3 different instances of heel strike. To ensure assessment reliability, the 2 assistants obtained these measurements independently for each participant. Stride length was measured through use of the distance, at the time of each heel strike, from the posterior heel to the forward-most portion of the opposite forefoot (ie, dis-

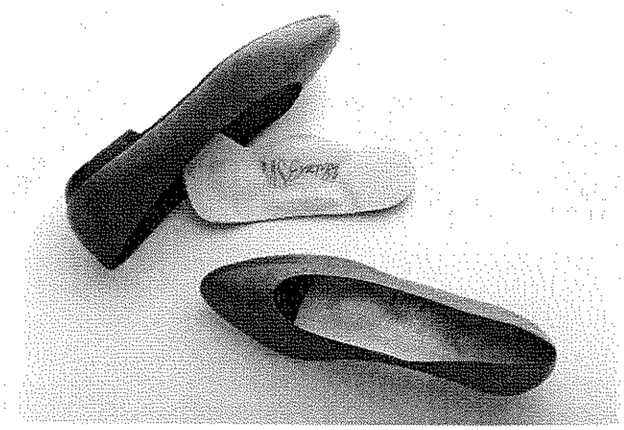

Fig 1. *Custom-made, flexible, full-length orthotics were provided to all subjects for use during the day in dress and/or oxford style shoes.*

Fig 2. *Custom-made, flexible, full-length orthotics were provided to all subjects for use in recreational shoes—eg, tennis or golf shoes.*

tal digit). More detailed information regarding objective gait analysis performed observationally is available.[16]

Fatigue Associated With 9 Holes of Simulated Golf

Fatigue was introduced by having each subject complete a 9-hole round of simulated golf. This required the subjects to walk a distance typical of 9 holes of golf; they were also required to wait for those ahead of them, which is typical of real course situations.[4] By measuring the outcomes described—namely, pelvic rotation and stride length—before and after the subject completed a 9-hole round of simulated golf, we assessed fatigue.

Various golf courses in the Minneapolis-St. Paul area were assessed for distance and difficulty, and an on-campus "golf course" was designed on the basis of the averages for the actual courses.[4] 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.[4] This provided different distances for the male and female subjects. According to their sex, subjects were given a distance for each shot, and they were then instructed to choose the club that they would use for that particular shot. All subjects were limited to the same number of shots per hole.

A supervisor was in charge of each group of golfers (there were no more than 4 subjects in any group) to lead them through the course and ensure subject compliance. Each supervisor completed a comprehensive checklist for each hole of the simulated course.

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 to each of the research participants, one of full-length and the other of three-quarter-length design; the former is intended for use in recreational shoes and the latter for use in dress and/or oxford-style shoes. Each male subject received a pair of full-length Firmflex Plus orthotics and a pair of Sir Energy Plus orthotics; each female subject received a pair of full-length Firmflex Plus orthotics and a pair of Ms. Energy Plus orthotics. These orthotics are manufactured from functional materials set in multiple layers, and each includes a pad made of Zorbacel, inserted into the heel for shock attenuation (Figs 1 and 2).

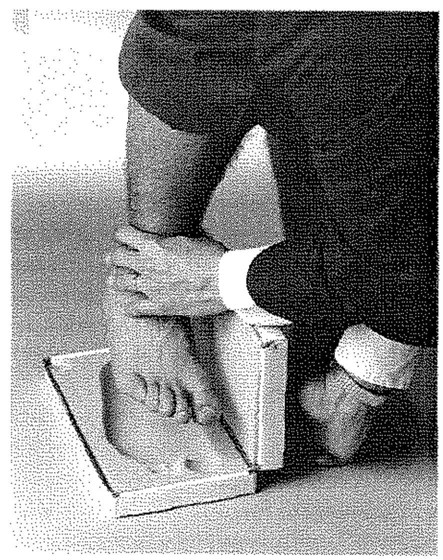

Fig 3. *To assist laboratory technicians in fabrication of custom orthoses used in this study, weight-bearing casting procedure was performed by certified orthotic technician according to manufacturer's protocol.*

Weight-Bearing Casting Procedure

The weight-bearing casting procedure was performed on the date of initial data collection by a chiropractic physician who was also a certified orthotic technician. The casting procedure followed the manufacturer's protocol—specifically, that provided by Foot Levelers, Inc (Fig 3).

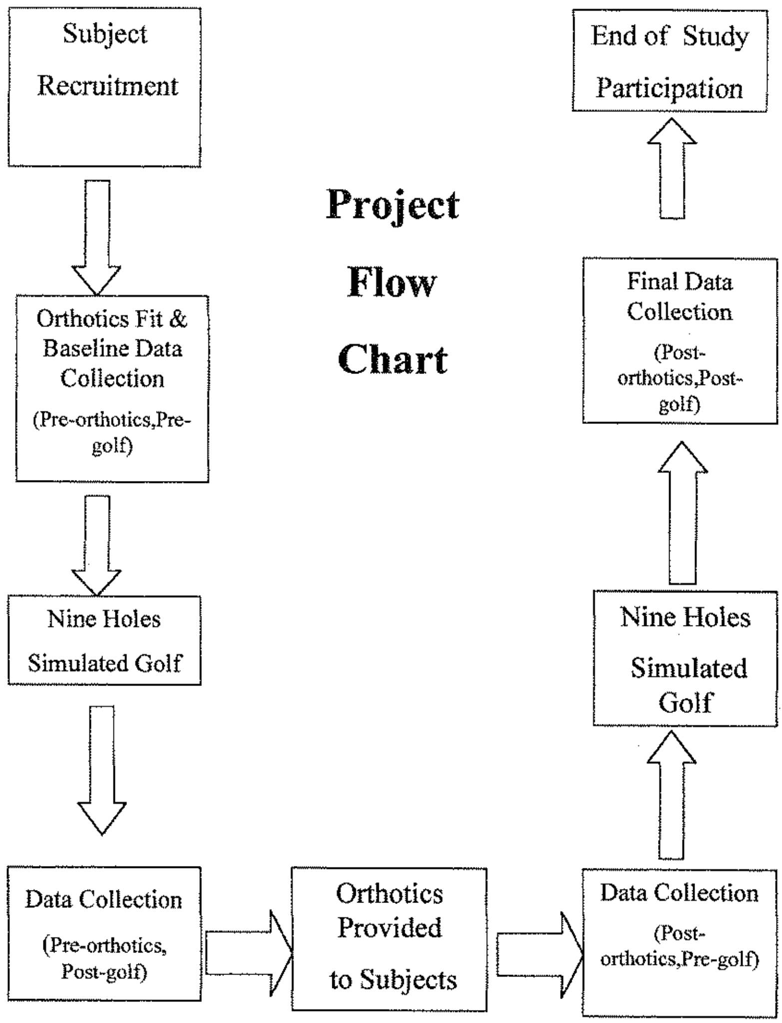

Fig 4. *Chronologic steps summarizing sequence of data collection events and interventions for subjects in study.*

Research Study Timeline and Wear Protocol

Subjects were cast for custom-made orthotics on the date of initial data collection. They returned to NWHSU 2 weeks later to receive their orthotics along with written and verbal instructions that accorded with the manufacturer's guidelines. Subjects were required to wear their orthotics daily for 6 weeks and were then retested. Fig 4 shows a summary of the chronologic steps relevant to data collection in the investigation.

Compliance and Subjective Feedback

Each subject was interviewed by telephone between the initial fitting and the final day of golf simulation assessments to ensure wear compliance. On the day that final measurements were collected, subjects completed an Orthotic Fit and Initial Response Questionnaire regarding their experiences with the orthotics.

Control

In this research design, there was no group assigned to wear sham orthotics; therefore, the control was within-subject. Stride length and pelvic rotation were assessed in each subject at the following times:

1. Before and after he or she completed a 9-hole round of simulated golf (for the effects of fatigue).
2. Before and after he or she wore custom-made, flexible orthotics for 6 weeks.

Statistical Analysis

The data were analyzed through use of a paired t test, modeling the effects of treatment before and after 9 holes of simulated golf and before and after orthotic intervention. The paired t statistic assesses participants' average change from preassessment to postassessment and indicates whether the overall average change for all subjects was significantly greater than zero.

A mathematical correction for multiple tests was used (the Bonferroni T procedure—also known as Dunn's multiple comparison procedure) for the number of statistical tests conducted in the study.[4] This strategy was introduced to decrease the likelihood that a result would seem to be

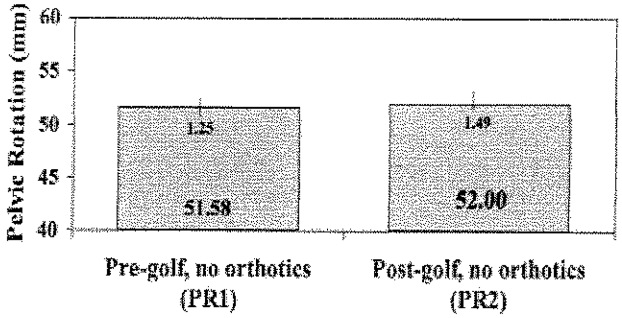

Fig 5. *Effect on pelvic rotation of fatigue associated with 9 holes of simulated golf in subjects who* ***had not*** *yet used orthotics: rotation before simulated golf (PR1) vs rotation after simulated golf (PR2; difference not statistically significant).*

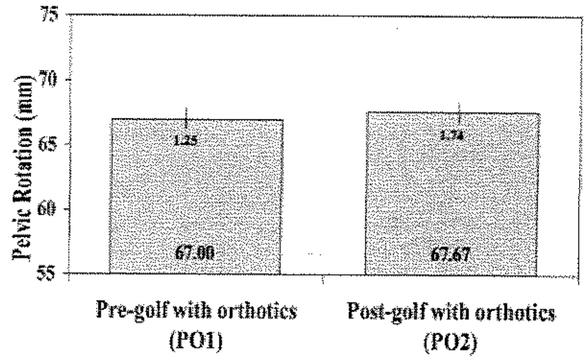

Fig 6. *Effect on pelvic rotation of fatigue associated with 9 holes of simulated golf in subjects who* ***had*** *used orthotics: rotation before simulated golf (PR2) vs rotation after simulated golf (PO2; difference not statistically significant).*

statistically significant when it was in fact due only to chance. Because the number of statistical group comparisons was at least 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 was a more conservative $P < .002$.

Statistical analysis was performed by establishing a preliminary data set with Alpha Four (Alpha Software Corp, Burlington, Mass) and then conducting mean and group calculations by means of SPSS statistical software (SPSS, Inc, Chicago, Ill).[17]

RESULTS

Figs 5 through 13 summarize the mean and SEM (SD divided by number of subjects) values and percent changes for all objective evaluations and comparisons performed in this study involving gait parameters relative to the use of custom orthotics and 9 holes of simulated golf.

Pelvic rotation as measured during gait was not affected by the effects of fatigue associated with 9 holes of simulated golf before the wearing of the orthotics (Fig 5). Similarly, fatigue associated with 9 holes of simulated golf did not affect pelvic rotation in subjects who wore orthotics (Fig 6). However, though fatigue did not appear to alter pelvic rotation, the actual degree of pelvic rotation was much greater in subjects who had worn orthotics for 6 weeks than in subjects assessed before wearing orthotics (Fig 7). Using custom orthotics was associated with an increase in pelvic rotation, even accounting for the effects of fatigue, and this was statistically significant (Fig 7).

Regardless of whether fatigue was present when pelvic rotation was measured, the use of orthotics for 6 weeks increased pelvic rotation, and this increase was significant (Figs 8 and 9).

Fatigue appeared to have no effect on pelvic rotation to the right side or to the left side (Figs 10 and 11), regardless of whether orthotics had been used. The use of orthotics, however, did significantly influence an increase in pelvic rotation, both to the right side and to the left side, regardless of whether fatigue was included as a variable.

Fatigue influenced gait patterns by influencing an increase in stride length, and this change appears to be relatively symmetric (Figs 12 and 13). A review of all of the relationships in Figs 12 and 13 strongly suggests that the use of orthotics increased stride length to some degree as well, though not to the degree observed when the effects of fatigue were present.

A summary of the relative percent changes in pelvic rotation and stride length associated with all of the comparisons and interventions used in this study is presented in Table 1. The consistent patterns that are revealed show relative increases in pelvic rotation, pelvic rotational symmetry, and stride length associated with the use of custom-fit, flexible orthotics.

DISCUSSION

Initially, it did not appear that fatigue influenced pelvic rotation after 9 holes of simulated golf, either with or without the use of orthotics. However, using orthotics did increase pelvic rotation. In addition, left pelvic rotation appeared to increase to a greater degree after a round of simulated golf (ie, fatigue) than did right pelvic rotation. In other words, after using orthotics, right and left pelvic rotation became objectively more symmetric. The initial asymmetric difference in pelvic rotation could be due to dominant side preference, inasmuch as each of the subjects was right-handed and had a slightly greater degree of right pelvic rotation to begin with.

There were differences in stride length due to fatigue, with a bilateral trend toward increased stride length after 9 holes of simulated golf. After orthotic intervention, there was a slight increase in stride length; however, this increase was not as significant as that associated with fatigue resulting from a round of simulated golf.

One of the reasons that there was a relative decrease in stride length after orthotics were used might be the concommitant and relative increase in pelvic rotation. The relative increase in pelvic rotation might result in a relatively reduced demand for a longer stride length—a proposed

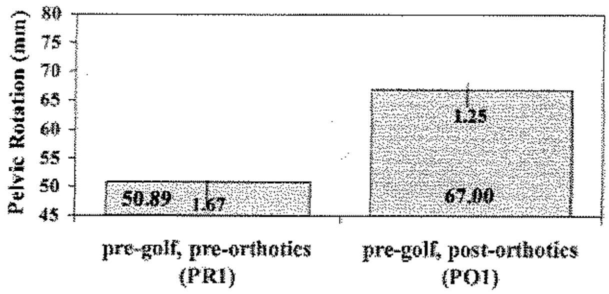

Fig 7. *Effect on pelvic rotation of use of custom orthotics for 6 weeks: rotation before completion of 9 holes of simulated golf in subjects who **had not** yet used orthotics (PR1) vs rotation before completion of 9 holes of simulated golf in subjects who **had** used orthotics (PO1; P < .001).*

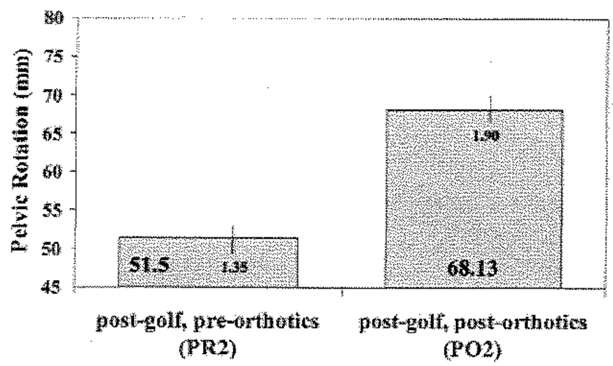

Fig 8. *Effect on pelvic rotation of use of custom orthotics for 6 weeks: rotation after completion of 9 holes of simulated golf in subjects who **had not** yet used orthotics (PR2) vs rotation after completion of 9 holes of simulated golf in subjects who **had** used orthotics (PO2; P < .001).*

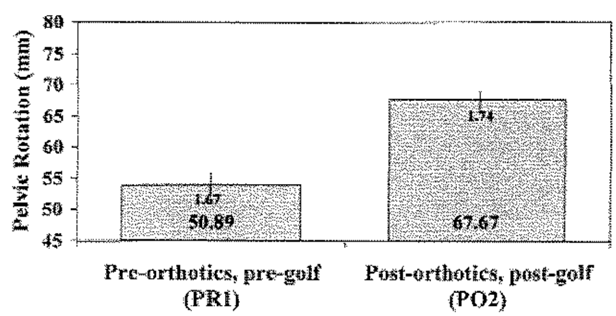

Fig 9. *Effect on pelvic rotation of use of custom orthotics for 6 weeks: rotation before completion of 9 holes of simulated golf in subjects who **had not** yet used orthotics (PR1) vs rotation after completion of 9 holes of simulated golf in subjects who **had** used orthotics (PO2; P < .001).*

premise for a more efficient gait pattern. In addition, the presence of an increase in pelvic rotation might create a more powerful and more efficient kinetic chain associated with the golf swing, especially around the golfer's center of gravity, and a more efficient swing might be one reason that

Table 1.
Summary of measured change in pelvic rotation and stride length during specific testing status comparisons

Testing status comparison		Measured change (mm)*
A. Pelvic rotation		
Total		
	PR_1 vs PR_2	0
	PO_1 vs PO_2	0
	PR_1 vs PO_1	+32
	PR_2 vs PO_2	+32
	PR_1 vs PO_2	+33
Right		
	PR_1 vs PR_2	0
	PO_1 vs PO_2	0
	PR_1 vs PO_1	+29
	PR_2 vs PO_2	+34
	PR_1 vs PO_2	+34
Left		
	PR_1 vs PR_2	0
	PO_1 vs PO_2	0
	PR_1 vs PO_1	+30
	PR_2 vs PO_2	+33
	PR_1 vs PO_2	+36
B. Stride length		
At time of right heel strike		
	PR_1 vs PR_2	+12
	PO_1 vs PO_2	0
	PR_1 vs PO_1	+5
	PR_2 vs PO_2	−7
	PR_1 vs PO_2	+8
At time of left heel strike		
	PR_1 vs PR_2	+15
	PO_1 vs PO_2	0
	PR_1 vs PO_1	0
	PR_2 vs PO_2	−9
	PR_1 vs PO_2	+9

PR, Preorthotics (ie, orthotics **had not** yet been used); *PO,* post-orthotics (ie, orthotics **had** been used daily for 6 weeks). PR_1, PO_1: Data collection was performed *before* completion of 9 holes of simulated golf; PR_2, PO_2: Data collection was performed *after* completion of 9 holes of simulated golf.

*Relative change measured for each specific comparison. Negative value denotes decrease in measured variable; positive value denotes increase in measured variable. (*Example:* PR_2 vs PO_2 for right pelvic rotation reflects a test for the effect of orthotics with fatigue included as a variable. This variable was measured *after* 9 holes of golf were completed; orthotics **had not** yet been used. The comparison is with the value for right pelvic rotation measured *after* 9 holes of simulated golf were completed and after orthotics **had** been used daily for 6 weeks. In this instance, there was both a relative increase and an average increase in right pelvic rotation of +34 mm after orthotics were used.)

the relative effects of fatigue were reduced. Stude and Gullickson[18] demonstrated that the use of custom-fit orthoses increased relative club head velocity in a group of experienced golfers, and this might have been related to improved proprioception, a more efficient gait pattern, a reduction of the effects of fatigue associated with golf-related activity, improved structural/skeletal alignment, or a combination of these elements.

Because custom orthotics are designed, in part, to help to correct structural deficiencies[19] identified on subject foot impression casts, the subsequent product might be helping to promote structural improvements and hence, more symmetric and improved functional performance outcomes.

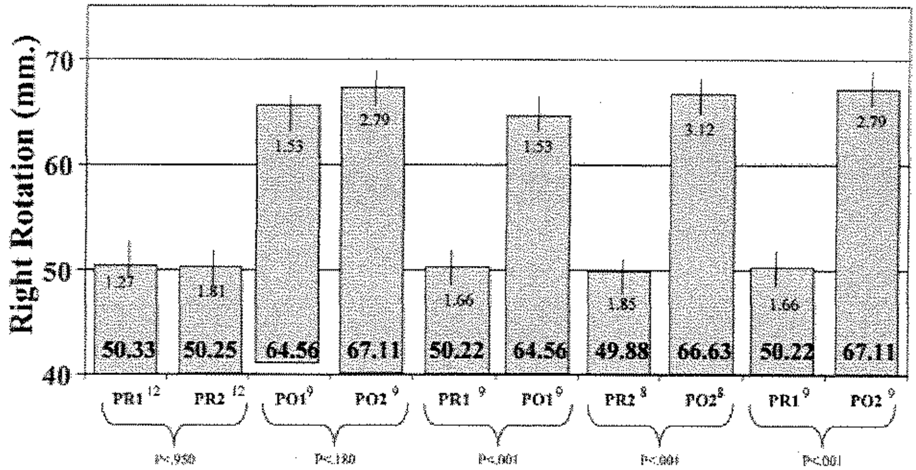

Fig 10. *Effects of testing status on right rotation of pelvis during gait on treadmill. Superscripts used in testing status categories represent numbers of subjects available for each comparison.*

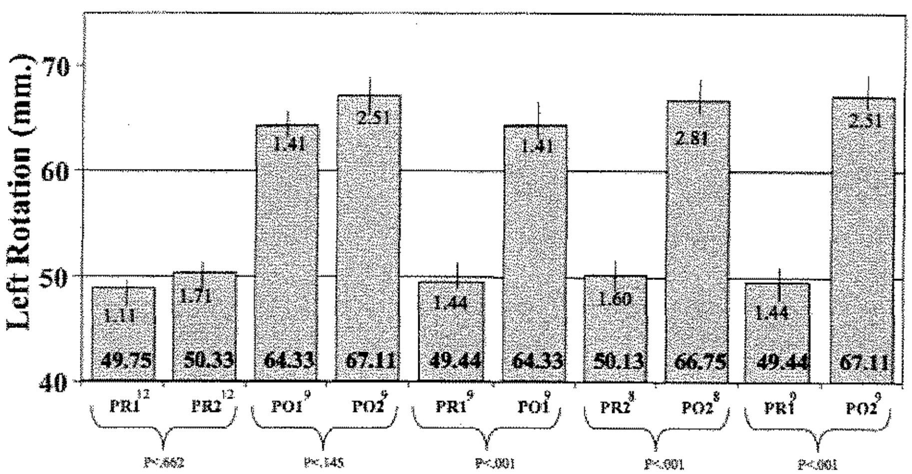

Fig 11. *Effects of testing status on left rotation of pelvis during gait on treadmill. Superscripts used in testing status categories represent numbers of subjects available for each comparison.*

Stude and Brink[4] showed that proprioceptive symmetry was enhanced in experienced golfers who had used custom-fit, flexible orthotics. There is additional evidence in support of a relationship between change in structural status and subsequent gait patterns. In comparison with control subjects, subjects undergoing unilateral or bilateral total hip replacement surgery showed marked improvements in the quantitative gait patterns that were measured, and the difference was significant.[20] Patients with idiopathic scoliosis treated surgically to reduce curvature deviations were found to have increased hindfoot weight-bearing, irrespective of the curve type or specific surgical procedure involved.[21] Indirectly affecting structural status, such as wearing shoes with higher heels, also affects gait patterns by causing a significant decrease in step length and stride length.[22]

All of these studies demonstrating a relationship between structural status and gait patterns might have been influenced by the body's tendency to protect its center of gravity by keeping it constant.[23] Even though findings similar to these are common in the literature, there is also evidence that sex-specific differences exist, though the etiology of this has not been clearly addressed.[24]

Functional exercise intended to train golfers to improve the efficiency of their golf swing, to increase their relative physical fitness status, and to address back pain complaints is used frequently.[25] Although this has not yet been tested objectively, the use of functional, custom-tailored exercise programs combined with the use of custom-fit orthoses could have long-term, synergistic benefits for the golfer. We have shown that the orthotics in this study, when used alone, affected pelvic rotation and stride length and appear to have influenced a more efficient gait pattern.

There is a strong correlation between loading patterns associated with repetitive walking on hard surfaces, altered lower limb mechanics, and joint degenerative changes.[26-35]

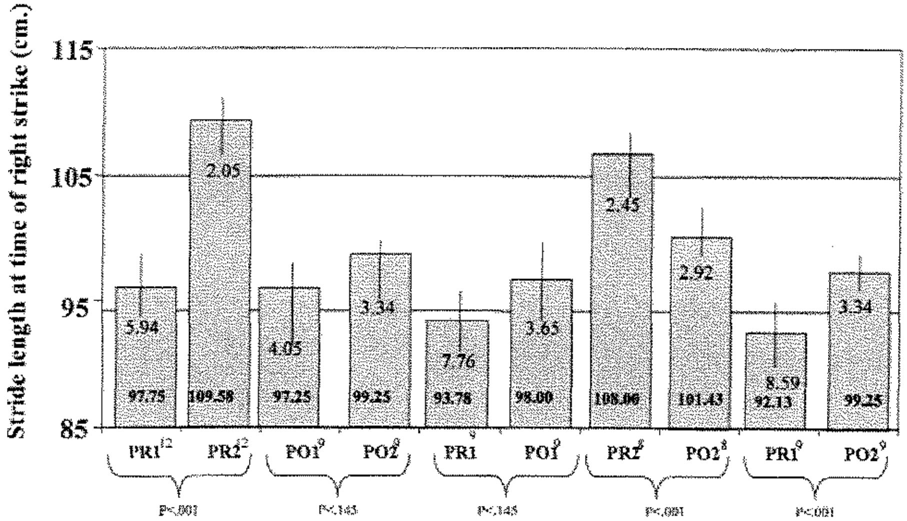

Fig 12. *Effects of testing status on stride length, measured at time of right heel strike, during gait performed on treadmill.*

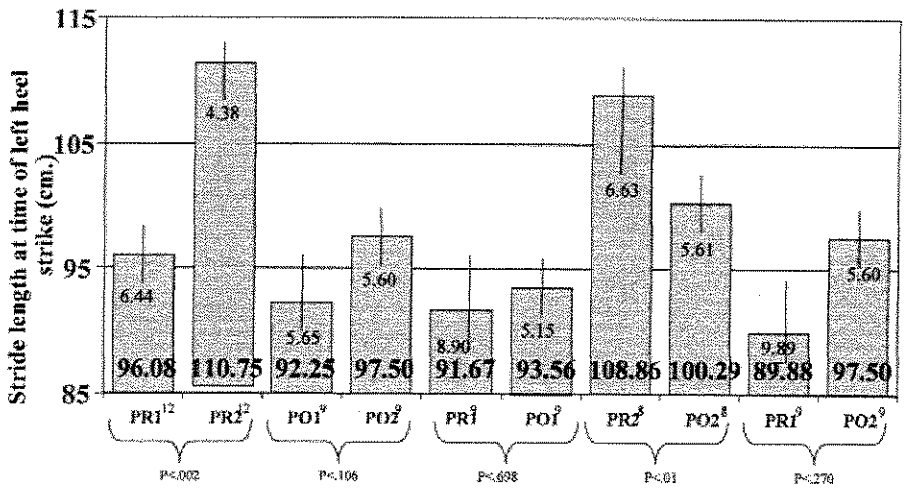

Fig 13. *Effects of testing status on stride length, measured at time of left heel strike, during gait performed on treadmill.*

On the basis of this information, we presume that the shock forces normally transmitted through the lower limb during walking are substantial and that the application of a method for their reduction could reduce both fatigue and the likelihood of progressive joint degenerative changes as well as improve whole-person performance consistency. The shock attenuation materials used in the orthoses in this study, in addition to indirectly affecting proprioception and structural status (ie, pelvic rotation and stride length), might also have impacted measured gait patterns by reducing fatigue through reduction of the transmission of force at heel strike. Because the golfers in the study carried their own golf bags and walked the work-load equivalent of a 9-hole course, the shock attenuation benefits in this scenario might have been substantial and therefore contributed indirectly, yet importantly, to the overall changes measured relative to gait and fatigue.

It is theoretically possible that when golfers begin to "feel" the effects of fatigue, they compensate by taking longer steps to reduce caloric expenditure. Improved gait efficiency through increased pelvic rotation might be a benefit that allows the golfer to reduce caloric expenditure without suffering as much from the effect of work-related fatigue.

CONCLUSION

Stride length remained consistent when orthotics were used, whether or not a round of simulated golf was completed (ie, the effects of fatigue were introduced). This strongly suggests that orthotics might substantially reduce the effects of fatigue associated with a 9-hole round of golf, possibly by promoting a more efficient gait pattern through its influence on pelvic rotation.

Wearing the custom-fit, flexible orthotics used in this study had a significant influence on the parameters associated with gait that we measured—specifically, pelvic rotation and stride length. There was an average increase in pelvic rotation of between 29% and 36% in subjects after they had worn the orthotics for 6 weeks. There was a concomitant increase in stride length when fatigue was introduced alone after a 9-hole round of simulated golf; however, using orthotics for 6 weeks reduced the degree of fatigue through a relative reduction in stride length. Because the use of custom-fit, flexible orthotics reduces the effects of fatigue associated with 9 holes of golf, such use could improve the likelihood for more consistent performance, possibly as a result of a more efficient gait pattern.

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