Analysis of the Change in Golf Swing Kinematics Associated with Learning

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Abstract

Success in golf depends on the precise timing and coordination of a complex movement pattern. Because of the time consuming nature of learning the golf swing, it is important to establish a more efficient teaching and learning strategy. Virtually Perfect Golf® (VPG) offers the student concurrent knowledge of performance combined with the company's representation of the correct movement. The information is relayed to the student through the VPG glasses connected to one of three cameras situated around the student. This research investigates the validity of the VPG learning system as a teaching and learning tool for beginner golfers. A multiple baseline single subject design was used to evaluate the effect of the intervention on each individual. Data for the angular displacement of the left elbow, spine, and right and left legs, as well as the linear displacement of the head and linear speed of the left wrist were collected at five critical events during the golf swing to analyze the movement kinematics following VPG interventions. The results indicated that each of the participants used the information from the intervention differently as changes in movement kinematics were not consistent. Participants that did not possess an already existing movement pattern gained information about distal movements of the golf swing from viewing the VPG model. All participants showed stability in their performance on several variables after the final intervention. The results of this study suggest that future learning studies consider the use of single subject designs to describe how individuals react to changes in the learning environment. The use of kinematic measures as dependent variables provided unique information compared to past studies that have used movement outcomes as dependent measures.

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Introduction

The golf swing is a complex motor task that requires a high degree of precision. To perform optimally, the golfer must move through a large range of motion to increase impulse during the swing, yet still be able return the club head to the ball and achieve the desired impact condition. If contact is off by a few millimetres, the club path is off by as much as a degree, or the club face is opened or closed a degree, the resulting shot can be disastrous. To achieve a high level of performance in golf, many years of frequent practice are required. Over the past two decades numerous teaching strategies have been developed to increase the efficiency of learning the golf swing.

Virtually Perfect Golf® (VPG) is a Canadian golf company that developed a unique learning system that claims to facilitate learning through their unique teaching methodology. The VPG system offers concurrent visual feedback to the student in an attempt to optimize the relevant information gained from the golf lesson. The purpose of this research was to measure and analyze changes in selected kinematic variables following the implementation of the VPG learning system.

Golf Swing Biomechanics Literature Review

Most research in golf swing biomechanics is intended to describe the kinematics and kinetics the correct motion pattern for the golf swing. Much debate has arisen concerning the sequencing of distal limbs to maximize club head speed at the critical instant of contact. The theories describing the correct limb sequence varied greatly. Three general movement concepts can be extracted from the literature: many believed that to achieve maximal club head speed segments had to be stopped at a proper time (Plagenhoef, 1966; Jorgensen, 1970; Broer, 1973), another concept described a force that had to be applied at a critical time (Williams, 1967; Daish, 1972; Cochran & Stobbs, 1968; Sprigings & Neal, 2000) the final theory was that maximal speeds of all segments involved had to be reached at the same time (Koniar, 1973). Milburn (1982) conducted a study that used videography to record and analyze the performance of the golf swing by advanced golfers to describe the most efficient method of achieving high club head velocity. Milburn found that, through the conservation of angular momentum, segmental velocities summated to reach a maximal speed at contact. A 2-D double pendulum model was used to show how proximal segments decelerated to accelerate distal segments.

Double Pendulum Model

The term double pendulum means the model uses two axes of rotation, one about the left shoulder and a hinge at the wrists. A built in stop in the wrist hinge is used to represent the anatomical end of range of ulnar and radial deviation. Some golfers appear to hinge their wrists more than 90° but that is not the case; to achieve this "apparent" wrist cock the grip is loosened by the golfer which allows the angle between the club and forearm to be maximized. There is no evidence to show that increasing the wrist angle past 90° increases power or velocity at impact. Loosening the grip does however; require the golfer to re-grip which may be a source of error. The double pendulum model has been used in many studies (Cochran & Stobbs 1968, Budney & Bellow 1982 and Milburn 1982) but has limitations. The fixed pivot at the left shoulder is not fixed during the golf swing as the left shoulder rotates about a central pivot between both shoulders. The double pendulum model also only accounts for the left arm; any action by the right arm is neglected. This model served its purpose by aiding researchers in determining how the club shaft and left arm move relative to each other. As researchers moved on and became interested in the rest of the body during the golf swing a new model was needed.

3-D Model

Two separate studies were done to determine the kinematic variable that had the highest correlation with greater clubhead velocity at impact. McLaughlin and Best (1994) compared kinematics of high ability players with low ability players while Robinson (1994) calculated hip and shoulder rotation. These authors developed a new 3-D model that allowed shoulder and hip rotation to be measured. The model consisted of a line joining the hips and line joining the shoulders and was added to the 2-D double pendulum model. It was found that hip and shoulder rotation were highly related to performance but the sequence of hip and shoulder rotations were still not well understood.

Burden, Grimshaw & Wallace (1998) used the 3-D model created by McLaughlin & Best and Robinson and combined it with 3-D videography. The purpose of Burden et al.'s (1998) study was to determine whether velocities of the hips and shoulders would summate and therefore begin the summation of velocities in the 2-D double pendulum model. Eight low handicap (below 10) golfers volunteered and hit 20 full swing shots with a driver. Of those 20 full swings the best one was chosen for further analysis. There is some debate whether selecting the best trial is an appropriate method of data analysis. It is appropriate if the purpose of the study is to gain insight into the movement as the best trial is likely to contain the fewest movement errors. If the goal of the study is to analyze the effect of manipulating the independent variable then a representative sample of trials should be used (trial averaging) rather than the best trial. Burden et al. (1998) showed that the hips and shoulders did begin the summation of velocities. This means that angular momentum is initiated in the downswing by a ground reaction force that allows the hips and core trunk segment to rotate. Since momentum is conservative and is a product of mass and velocity, if a heavy body segment decelerates a light segment must accelerate. This lighter segment must accelerate more than the heavy segment decelerated and the difference is proportional to the difference in the segments' masses. This phenomenon allows high velocities of distal segments to occur when proximal segments decelerate in the proper sequence.

Hip and Shoulder Rotation

It was found that the backswing took 78% of the time for the swing which was in accordance with previous literature. The downswing was completed in 0.26 s, which was less than the average downswing time for PGA tour players which was 0.29 s (McTiegue, Lamb, Mottram & Pirozzolo, 1994). The shorter downswing time for the amateur participants in this study is attributable to a shorter length of downswing rather than the downswing reaching a higher velocity. The length of the downswing could have easily been measured but the researchers were only concerned with the timing of movements rather than position measurements. It is difficult to compare such small time differences from study to study as each researcher may have their own method of timing, like when backswing stops and downswing starts. At impact the hips were found to be in an open position (left hip is posterior to its initial position); this supports the summation of velocities principle since the hips began the rotation toward the target. The average hip rotation was 32° while average shoulder rotation was 102° and half the participants began hip rotation toward the target before the completion of the backswing. The hips started rotating back toward the target a mean of 0.12 s before the shoulders (Burden et al. 1998). The shoulders were found to be open 10° at impact compared to 20° open by the hips. These findings are in agreement with observations of elite level golfers as hips and shoulders are both known to be open at impact although the hips more so than the shoulders. It was stated by Burden et al. that changing direction of hip rotation before the completion of the backswing will cause spinal rotator muscles to contract in an eccentric-concentric sequence. An eccentric-concentric sequence is more powerful than a concentric contraction and will increase the acceleration of the shoulders. More research needs to be done to determine whether this phenomenon improves results.

Wrist Torque

To settle the controversy of whether the wrists should unhinge from centrifugal force or whether muscular torque should be applied in sequence an optimization study was done by Sprigings and Neal (2000). This study used a three-segment, 2-D linked system model to measure segment motion. The segments consisted of golf club, arm and torso segments moving in a plane tilted 60° posteriorly from vertical. Passive protective linear-elastic torque elements at each joint prevented the model from going through a range that is unrealistic for a human to reproduce. Sprigings and Neal found that applying wrist torque would produce optimal results when the arm is 30° below horizontal. A limitation of the study is that the researchers assumed the downswing started from a static position. It was shown by Burden et al. that there is a good chance the hips will begin rotating towards the target before the completion of the backswing. This means the optimization study used only torque generated by the segments of the model to overcome the inertia of a static system.

Golf Equipment

The golf clubs used by golfers pose a specific problem in both analyzing swing kinematics and giving instruction. The behaviour of the golf club cannot be controlled by the golfer; its properties are constant. If a golfer is fitted with clubs then receives instruction and changes his/her swing the clubs may not suit the individual anymore. When analyzing an individual's swing kinematics, biomechanically, there may be only minimal error but in performance there is much more error. If the properties of a golf club (shaft in particular) are not matched to an individuals swing kinematics error will be increased and results will be unpredictable. This presents a limitation when assessing a change in swing kinematics using performance as a dependent variable. Change may not be seen as positive if performance does not improve. Mather and Jowett (2000) did a study that examined how the shaft behaves during the swing and whether it is likely that the shaft is a significant source of error in most golfers. This study has many obvious practical applications but also many biomechanical applications. By understanding how the shaft behaves the swing plane of the ideal model can be adjusted so the club face is perpendicular to the target and the sole is horizontal at impact. It was found that applying a greater force to the shaft, or the same force to a weaker shaft, causes the shaft to bend more. The plane, in which the difference of bend was measured however, was not in the plane of the swing. More bend was recorded in shaft "droop", or bend that causes the toe of the club to point down (Mather & Jowett, 2000). If a right-handed golfer with a club that is fitted for his/her normal swing, swings faster than normal it is likely that the ball will go to the right. The results of this study revealed that improving the kinematics of the swing may not necessarily produce better results if different forces are applied to the shaft. In future biomechanical experiments that propose to measure performance as a dependent variable shaft behaviour should be either controlled for or listed as a limitation. As a practical application, by knowing the 3-D shape of the shaft during the swing, adjustments can be made in the specifications of the golf club so the club face reaches impact in the desired orientation.

Motor Learning Literature Review

The study of motor learning helps develop a more efficient learning method to solve a problem. This is done by identifying the variables that affect learning and understanding *how* they affect learning. Most generally, intrinsic feedback and extrinsic feedback have been identified in the literature as variables that contribute to learning. Intrinsic feedback is sensory information gained by performing the movement. Intrinsic information is most commonly represented as proprioceptive or visual feedback (Magill, 2001). The combination of proprioceptive and visual feedback gives the performer information that may allow him/her to detect performance errors. Error detection is developed through understanding the relationship between his/her movement pattern and the outcome of the movement. In the golf swing, for example, the performer gains information about how his/her body moved through space from proprioceptive feedback. Information about the movement outcome is gained visually by seeing a portion of his/her movement and the ball's flight. These factors allow the performer to manipulate his/her movement and see the result of the modified movement.

Extrinsic feedback is also referred to as augmented feedback as it "augments" or, adds to what is learned from intrinsic feedback. Augmented feedback can be supplied before the movement (prescriptive) to inform the learner how to coordinate his/her movement. Concurrent feedback provides the learner with information during the performance of the movement. Augmented feedback given after the performance is known as terminal feedback but more specifically as knowledge of results (KR) and knowledge of performance (KP). KR is verbalizable, terminal information that tells the learner about the performance outcome. KP supplies the learner with information about the movement coordination pattern that leads to the performance outcome (Salmoni, Schmidt & Walter, 1984).

The contribution of the information to learning that is supplied by these variables is not constant. The level of experience of the performer, the complexity of the skill and the specific demands of the task determine what type of information facilitates learning most. This review will outline debate concerning the validity of testing methods, definitions and research on the effects of these variables in various performance situations.

What is Learning?

One definition of motor learning accepted by the literature is "a set of processes associated with practice or experience leading to a relatively permanent change in the capability of responding" (Schmidt, 1988, p. 346). To say that a performer has learned implies that a change in his/her ability to respond to a task stimulus has occurred. The definition does not specify whether the change must be an outcome change, a kinematic change or both. Schmidt also states that the change must not recede immediately. A temporary change in response or performance is argued to be a test of motor performance rather than motor learning. The duration of permanence of change in performance is not specific, ranging from hours to years (Schmidt, 1988). Durations of permanence are chosen based on the nature of the skill, previous studies or are manipulated post hoc. There is some debate whether the permanence of the change in response is a characteristic of learning or of memory and that permanence is due to stimulation of the memorial system rather than a function of learning. However, the literature has typically not accepted changes in performance as indicators of learning unless that change can be shown to be relatively permanent. It can be argued that a change in motor pattern that resembles the motor pattern the subject is trying to achieve represents motor learning. This view is similar to that of Adams (1971) before Schmidt added the factor of permanence. Adams stated that a change in performance is simply a change but if the new movement pattern more closely resembles the reference of correct movement then the change is a function of learning. If there is permanence to the change then the movement pattern has been stored in memory. The current study investigates change in movement patterns as well as the permanence of the change.

Adams (1971) developed a closed-loop theory that described how subjects improved performance of a graded response. A closed-loop system is a system that supplies feedback to change the response to the stimuli; unlike the open-loop system where the response to stimuli is always the same. In this theory, the subject gains information about how the movement should be performed. Through experience performing the movement the subject gains information about past movements, Adams called this information perceptual trace. Perceptual trace must be acquired from movement feedback or verbal transforms of it. Movement feedback that informs the learner of success relative to the desired outcome is referred to as knowledge of results (KR). In the closed-loop theory the subject compares the reference of correct movement to his/her perceptual trace for error correction – the motor program is then manipulated if necessary. The stage of acquiring the perceptual trace was named the Verbal-Motor Stage. This was one of the first suggestions of a hierarchical relationship between important information for experienced and inexperienced learners. Inexperienced learners had to rely on extrinsic movement feedback (KR) to develop a perceptual trace while experienced learners use internal error detection and correction by comparing their perceptual trace to the reference of proper movement.

Salmoni et al. (1984) argue that when assessing the effect of KR on motor learning a relatively permanent change in response must take place, otherwise, motor performance is being tested rather than motor learning. To resolve this argument the method of storing and retrieving information must be addressed. In Adams' closed-loop theory, for learning to take place a reference of correct movement and a perceptual trace must be present. If a permanent change is required to deem the change in movement be due to learning, the learner's memory of the reference of correct movement and perceptual trace is being tested rather than his/her ability to alter the movement to produce an outcome.

As mentioned before, the relevance of feedback information is not equal in all situations. Many studies (Adams, 1971; Newell, 1991; Magill & Schoenfelder-Zohdi, 1996; Scully & Carnegie, 1998) have shown that during acquisition of a motor skill, augmented information that describes the movement topology required for the performance is more important than information that describes the performer's movement outcome. The performer requires a representation of the movement topology so he/she can plan a movement coordination pattern. The coordination pattern is the general sequence of limb movements relative to each other, both spatially and temporally. In a movement such as the golf swing, an efficient coordination pattern is one that optimizes the combination of segmental velocities (temporal component) and degrees of freedom (spatial component). As the movement becomes more learned, augmented information about the movement outcome becomes more important as it increases the permanence of the change in the ability to respond. KR and KP provide the performer with outcome information so the relationship between the movement performance and the movement outcome can be understood. Augmented information about movement outcome allows the learner to develop error detection so the goal of performing the appropriate movement without augmented information can eventually be achieved. Movement parameterization is a result of error detection which refers to the amount of force required by the task. The relationship between movement pattern acquisition and parameterization is thought of as hierarchical, in that, more advanced learners require different information to improve performance. During parameterization the subject learns to scale his/her movement based on environmental conditions to achieve a desired outcome without changing the coordination pattern (Swinnen, 1996).

Scully and Newell (1985) addressed the question of the role of observational learning. They theorized that, during the acquisition phase of learning a novel movement skill, observational learning is more beneficial to the learner because of how the information being inputted is processed. It is thought that information gained from demonstration when learning a novel skill is used as a blueprint for the coordination of segmental movements that compose the skill. The adjustments made that are related to force and effort and are intended to improve performance are considered parameterization. Movements become parameterized through overt practice. This theory of observational learning stems from Sheffield's (1961) symbolic representational theory. Sheffield felt that acquisition and performance of complex movements were controlled by the same cognitive process. During observational learning the information is coded and organized to a cognitive representation that can be retrieved and produce performance.

Biological Motion as Demonstration

The point-light displaying technique developed by Johansson (1973) is used to study visual perception of biological motion as a method of learning. In this technique humans are filmed performing a movement with small lights attached to their major joints. The exposure is adjusted so only the lights are visible on film. Johansson found that when using point-light displays (PLDs) in observational learning studies the participants viewing the PLDs gained as much or more information about the movement than those who viewed the same movement filmed regularly. This finding indicates that the perceptual information gained from viewing motion of the major joints relative to each other is consistent with information gained from viewing the entire system. Much research has been targeted toward describing why viewing the relationship between the points of light produce such rich perceptual information. This area of research also offers great insight into what is gained from observing a demonstration and how that information facilitates learning a motor skill.

Runeson (1994) theorized that the usefulness of the information comes from viewing the relationship between the kinematic movement pattern and inducing the kinetic reason or cause of the movement. Runeson felt that the observers subconsciously understood what movements were in response to balancing or displacing a net force. He later gave further evidence to this phenomenon by showing that viewers were very accurate in predicting relative effort of the performer. The observers could distinguish between PLDs on a stationary bike and a real bike, predict relative effort of a performer lifting a weight and whether the performer was painting a wall or pretending to. Runeson called this inherent knowledge *kinematic specification of dynamics*, or the KSD-principle. According to the KSD-principle, when creating a model for demonstrating a movement, a distal approach should be taken rather than a proximal approach. This implies that the researcher not be in control of the patterns of motion – or the proximal events. By only being able to manipulate distal events (i.e. person performing the task or the task being performed) the KSD signature is preserved. By preserving the KSD-principle in a movement demonstration, relevant information gained from the demonstration is thought to be maximized.

Scully and Carnegie (1998) investigated what information was most critical in demonstrations using the point-light technique. The subjects were required to perform a ballet dance step after viewing a demonstration that was manipulated in various conditions. The results from the first experiment suggested that a slow motion demonstration compared to normal speed or still frame demonstration facilitated learning of kinematic information but inhibited learning of kinetic information. This implies that novice learners may benefit more from a slow motion demonstration while more advanced learners would learn to parameterize their movements better with a real time demonstration or even still frames. The speeds and number of still pictures were not mentioned.

The second experiment focused on what points of light were most important in the demonstration. The demonstration conditions tested were: all points of light visible, hips not visible, knees not visible, ankles not visible, and toes not visible. The results showed that the 'no toes' and 'no ankles' group performed significantly worse than the other groups.

The final experiment showed that learners performed better when attention was cued to the ankles compared to the knees. This finding supports the previous experiment, in that distal joints may be more informative in a demonstration than proximal joints. This may indicate the importance of distal points of light in demonstrations which may support the findings of Wulf, Lauterbach and Toole (1999) who showed that an external focus of attention yielded a learning advantage in golf compared to an internal focus. An external focus relates to distal motion of the body (i.e. club, hands and wrists) rather than proximal motion (i.e. core rotation, hip translation). Based on these findings, humans may be able to induce proximal motion based on distal motion. Another explanation may be that distal motion provides more detail about the movement because of the revealing nature of displacement in distal limbs. This means that in most movements, since the radius of rotation is greater for distal limbs, the displacement of distal limbs is greater, making proximal movement patterns more easily observed through their effect on distal limbs.

Demonstration and Knowledge of Results

Information provided before the movement is called prescriptive feedback. Demonstration (also modeling or observational learning) or verbal instructions are examples of prescriptive feedback. According to Richardson and Lee (1999) modeling or mimicking the movement of another performer is a learning method used to gain conceptual knowledge about how to perform the skill. The information gained from demonstration focuses internally on how to coordinate segmental movements. Individuals in the early stages of acquiring a novel skill are considered to benefit most from prescriptive feedback, as their primary objective is the development of the correct movement topology.

Post performance extrinsic information is referred to as knowledge of results (KR) and supplies information which augments intrinsic information by offering error correction information. Richardson and Lee (1999) conducted a study to determine whether modeling (prescriptive) information or knowledge of results (terminal) would facilitate learning performance in both acquisition and retention trials. The task was to sign various letters of the American manual alphabet. Test conditions varied such that the participants were offered prescriptive demonstration or terminal demonstration. Task difficulty was established by the number of handshapes the participant was required to reproduce. Task difficulty conditions were either one handshape or three performed consecutively. Performance in acquisition trials was better in the prescriptive condition but retention performance was higher by participants who received terminal feedback. The researchers offered several possible explanations for their results. The learner could easily reproduce the visual cue provided in the prescriptive condition but without terminal information the learner became dependent on the prescriptive condition. In the absence of prescriptive information performance was facilitated and inhibited in the acquisition trials. This theory suggests that when learning novel skills prescriptive information should be provided in the acquisition phase with the emphasis shifting to terminal information once the learner understands the concept of the movement or skill. The researchers stated that for a learner to benefit from extrinsic information the information must be presented in a manner that does not eliminate the retrieval of stored information. If the learner relies solely on the information from the demonstration he/she will become dependent on the demonstration and learning will be inhibited. Another explanation for the results indicated that the task may have been too easy for the learner to reproduce the prescriptive information; there was not enough cognitive effort put forth by the learner to facilitate retention. Prescriptive retention scores were lower because too little cognitive effort was required in acquisition. This may be the reason for the terminal group scoring higher in retention rather than terminal feedback's influence on learning. Further research should be done that investigates the effect of cognitive effort on learning. The guidance hypothesis (Salmoni et al. 1984) supports the results of Richardson and Lee and states that augmented information will improve performance in the initial stages of learning. However, the gain in performance in acquisition trials will recede if the learner became dependent on the augment feedback rather than attending to the available intrinsic information. (See Guiding Effects of KR).

Hodges and Franks (2000) investigated the effect of altering the type of demonstration and whether feedback would affect learning a bimanual coordination task. The bimanual coordination movements done in this experiment were circular arm movements done either in phase (IP) or in phase but staggered relative to each other (RP). One group was told only what the goal of their movement was (NO DEMO). Three groups received a demonstration of the movement, of these three; one group viewed a demonstration of the correct movement and no further information was given (DEMO), one group was instructed to direct their attention towards the feedback of their movement (EXTERNAL), and the last group was both given a demonstration and informed of the relation their arm movements had on the feedback they received (RELATION). The researchers hypothesized that the relation group would show the best learning effect as this method combines the benefits of an external focus during movement and knowledge of results (KR). It was found that inter-trial variability was reduced when feedback was available. The results indicated that the DEMO group showed the slowest rate of acquisition, even slower than the NO DEMO group. The researchers felt this was because the participants in the DEMO group concentrated on matching their movements to that of the demonstration and did not attend to the available feedback. In this movement situation the demonstration was a distracter. The NO DEMO group showed the highest movement variability during acquisition. This is in accordance with other related literature as the demonstration aided the other groups in coordinating their movements. When feedback was removed all groups were affected and the difference between groups did not reach statistical significance. Hodges and Franks predicted that the NO DEMO group would be most negatively affected because they were not given internal information that related to how the movement should be performed. The researchers did not offer an explanation as to why the NO DEMO group was not significantly affected.

In a study by Magill and Schoenfelder-Zohdi (1996) the effectiveness of a visual model was compared to knowledge of performance (KP) in learning rhythmic gymnastics. This study made the distinction between the cognitive aspects of KP and modeling. The authors theorized that viewing an expert perform the task as a model the student learns how the skill should be performed but may not know how it relates to their own performance of the movement. Conversely, KP gives the student feedback based on how they perform the movement but the student may not have a complete cognitive representation of how the movement should be performed. It was thought that there would be an interaction effect between KP and visual demonstration but the findings indicated that the combination of KP and visual demonstration did not increase learning more than what was found in either learning condition on its own. Magill and Schoenfelder-Zohdi attributed this finding to there being redundancy in the information produced by each learning condition. Another key finding from this study was that students who received demonstration required external instructions to improve further. The implication is that viewing a demonstration provides the learner with internal instructions but lacks external information. The opposite is true for those who received KP, they required internal instructions to improve since their internal representation of the skill were incomplete compared to those who viewed a demonstration. When learning a novel skill, it is thought that there must be some similarity in what the student learns or remembers by using KP or visual demonstration since, combined, both forms of feedback did not produce an interaction effect.

In an experiment by Weeks and Anderson (2000) three methods of demonstrating a movement task (overhand volleyball serve) were tested. All three groups viewed 10 videotaped demonstrations and performed 30 trials. One group viewed all 10 demonstrations prior to any kind of practice, after viewing the demonstrations all 30 trials were performed in block – this group was called pre-practice (PP). One group, labelled comparison (Com), viewed one demonstration then performed three trials; this pattern was repeated until all 10 demonstrations were viewed and 30 trials were completed. The last group viewed five demonstrations then followed the pattern of the comparison group until all the demonstrations had been viewed. Fifteen block trials were then completed to add up to 30 trials. The researchers hypothesized that the combination group would show the best learning effect because of the interaction effect between observational learning and overt practice. Previous literature (Scully & Newell, 1985; Newell, 1991; Scully & Carnegie, 1998; Richardson & Lee, 1999) has stated that observational learning is most beneficial during the skill acquisition phase and overt practice is more beneficial after the technique has been learned. This is very comparable to other research findings that state demonstration to be more beneficial in acquisition and KR more beneficial in retention. The comparison group had more demonstration viewing in the beginning of the experiment and more practice at the end. This pattern of observational learning and overt practice was intended to reproduce the results of previous research in the field. The researchers concluded that, when learning a skill, pre-practice skill demonstration followed by inter-practice modeling and overt practice at the end of practice optimizes learning. It was also noted that inter-practice modeling should be terminated early enough so that the performer does not become dependent on the model.

Guiding Effects of KR

Salmoni et al. (1984) hypothesized that evaluating the effect of KR in learning often changes the learning environment. The learner is thought to attend to the augmented feedback over intrinsic feedback. The increase in performance leads the researcher to believe that the KR condition caused learning. In many cases however, the learner became dependent on the KR condition and showed a drastic decrease in performance when the KR is removed. The learner has consequently not "learned" since a relatively permanent change in the ability to respond has not occurred. KR tells the performer what the outcome of their movement was and implies the necessary change to produce successful performance. KR may distract the performer from attending to other information sources that would be used in the absence of KR. The nature of the augmented feedback determines its guiding effects. If the learner is able to use KR as information that facilitates performance but performance only increases in the presence of KR then the user's performance depends on KR and the KR is deemed to be guiding. Although the KR aids the learner in acquisition, since it distracts the learner from intrinsic information, KR is potentially misleading and will likely hinder performance in no-KR transfer testing. Reduced frequency KR has been shown to reduce the guiding effects of KR. When the participant is not given KR after every trial he/she must focus on intrinsic information thereby developing error detection and correction (Schmidt, Young, Swinnen, & Shapiro, 1989).

Discovery Learning versus Teaching

Vereijken and Whiting (1990) suggest that when learning a complex motor skill the method of training has an effect on performance of the skill. In their 1990 study, participants learned to use a ski simulator. Their findings indicate that extrinsic feedback, or knowledge of results, was critical in learning complex motor skills, more so than simple motor skills. The difference between a complex motor skill and a simple motor skill is the degrees of freedom required by the skill. The authors viewed a novel motor task/skill as a problem the learner is required to solve. The solution lies in the movement pattern that can produce the desired outcome. The knowledge of the results of the movement are seen, by Vereijken and Whiting, as information that helps the learner "discover" how certain movement pattern modifications affect performance. This knowledge is believed to lead to error detection and correction which is found in more advanced performer's movements.

Vereijken and Whiting (1990) state that when teaching a complex motor skill the instructor is often reducing the degrees of freedom and thus, just making the task less complex. The researchers use the example of a mother teaching a child to ride a bike. While the mother holds the child upright the task requires fewer degrees of freedom as balance is eliminated and the child can concentrate on the operation of the pedals. According to Vereijken and Whiting, there is no significant difference in learning when instruction is supplied compared to discovery learning. The authors feel that discovery learning is a form of problem solving. When practice is done properly the movement is not merely repeated over and over but a more optimal way of performing the movement is developed based on knowledge of results. Neither teaching nor discovery learning were found to be more beneficial in a given situation. Instead, the method of learning that should be elicited depends on the individual, their level of ability and the complexity of the skill being learned.

Al-Abood, Davids and Bennett (2001) argued that using a ski simulator to measure observational and discovery learning may not be accurate because of the physical constraints caused by the equipment. Al-Abood et al. designed an experiment that was intended to determine whether discovery learning was effective when the task solutions were not constrained by equipment or instructions that specify the recommended movement pattern. The task was throwing a dart to a horizontal dart board. Movement kinematics and outcome measures were recorded for three groups: a control group (discovery learning), a verbally directed group and a modeling group. The researchers theorized that observing a demonstration would influence the participants in the modeling group to mimic the model's coordination pattern. The verbally instructed group was predicted to approximate the model's coordination in less time than the discovery group and produce better performance outcomes than both groups. The discovery group may not necessarily even produce movement that approximates the model as the only extrinsic information they were supplied was performance error information. The results indicated that there was a main effect between performance and time. Accuracy increased and movement variability decreased with practice. The modeling group approximated the coordination pattern of the model most closely and the quickest in both acquisition and retention trials. The verbally directed group approximated the coordination pattern of the model in significantly more time than the modeling group while the control group's movement pattern did not approach the coordination of the model.

In response to the ski simulator studies, it is suggested that when there is a low level of task constraint the participant will search stored information to find an already existing movement pattern that may help produce a solution for the task. The effects of observational learning, when learning a novel movement pattern, are to help the learner approximate the model's relative motion pattern and understand the relationship between the movement pattern and the movement outcome. The researchers emphasized that it is the novelty of the movement pattern rather than the task that determines whether modeling will be more effective than discovery learning. This means that there must be constraint on the task, either physical or instructional, to reduce the degrees of freedom and increase the chance of discovery learning being an effective means of accomplishing a movement task.

Concurrent Feedback

Concurrent feedback is information that is given to the performer during the movement. The most studied form of concurrent feedback is concurrent visual feedback (CVF). Research on CVF is often conducted on spatial limb movements. Concurrent information feedback supports Adams' (1971) and Schmidt's (1975) motor learning theories. In a closed-loop system information from several sensory channels has been shown to facilitate performance in acquisition with KR and transfer with no KR. The information gained from CVF is thought to help participants reduce movement errors. The concurrent information studied by Schmidt and Adams was intrinsic sensory information. Recent research (Swinnen, Jardin & Meulenbroeck, 1996; Sherwood & Kaiser, 2002) has used concurrent augmented feedback to study information feedback processing. These studies showed that the performer must also direct attention to the source of the CVF for it to be beneficial. The visual focus of these studies was the participants' moving limbs, because of the relatively slow movement, the concurrent feedback allowed the participants to make online corrections. The feedback facilitated performance in acquisition but was likely guiding if delivered too frequently. Other studies on concurrent visual feedback use a visual display of output data as the feedback. This form of CVF is usually seen as a distracter. The participant must recode the information into movement information and is not left with enough time to make online corrections. Processing the information also likely requires a large amount of attention which will distract from attention being allocated to performing the movement.

A case could be made that CVF should only be considered extrinsic information if the feedback has been augmented in some way or if it is in combination with augmented information. CVF supplemented with transitional information offers similar information to knowledge of performance if the transitional information makes reference to the quality or the correctness of the movement. If no augmented information is supplied in combination with the CVF, the CVF should be thought of as intrinsic visual information

KR Manipulations and Transfer

Many studies have shown that certain manipulations of KR are more likely to produce long term learning effects than simply providing KR as early and as often as possible. Recent research has focused on manipulating the delivery of KR to limit its guiding and potentially misleading effects. Summary length, relative frequency, bandwidth manipulations and temporal presentation of KR and KP conditions are most studied by researchers.

Relative frequency of KR is recognized as the proportion of trials KR is given, whereas absolute frequency of KR indicates the total number of KR trials. McCullagh and Little (1990) conducted an experiment testing the effects of demonstration, KR, and practice on learning a simple movement timing task. Three groups: demonstration + KR, 100% KR, and 33% KR were tested. The demonstration + KR group received two correct demonstration trials followed by one physical practice trial with KR every block. The 100% KR group performed six trials, with KR after each trial, per block. The 33% KR group performed six trials, with KR after only two trials (chosen randomly), per block. Previously, it was thought that physical practice was necessary for learning to occur. This study showed that demonstration in combination with KR yielded similar acquisition rates as practice with KR even though fewer physical trials were completed by the demo + KR group. This study did not separate demonstration from KR so it could not be determined whether a main effect for either variable or an interaction effect between both variables was responsible for the changing response. There was no reduced frequency demonstration group either, so conclusions could not be made about the effect of reduced frequency KR.

A study by Guay, Salmoni and Lajoie (1999) investigated the effect of spacing and summarizing techniques for delivering KR when learning a ballistic movement task. The results agreed with the guidance hypothesis in that spatial accuracy during acquisition was highest when KR was given after every trial, while performance in no-KR retention tests was highest by participants who only received KR after every fifth trial. When offered after every trial the KR was found to be guiding and the participants became dependent on the feedback.

Liu and Wrisberg's (1997) study also supports the guidance hypothesis, they found that immediate feedback facilitated performance in acquisition trials while participants in the delayed feedback group showed higher movement accuracy in no-KR retention tests. This study however, introduced a new variable in combination with KR. The immediate and delayed KR groups were further split into error estimation and no-error estimation groups. In the error estimation condition, participants are required to estimate the error outcome of the performance before being given any feedback. The interaction of delayed feedback and error estimation showed highest movement accuracy lowest movement variability in transfer tests. The error estimation condition is hypothesized to reduce the guiding effects of KR as the participant must use intrinsic information to detect performance errors and not rely solely on the KR. The participant must also recode the movement information by verbalizing the error estimation thus requiring greater cognitive effort and awareness.

Bandwidth KR is a feedback method where augmented feedback is only given when performance errors are outside a predetermined threshold. There may be some redundancy between relative frequency feedback and bandwidth KR since feedback is not given after every trial in either learning strategy. The literature has shown that bandwidth KR aids the intrinsic learning process. It is hypothesized that the trials followed by no KR improve retention in no KR conditions not only because of the specificity to the testing condition but the performer also develops error detection and correction during these blank trials (Sherwood, 1988; Lee and Carnahan, 1990).

Shewokis, Kennedy and Marsh (2000) investigated the effect of bandwidth KR on learning a sub-maximal, isokinetic strength task. Four groups were compared: a bandwidth group (BW), a yoked, a verbal 100% retroactive KR and a concurrent visual 100% KR group. The bandwidth group received verbal feedback of force output when performance was outside 70% of the training criteria. The participants were aware that the absence of feedback implied that the performance was "approximately" correct. The experimenters divided the BW group into two feedback conditions: quantitative error KR (outside performance criteria) and qualitative no-error KR (within performance criteria). Members in the BW group were given partners who made up the yoked group. The yoked group members received feedback on the same trials and in the same condition as their partners in the BW group. The comparison between these groups was designed to separate the learning effects of BW from relative frequency KR. The verbal group received verbal feedback of force output after each trial while the visual group viewed a display screen after each trial. There was an interaction effect between the reduced frequency groups and the feedback condition. The BW group performed with significantly less errors, compared to the yoked group, when they received quantitative error KR. The reduced frequency groups also performed more consistently than the visual control group. Performance in retention trials was more consistent by reduced frequency groups compared to 100% frequency groups. The experimenters attributed this difference to the reduced frequency groups' ability to process intrinsic information for error detection and correction.

Bandwidth KR was applied to learning a golf pitch shot in a study by Smith, Taylor and Withers (1997). To generalize the findings of bandwidth KR to a total body movement, 0% (control), 5% and 10% bandwidth conditions were used as the feedback frequency condition. Another condition, feedback type, determined whether the participants received transitional information concerning the movement or KR concerning the outcome of the movement. According to the literature the 10% bandwidth condition should have facilitated retention. In this study the 10% bandwidth condition improved the participants' movement consistency but only with the interaction of transitional information rather than KR.

Janelle, Barba, Frehlich, Tennant and Caraugh (1997) tested a modification of bandwidth KR. Instead of the researcher determining the performance criteria, Janelle et al allowed the participant to view a video taped replay of his/her movement on a self controlled schedule. This method is thought to produce similar findings as bandwidth KR studies because the participant was not expected to view the feedback when it was not necessary. Participants in the self-controlled group performed better in transfer testing than the yoked group, the summary group and KR group. The researchers concluded that being able to control the learning environment allows the learner to optimize feedback frequency.

Schmidt, Lange and Young (1990) investigated when KR should be employed to optimize skill learning (summary length). In this study KR was given in the form of a graphical display that informed the learner where errors occurred in a coincident-timing task. There were four different KR conditions. The learner would either receive immediate feedback (1 trial condition), or in the five trial condition the learner received KR for the first five trials immediately following the fifth trial. For the ten and fifteen trial conditions KR was given after the tenth and fifteenth trials, respectively. Retention was measured 10 min after acquisition and 2 days after acquisition in the delayed retention condition.

The findings showed that participants in the 5 trial group showed the largest increase in movement control. The results indicated that there is an inverted-U relationship between summary length in acquisition and retention. When more trials were conducted between KR interventions the participants seemed to benefit less compared to when KR was given after every fifth trial. When receiving KR after every trial the participant's ability for error correction suffered as they may have become dependent on the KR. This is similar to the findings of Richardson and Lee (1999). When feedback is supplied more frequently the learner may not be required to rehearse the movement and recruit stored information causing them to become dependent on the feedback.

In another ski simulator study, Wulf, Horger, & Shea (1999), investigated the efficiency of supplying block vs. serial feedback for a complex movement task. Participants in the block KR group received KR about the same foot after every trial, switching feet every day for 4 days. Participants in the serial KR group received feedback that alternated feet every trial. The purpose was to distinguish whether information about a different aspect of a novel complex skill would facilitate learning by informing the performer about the whole movement or would hinder learning by confusing the performer. The dependent measures used were movement amplitude, movement frequency and force onset. Significant differences between groups were recorded for movement amplitude and movement frequency. The serial group showed better performance for both dependent variables during acquisition and no KR retention tests. As mentioned by Al-Abood et al. (2001), ski simulators have a high level of task constraint and the results may only be generalizable to tasks with a similar level of constraint.

Summary

For an individual to learn a complex novel movement skill most efficiently the augmented information must be supplied carefully so the information is relevant and helps the learner form the correct response. The augmented information must also be offered in a manner that does not make the learner ignore the available intrinsic information. In the early stages of learning prescriptive information such as verbal instructions and demonstration should be given to help the learner form a blueprint for the correct movement pattern. As the learner becomes more competent in performing the movement skill and starts to understand how to produce the correct movement pattern the frequency of prescriptive information should be reduced and terminal information should be introduced to begin the development of error detection and correction. As the learner's competency increases further the terminal augmented feedback should be offered in reduced frequencies and more specific to the needs of the learner.

Methods

Participants

A convenience sample of five volunteer, beginner level participants was chosen to participate in a series of golf lessons using the VPG learning system. Participants 1-3 were considered absolute beginners as they had played less than 2 complete rounds of golf. Participants 4 and 5 were more advanced, although still considered beginners, they had played golf for several years but very infrequently (less than three rounds per year). Written consent forms were filled out by each golfer (Appendix A). The participants' age and sex were documented in the participant information form (Appendix B). Each participant performed approximately 20 golf shots during each observation period, the final three trials were chosen and averaged for analysis. Each of the intervention (lesson) sessions was in accordance with the Virtually Perfect Golf lesson manual.

Data Collection

Experimental sessions were grouped as either observation sessions or intervention sessions. During observation sessions the participants were instructed to make a full swing and hit a plastic golf ball against a wall located 9 m away. The hitting surface approximated a real playing situation while eliminating extraneous variables such as weather and ground conditions. After baseline measurements, transitional information was given, verbally, to the participants to remind them of the previous lesson's objective.

During interventions, transitional information was given if the participant needed help understanding any aspect of the lesson, such as language or theory. The movement was performed in a calibrated field (see Figure 1) in accordance with the video data collection procedures required by the Peak Motus® motion measurement system. Each participant used the same length club during all observation periods to increase reliability. The length of the club was based on the participant's height and determined by the instruction manual.

At the beginning of every intervention session the participant viewed a video supplied by VPG that introduced the concepts and objectives of the intervention. Each VPG lesson was divided into four sections. The beginning of the lesson would emphasize the proximal components of the lesson; each section would either add a distal segment or increase the range of motion. For example, the first lesson started with a slight hip rotation, the next section increased the range of motion of the hip rotation, the last section directed the participant to rotate 90 degrees so that the chest faced the target. The participant viewed each section along with a demonstration by the model in three different camera views before moving on to the next section of the lesson. The participant then attempted to repeat the movement of the VPG model. The participant was allowed to view the model as often as he/she needed. The participant was also allowed to view him/herself performing the movement through the VPG glasses as often as necessary to feel comfortable with his/her performance of the movement.

The observation data was collected using two digital cameras supplied by VPG located at 90 degrees to each other with a focal length of 1.35 m (see Figure 1). A short focal length was used because of the shape of the lens on the supplied cameras. The lenses distorted the image but were not a source of invalidity since the model the participants were compared to was generated to match the distortion. A sampling rate of 60 Hz was used for each of the trials. The supplied cameras had a fixed shutter speed so lighting conditions were adjusted to match camera exposure. When necessary joint centers were marked with white athletic tape to provide colour contrast and improve digitizing accuracy.

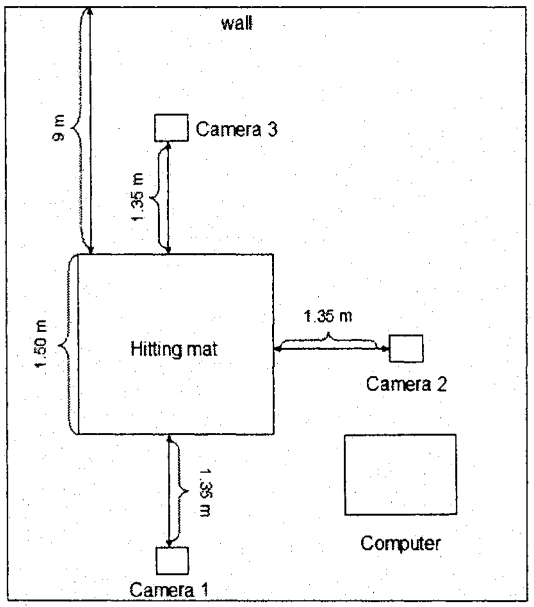


Figure 1: Experimental layout

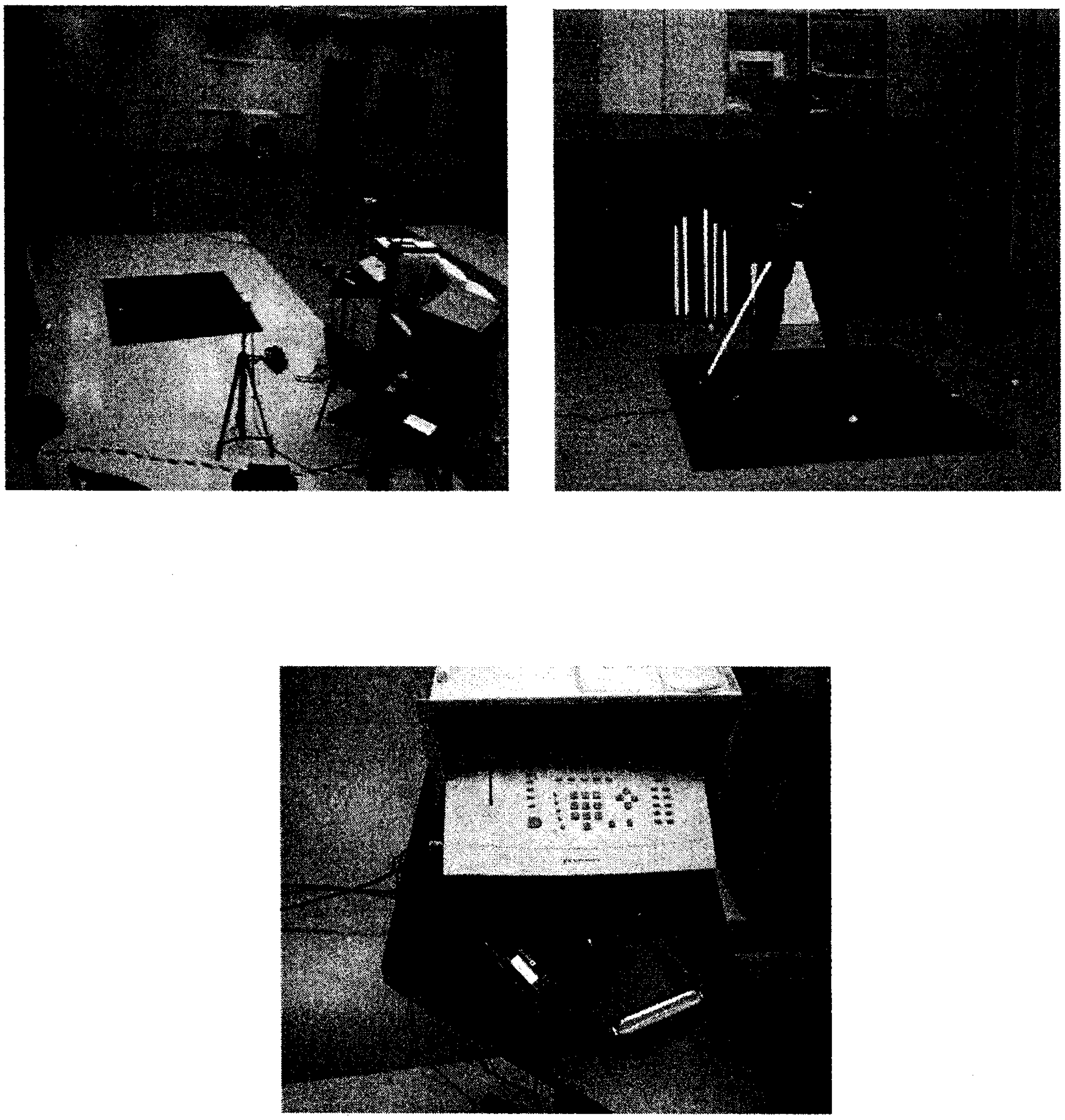


Figure 2: VPG equipment

Golf Log

The level of exercise was an important variable to monitor as an increase or decrease may be associated with changes in range of motion and strength, or with any observed improvements. An increase in the range of motion can lead to greater potential energy in the backswing and make it possible to apply a greater force to the ball at impact. Strength training may also influence the performance and needed to be accounted for in any interpretations of the data. The number of rounds played and time spent practicing may also cause a change in swing kinematics. Previous literature indicates that practice facilitates learning (Weeks & Anderson, 2000). If a participant increased his/her time spent practicing between observation sessions it would be difficult to record swing kinematics that produce a reliable baseline. By increasing the time spent practicing during the experiment it may appear that the intervention had a greater effect on learning than it really did.

Dietary habits and injuries or illnesses can affect a participant's strength, range of motion and ability to concentrate. A negative change in diet or a recent illness or injury can cause a decrease in performance.

Each participant was required to complete a golf log (see Appendix C) before experimental sessions. Age, sex, body composition, practice, exercise and dietary habits were recorded by the participant on a standardized information sheet (see Appendix B). Before every observation session, the handicap index, number of rounds played, time spent practicing, additional golf instruction, change in diet, change in exercise and any injuries or illnesses (if applicable) were documented in the golf log. The golf log was intended to help control maturational threats to internal validity.

Research Design

A single subject (multiple baseline across subjects) design was used to evaluate the effect of the treatment on each individual participant. The multiple baseline across subjects design was used to increase the generalizability of the data. Throughout the course of the experiment there were a total of three VPG intervention sessions per participant. During an intervention session the participant received a structured golf lesson prepared by VPG. Kinematic analysis was conducted over 4-6 observation periods (probes) prior to the delivery of the VPG intervention to establish a baseline of performance. The data were used to describe the participants' original level of performance and allowed predictions to be made about future performance in the event that no further treatments were administered. The baseline movement data were also assessed for each of the subjects in order to determine the degrees of variability in the performance (Kazdin, 1978).

The number of observation periods before, between and after intervention was not constant across all participants. Staggering the administration of intervention sessions allows a change in trend to be more easily observed graphically. This procedure was intended to eliminate testing as a threat to internal validity (see Figure 3).

Participant 1 performed golf swing trials during each of six baseline observation periods prior to the first intervention. After baseline measurements each intervention was followed by three probes until the end of the experiment. Participants 2, 3 and 4 were recorded for five baseline observations, two probes in between each intervention and four probes after the final intervention. Participant 5 performed in four baseline observations, two probes in between interventions and four probes after the final observation period.

The changes in golf swing kinematics (performance) which were measured and analyzed were hypothesized to be indicative of any changes caused by the VPG intervention. The 2-D movement kinematics which were measured (2-D joint displacements and angular displacements), served as the data to be plotted and used for comparison to the model at critical events throughout the skill.

To satisfy the experimental criterion there must not be an overlap between treatment data and baseline data. If the observed behaviour after treatment deviates from predicted behaviour it may be possible to infer causality. If there is a treatment effect that is relatively permanent then the participant will be said to have "learned" (Kazdin, 1982).

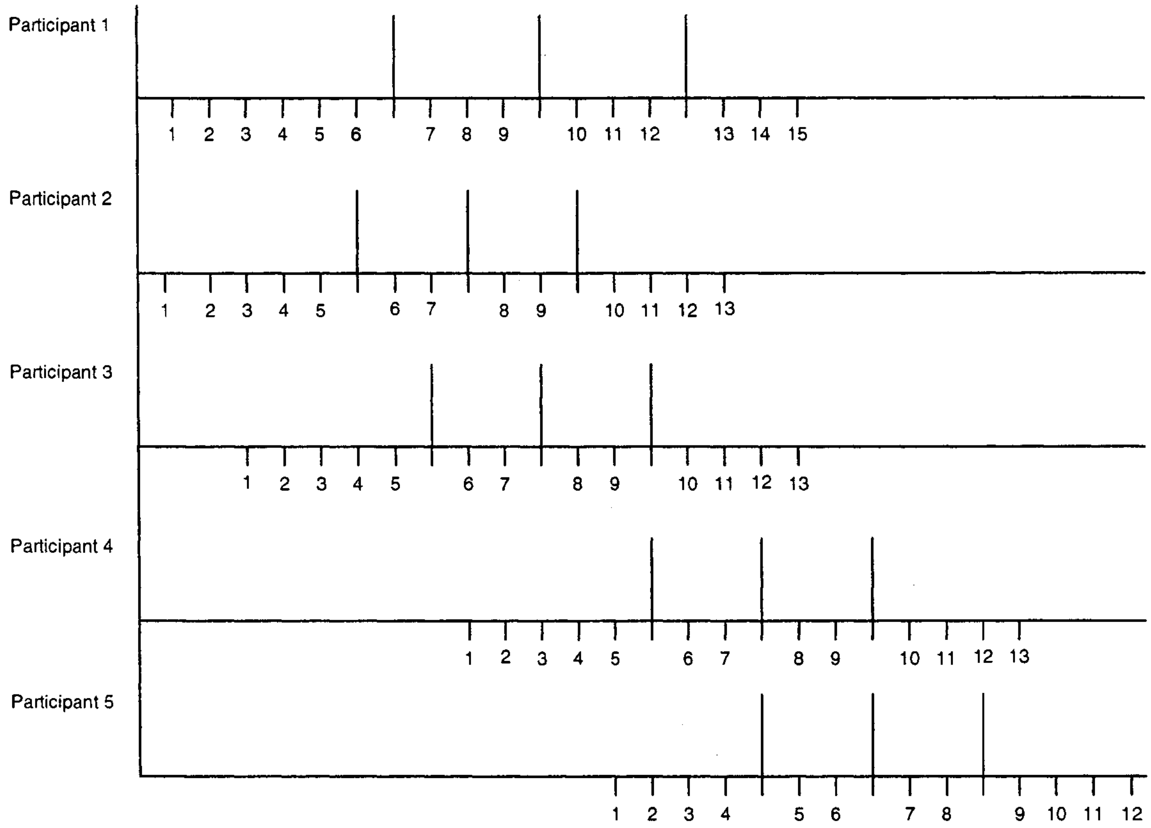


Figure 3: Layout of the multiple baseline single subject design.

Each intervention represents a VPG lesson and is indicated by a vertical line. The numbers along the x axis represent the probes during both the baseline and post intervention phases.

Kinematic Analysis

To create a digital model of the participant specific frames of the video recording was digitized using the Peak Motus® software. The ankle, knee, hip, shoulder, elbow, wrist, top of head, club grip and club heel were digitized to create a spatial model. Virtual points were created at the bisection of the hips and shoulders to create a spine segment. Digital recordings were digitized by manually clicking on each joint centre of interest, in every frame captured, for each camera view. The field was calibrated by digitizing an object of known length while minimizing perspective error. The system calibrates the field by converting real world units of measurement into pixels. The calibrated stick figure allows analysis of body segment motion relative to any other calibrated point of reference.

2-D digital models of the participants in the frontal and lateral views were compared to VPG model in the same views. 2-D videography was used instead of 3-D to allow more direct comparisons between the participants and the VPG model. 3-D videography would allow a more in depth analysis of variables measuring body rotation and the path of the club head but the same information cannot be extracted from the VPG model since it was created two dimensionally. The purpose of the analysis is to determine whether the participants begin to simulate the performance of the movement they viewed as a demonstration. By using 2-D videography comparisons can be made in the same planes and the distortion by the camera lens is constant.

Variable Definitions

Two dimensional joint displacements and angular segmental displacements were measured as dependent variables assumed to be indicative of learning. These variables were generated from a review of the biomechanical literature on the analysis of golf technique along with considerations of the objectives of the VPG learning system. Trial averaging is a procedure in the Peak Motus® software that standardizes the number of frames in each trial and averages the joint coordinates for each frame. Three trials were averaged from each observation session and compared to the model and other observation sessions. The variables selected for analysis were angular displacement of the left elbow, angular displacement of the spine, linear displacement of the head, angular displacement of the right and left knees and the linear speed of the left wrist at contact. The angular displacement of the left elbow was measured in the frontal view. The angle between the left upper arm and the left forearm represents the left elbow angle using the elbow joint as the axis of rotation (see Figure 4). The spine segment was created by connecting the bisection point of the shoulders and the bisection point of the hips. Angular displacement was measured relative to vertical in the lateral view (see Figure 5). Displacement of the head was measured in centimetres in the frontal view relative to its starting position (see Figure 6). The knee angles of both right and left legs were measured as the angular displacement between the upper leg segment and the lower leg segment in the lateral view (see Figure 7). Linear speed of the left wrist was used to represent motion of the distal segments at contact. The instantaneous linear speed was used at the moment of ball contact.

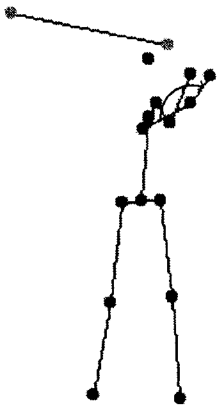


Figure 4: Angular displacement of the left elbow

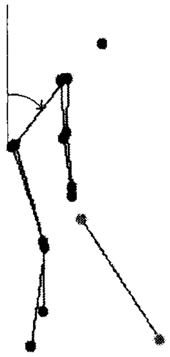


Figure 5: Angular displacement of the spine

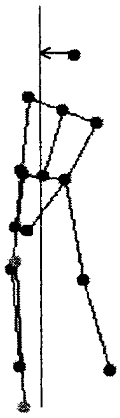


Figure 6: Linear displacement of the head

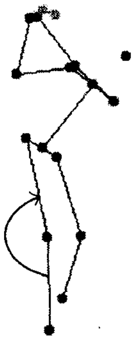


Figure 7: Angular displacement of the legs

Critical Events

The above variables were measured and analyzed at five critical events during the golf swing. The first critical event represented the starting position and was defined as the instant before the onset of movement. The second critical event was the first moment when the club shaft reached horizontal in the backswing. The third critical event in the swing was when the hands changed direction of rotation around the body. The fourth critical event was the instant when the club shaft reached horizontal on the downswing. The fifth event represented the instant of ball contact (see Figures 8-12).

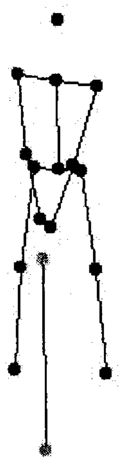


Figure 8: Critical event #1

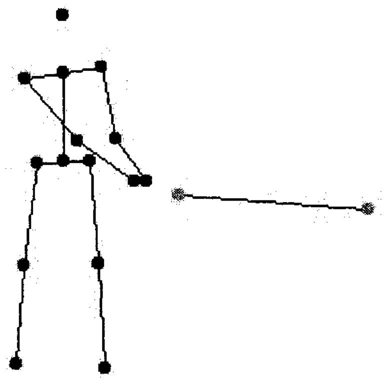


Figure 9: Critical event #2

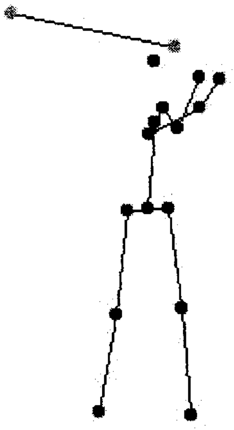


Figure 10: Critical event #3

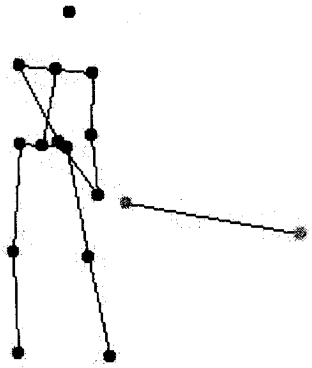


Figure 11: Critical event #4

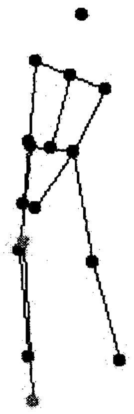


Figure 12: Critical event #5

Data Analysis

Single Subject Design

Two criteria are commonly used in single subject design to determine whether the intervention had an effect, the experimental criterion and the therapeutic criterion. The experimental criterion refers to how the data is analyzed to determine the relationship between the independent variable and the dependent variable. In this study, the data was visually analyzed for changes in mean, level, trend, latency and variability. The mean represents the average score for a dependent variable in a baseline. The level refers to the change in magnitude of the score for a dependent variable from the end of one baseline to the beginning of the next baseline. Trend describes the tendency of the data to increase or decrease over time. Latency measures the change in performance during a given baseline. Variability refers to the consistency of the performance during a baseline (McPherson, 1987).

To evaluate the therapeutic criterion several applications of the effect of the intervention need to be investigated. Quantitative analysis techniques determine whether there is a change in performance at some time during the experiment but do not question the practical significance of the performance change. The required time and cost of the intervention must also be considered in the therapeutic criterion. If the intervention is relatively cost efficient and not time consuming then it may be worth giving the intervention even if only small changes are seen. The intervention must also be evaluated on its capability to transfer performance changes to a practical situation.

Log-Log Linear Transformation

In the mid-late 1800's psychologists searched for a law to describe the relationship between actual stimulus intensity and apparent stimulus intensity. Fechner (1877) claimed that changing the relative stimulus increment non-linearly produced a constant response in reporting apparent stimulus magnitude. He felt that the difference between the two measures of stimulus intensity had a logarithmic relationship. Fechner's Law predicted that stimulus intensity increments on the decibel scale should be proportional to apparent loudness. This prediction was later disproved when precision recording instruments were developed and allowed the law to be tested.

Stevens (1957) proposed the power law which later emerged as the dominant psychophysical law, showing that stimulus sensation ψ grows in proportion to the stimulus φ raised to a power.

Equation 1: Power function

$$\psi = k\varphi^{\beta}$$

where β is the exponent of the power function and k is a constant. Taking the log of the power function gives a straight line with slope being the exponent.

Equation 2: Log-log linear transformation of the power function

$$\log \psi = \beta \log \varphi + \log k$$

The log-log transformation of the power function allows several data points to be represented by one. In the current study, five data points representing the five critical events from one observation period were transformed linearly and the slope of the straight line was used as a composite score to describe the dataset. A y-intercept of 0 was used so the straight line passed through the origin. The data from one observation period was composed of three trials that were averaged. The log-log data describes the motion pattern for one participant over one variable during one observation period. Single subject data analysis techniques were then used to compare movement outcomes across observation periods, variables, and participants.

Log-log data points were then plotted versus time (observations sessions). The plotted data was visually analyzed for change in mean, level, variability, trend and latency. The data for the model was also plotted and used as a reference of "correct" movement (see Figure 13). It was hypothesized that if the participants improved as a result of the VPG intervention then their movements should approach the performance of the VPG model. The log-log data is scalar so a change in magnitude of the composite score does not imply the quality of the change or the contribution of the individual events to the change in performance. The log-log composite scores show at which probes during the experiment a change in performance takes place but does not describe *how* the performance changed. To analyze the contribution of each event in a baseline to the log-log composite score a t-test was used.

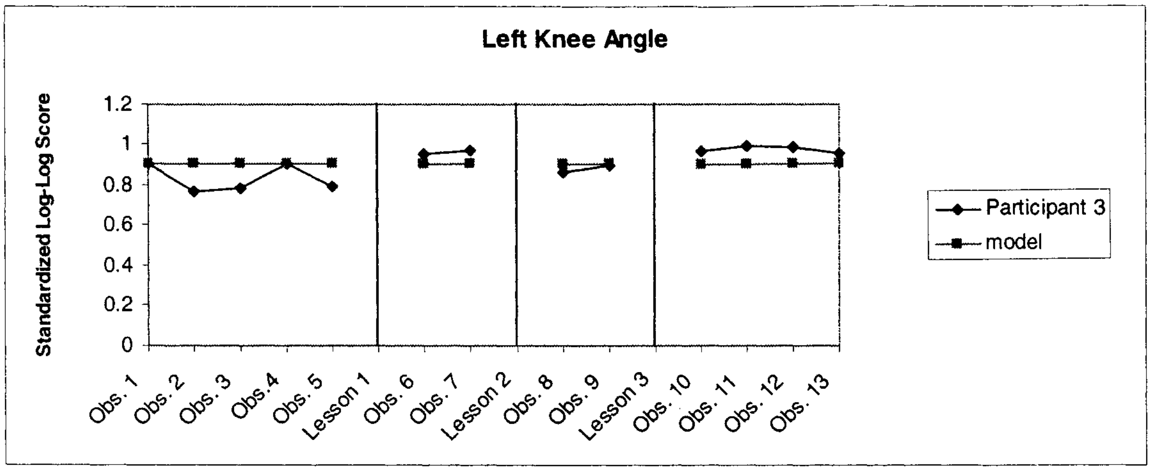


Figure 13: Log-log data

T-Test Analysis of Critical Events

A one sample t-test was used to compare the average difference of each critical event of the participant, during one baseline measurement, to the score for each critical event of the model. There was no variability in the performance of the model. The difference between the average score for the participant (observed) and the score of the model (expected) was divided by the standard error of the observed score (see Equation 3). The t-test was computed using SAS® (see Figure 14); the output was analyzed for change in the observed performance compared to the model and a change in the standard deviation of the observed performance. Since each baseline was composed of a different number of probes the degrees of freedom in the formula were not consistent. The average of the observed scores compared to the model was used in the analysis comparing baselines rather than the t score. The observed standard deviation was analyzed to evaluate variability of the performance. The average difference from the score for the model was then used to describe the contribution of each critical event's score to the difference of the composite score from the model.

Using the one-sample t-test to describe the difference in performance between each participant and the model does not violate the single subject design. The statistical procedure was not used to make comparisons between participants or generalizations about the population.

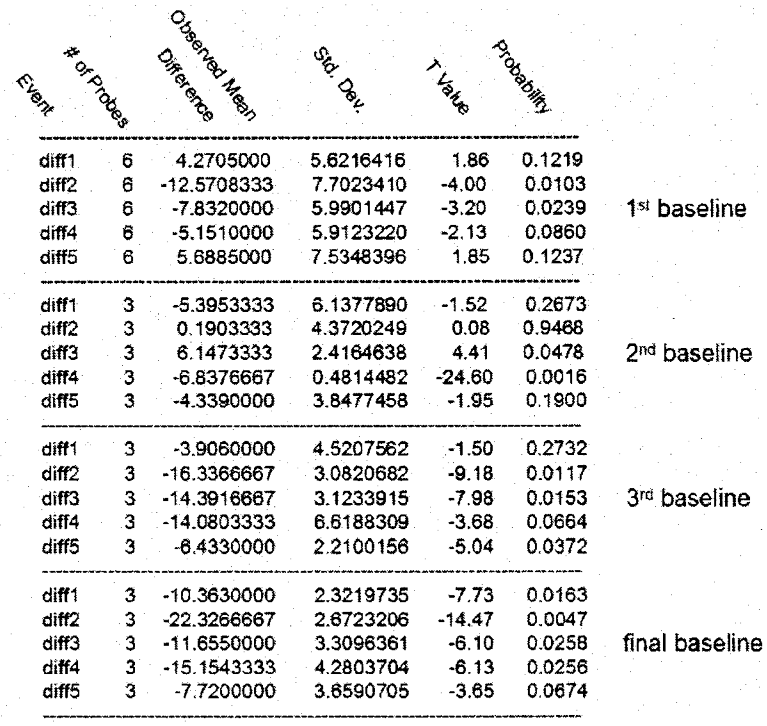
Equation 3: T-test formula

$$t = \frac{\overline{X}_{obs} - \overline{X}_{exp}}{\frac{s}{\sqrt{n}}}$$

A t-test for independent samples was used for each subject, independently, to compare the expected score demonstrated by the VPG model, against each of the following average critical event scores (for participants 2, 3, and 4):

1. the average critical event score at the baseline,
   - *where the average baseline score is comprised of 5 critical event scores*
2. the average critical event score following intervention 1&2,
   - *where the average score following intervention 1&2 is comprised of 2 critical event scores*
3. the average critical event score following the final intervention
   - *where the average score following the final intervention is comprised of 4 critical event scores*

Figure 14 illustrates the SAS® output for Participant 1 which highlights the computation of mean, standard deviation and t-score for each baseline.



Event	# of Probes	Observed Mean Difference	Std. Dev.	T Value	Probability	
diff1	6	4.2705000	5.6216416	1.86	0.1219	
diff2	6	-12.5708333	7.7023410	-4.00	0.0103	
diff3	6	-7.8320000	5.9901447	-3.20	0.0239	1st baseline
diff4	6	-5.1510000	5.9123220	-2.13	0.0860	
diff5	6	5.6885000	7.5348396	1.85	0.1237	
diff1	3	-5.3953333	6.1377890	-1.52	0.2673	
diff2	3	0.1903333	4.3720249	0.08	0.9468	
diff3	3	6.1473333	2.4164638	4.41	0.0478	2nd baseline
diff4	3	-6.8376667	0.4814482	-24.60	0.0016	
diff5	3	-4.3390000	3.8477458	-1.95	0.1900	
diff1	3	-3.9060000	4.5207562	-1.50	0.2732	
diff2	3	-16.3366667	3.0820682	-9.18	0.0117	
diff3	3	-14.3916667	3.1233915	-7.98	0.0153	3rd baseline
diff4	3	-14.0803333	6.6188309	-3.68	0.0664	
diff5	3	-6.4330000	2.2100156	-5.04	0.0372	
diff1	3	-10.3630000	2.3219735	-7.73	0.0163	
diff2	3	-22.3266667	2.6723206	-14.47	0.0047	
diff3	3	-11.6550000	3.3096361	-6.10	0.0258	final baseline
diff4	3	-15.1543333	4.2803704	-6.13	0.0256	
diff5	3	-7.7200000	3.6590705	-3.65	0.0674	

Figure 14: SAS® output for Participant 1

Raw Data Analysis

The purpose of the t-test was to describe the average difference of the participant from the model at each event of the swing for a given baseline. It is possible for the observed score to be close to the expected score and still produce poor performance of the movement. The direction of movement through each event is important to analyze. If a joint moves through the correct angle at a critical event but is opening instead of closing the t-test analysis may be misleading. To describe the motion pattern, or the direction of motion through each critical event, the raw data was analyzed. The motion pattern of the VPG model served as the reference of "correct" movement and was the basis for comparison of the participants.

Results and Discussion

The purpose of this study was to determine whether the VPG learning system was a valid tool for teaching and learning the golf swing. Participants were given a series of lessons prescribed by VPG. A golf log was recorded to monitor the participants' golf activity outside of the experiment. Since the experiment took place in October and November none of the participants played or practiced golf at any time during the experiment other than what was outlined in the methods. There was also no change in any of the participants' health, diet or exercise regimen.

Six key variables were monitored for change throughout the study to evaluate whether the participants learned a new coordination pattern from the lessons. There was a difference in performance changes between participants 1-3 (absolute beginner) and participants 4 and 5 (advanced beginner). Participants 1-3 gained external information that helped them increase their range of motion where participants 4 and 5 showed very little change throughout the study. Although participants 1-3 showed similar changes in range of motion, the way they accomplished the change was not consistent among any of them. Inter individual differences explain the discrepancy between all participants and lend support for the single subject design methodology.

KSD Movement Signature

The single subject data was visually analyzed in order to describe the change in performance of the participants. There were observable differences seen between the absolute beginner participants (participants 1, 2 and 3) and the more advanced beginner participants (participants 4 and 5). Although the more advanced beginner participants were still very limited in their golfing knowledge and experience, the difference in experience was enough to distinguish their performance characteristics from the other three participants. The absolute beginner participants gained information from the demonstration that allowed them to increase their range of motion. An increase in range of motion was seen because the participants attended to the distal movements of the model and tried to reproduce the range of motion of the model. Demonstration was more useful to the absolute beginner participants than the more advanced participants because the absolute beginners did not have an existing "blueprint" of the coordination pattern; participants 4 and 5, whether right or wrong, likely had an already existing coordination pattern (Scully & Newell, 1985). Although these participants gained information from the demonstration, the information only related to the motion of distal segments. Information regarding the correct proximal motion pattern was not gained because the VPG model did not have a KSD signature. All three beginner participants showed more lateral trunk translation than the model. Had the demonstration used biological motion the participants may have been able to infer proximal movements (Runeson, 1994). Using such a demonstration would have likely allowed the participants to show the same increase in range of motion but with less lateral motion. Table 1 illustrates the difference in head translation between the absolute beginner participants and the VPG model.

Table 1

Linear head displacement of absolute beginner participants at final probe

	Linear Head Displacement (cm)			
	Model	Participant 1	Participant 2	Participant 3
Event 2	0.013	0.115	0.040	0.078
Event 3	0.064	0.211	0.069	0.163
Event 4	0.044	0.089	0.018	0.060
Event 5	0.054	0.063	0.006	0.028

Participants 1 and 3 showed more displacement away from the target than the model during the backswing (critical events 2 and 3). Participant 2 showed more displacement toward the target during the downswing (critical events 4 and 5).

Performance Stability

From the analysis of the single subject data, each of the participants showed stable performance, on most variables, after the final intervention when the augmented information was removed (see Figures 15-19). Since performance did not decline in the absence of augmented feedback the participants were not dependent on the model. The final baseline measurements were taken over a two week period during which the participants were not given augmented feedback about their performance. According to the literature (Schmidt, 1988), this length of time is adequate to say that a relatively permanent change in the capability of responding has taken place and therefore, learning has occurred. This learning effect can be attributed to the relevance of the information gained from concurrent visual feedback. The participants received feedback on several sensory channels, which has been shown to facilitate performance in acquisition with KR and transfer with no KR (Adams, 1971; Schmidt, 1975).

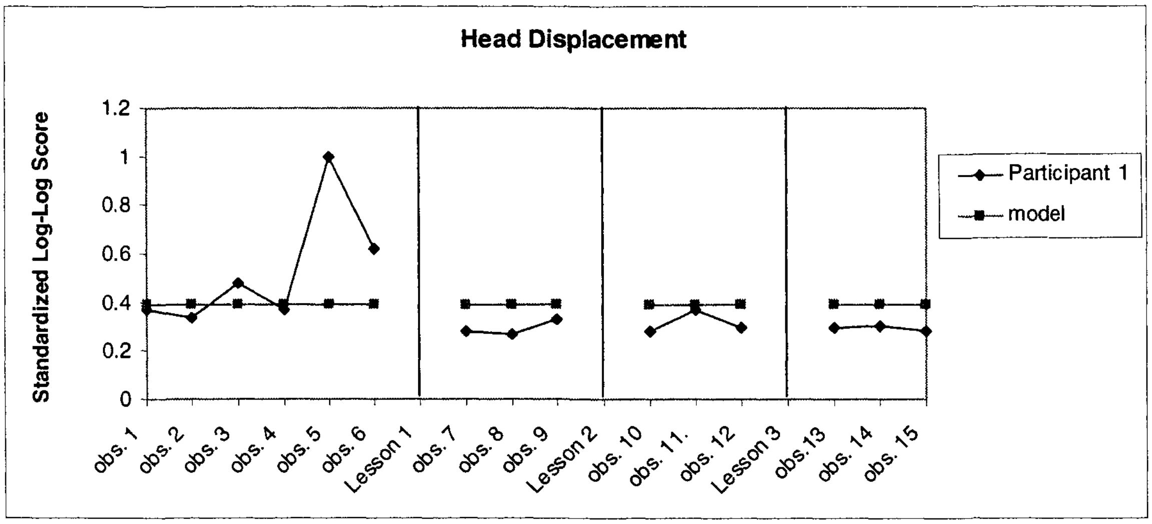


Figure 15: Performance stability after first intervention

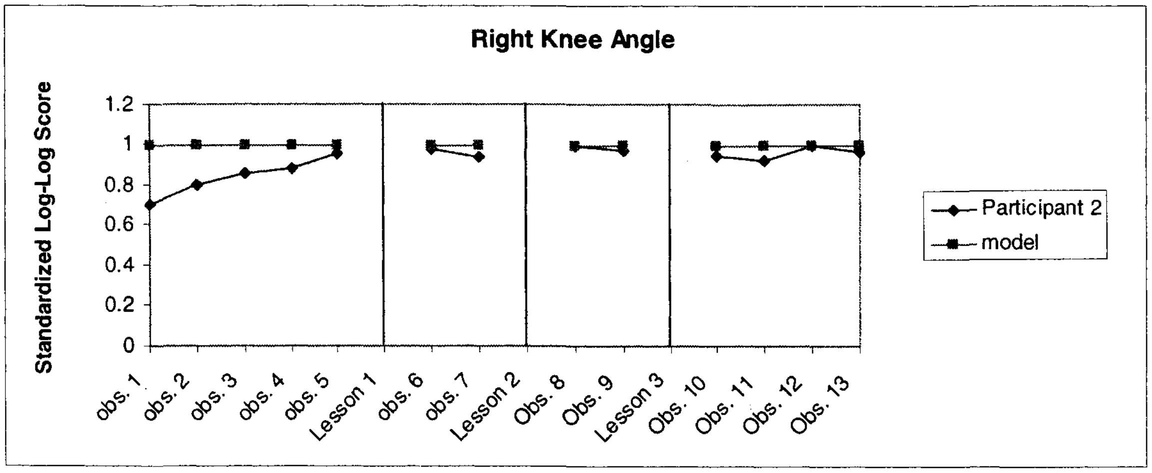


Figure 16: Performance stability after first intervention

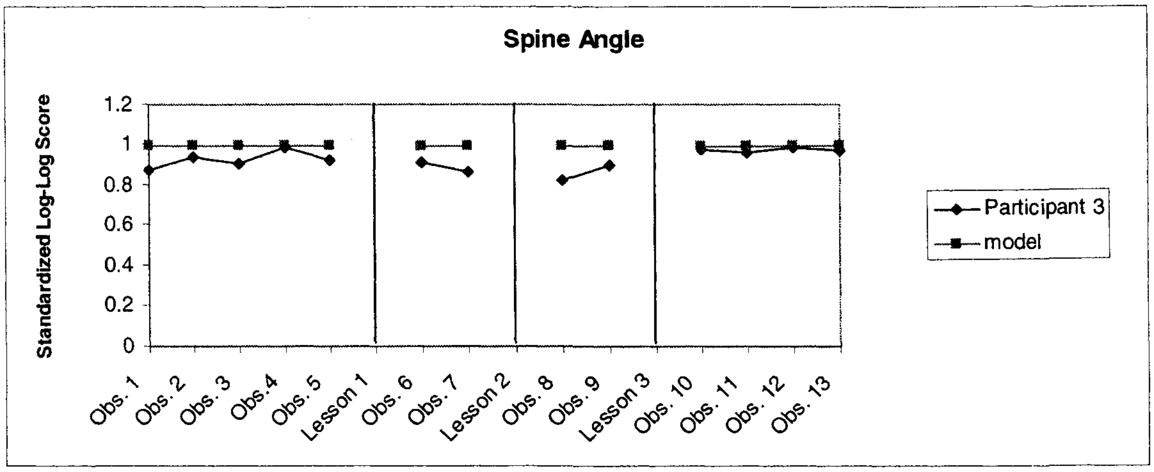


Figure 17: Performance stability after final intervention

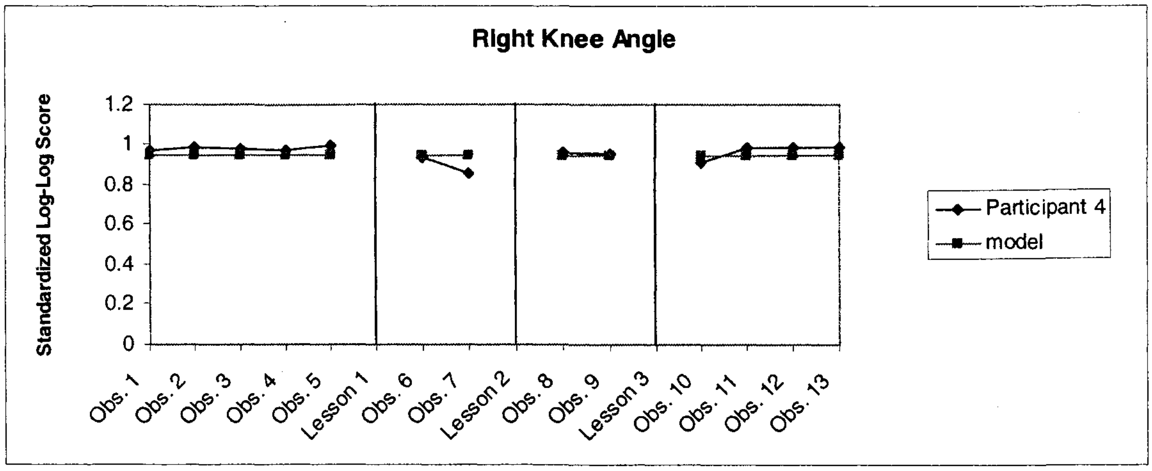


Figure 18: Performance stability throughout experiment

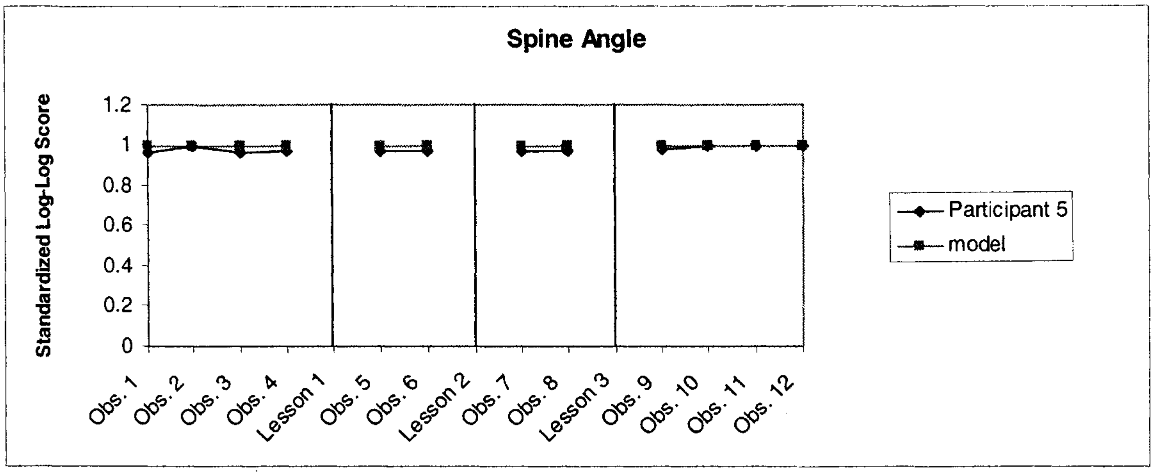


Figure 19: Performance stability throughout experiment

Left Wrist Speed at Contact

The magnitude of left wrist speed increased after the final intervention for all three beginner participants (see Figures 19-21). Visual analysis of the mean and level demonstrates the change in speed. The increase in left wrist speed at contact may be attributed to the increase in range of motion. An increase in the range of motion increases the impulse of the downswing allowing the club head to accelerate for a longer period of time. Although the beginner participants did not match the motion pattern of the model for spine angle and head displacement, the participants did approach the motion pattern of the model as their left wrist speed increased. These participants likely would have shown left wrist speeds closer to the model if they learned the proper proximal movements.

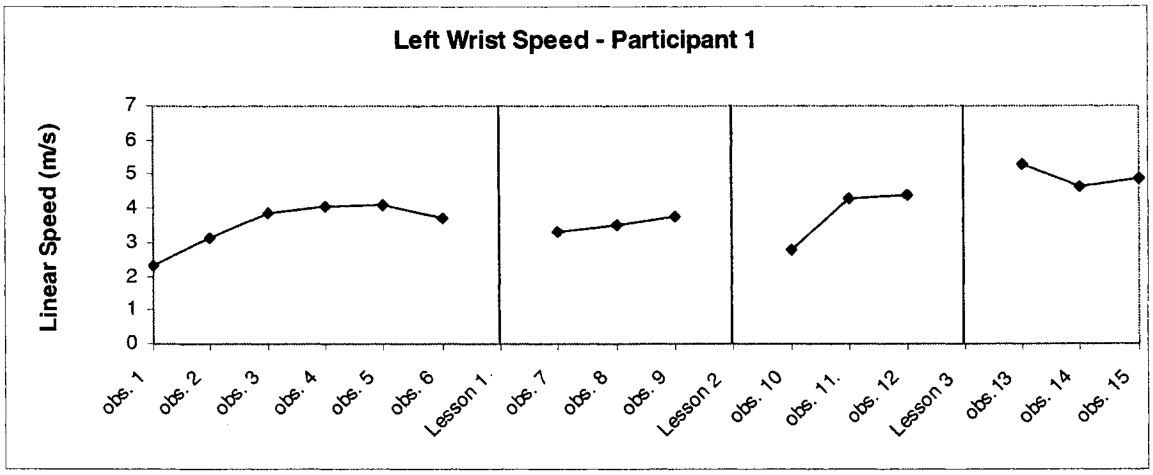


Figure 20: Increase in left wrist speed after final intervention

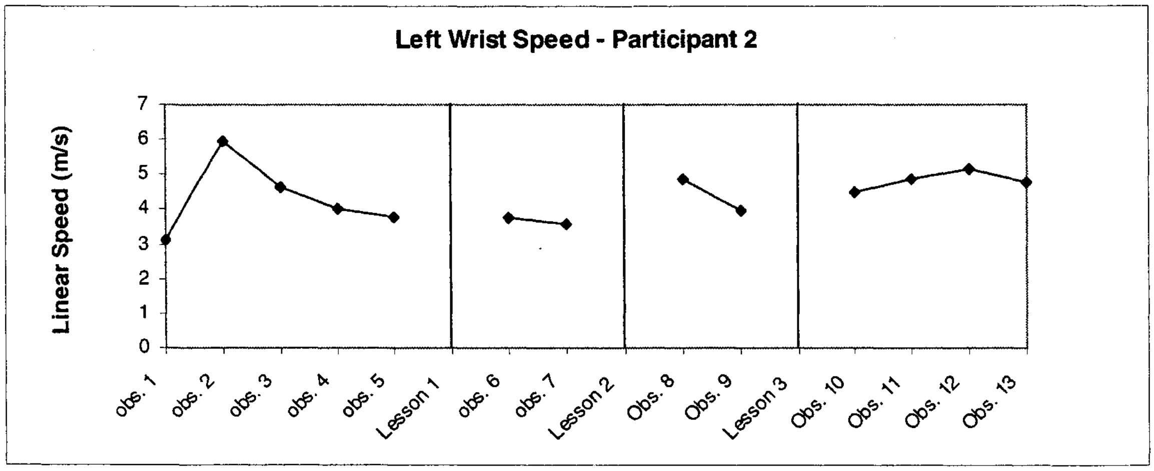


Figure 21: Increase in left wrist speed after second intervention

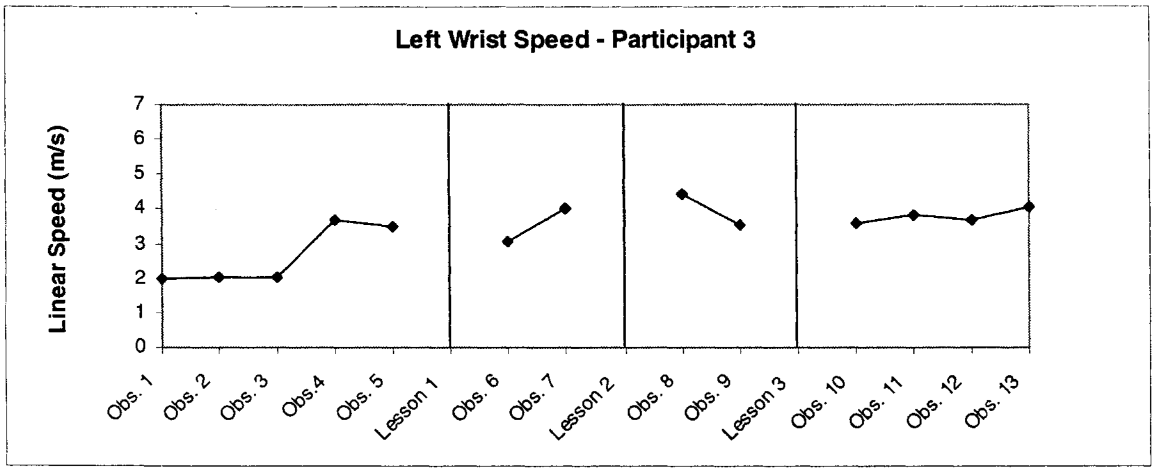


Figure 22: Increase in left wrist speed after first intervention

Inter-Participant Variability

Observed changes in performance were inconsistent among the participants and across all variables. All participants showed improvements in certain variables at certain times in the experiment but there was no consistency in the time of the change or the variable that changed. According to the literature the participants should have approached the performance of the model for every variable measured in the presence of a demonstration and concurrent knowledge of performance (Al-Abood et al. 2001; Magill & Schoenfelder-Zohdi, 1996; Richardson & Lee, 1999; Salmoni, Schmidt & Walter, 1984; Swinnen, Jardin & Meulenbroeck, 1996). However, the findings of the motor learning literature are based on group designs and may not be inferable to the results found using the single subject design of the current study. The inconsistency of the results shows that the individuals in the study used the available information differently. Results generated using group designs may mask the variability of the individuals within the groups by comparing group means. It is also possible that the constraints of kinematic analysis prevented inadequate number of probes. This will be discussed later in the results.

2-D Videography

A limitation of this study is the analysis of only those variables which could be generated using 2-D videography. 2-D videography was selected because the VPG model was two dimensional. This method allowed for direct comparisons of the participants to the model and allowed for use of the company's cameras. Two dimensional video analysis does not allow for the analysis of variables that are rotating in more than one plane. Changes more consistent with the literature (Adams, 1971; Magill & Schoenfelder-Zohdi, 1996; Newell, 1991; Scully & Carnegie, 1998) may have been found if variables that could measure motion in several planes had been selected for analysis. Variables such as hip and shoulder rotation and path of the club may be more representative of the overall performance of the movement. The path of the club would be the ultimate dependent variable and the relationship between other rotating segments would contribute to the motion of the club. In this study, it was important to compare the performance of the participants to the model to know what information was learned directly from viewing the model. The selected variables were intended to represent advanced golf swing kinematics and if the participants were improving their golf swing it was expected that they would begin to show more advanced swing kinematics.

Advanced Swing Characteristics

Participants 1-3 did not approach the motion pattern of the model for spine angle and head displacement. However, after analyzing the motion pattern of the model, the behaviour of the spine angle and the displacement of the head seem to be reactions to high club head speed to keep the body balanced. Spine angle in the lateral view became more vertical as the model approached the critical instant of contact. The changing spine angle is a reaction to the centrifugal force at contact. The centrifugal force at contact acts on the body by pulling it anteriorly. To keep from falling forward the model must move its centre of mass posteriorly. Posterior movement is accomplished by decreasing the spine angle relative to vertical. The data presented in Table 2 highlights the motion pattern of the VPG model compared to the absolute beginner participants. Another balance manipulation by the model is a slight head translation away from the target at contact. In addition to the centrifugal force pulling the model anteriorly at contact, linear momentum pulls the model toward the target at contact. To keep the centre of mass within the base of support without reducing club head speed the model moves its head in the opposite direction of the moving club head at contact. The motion pattern of the spine angle and head displacement are considered advanced swing characteristics because they are reactions to a very high club head speed. High club head speed must be reached by sequencing the proximal and distal segments properly. The absolute beginner participants begin limb sequencing with correct proximal movement and should not have been expected to approach the motion patterns of these variables since they did not achieve significantly high enough club head speed. Their left wrist speeds were measured and did not match the speed of the model, so these centre of mass manipulations were not necessary to remain in balance. When using advanced swing kinematics as a measure of performance for novice golfers the variables should be carefully examined to ensure that they are not dependent on club head speed.

Table 2

Spine angle of absolute beginner participants at final probe.

	Spine Angle (degrees relative to vertical)			
	Model	Participant 1	Participant 2	Participant 3
Event 1	40.018	38.587	30.476	35.735
Event 2	40.025	35.956	20.614	35.921
Event 3	38.974	30.577	10.239	26.363
Event 4	35.275	40.587	22.738	33.157
Event 5	29.347	40.121	22.209	30.817

All three participants' spine angles reach most vertical position at critical event 3.

Design Constraints based on Quantitative Kinematic Analysis

A limitation of the current study was the number of probes that could be incorporated to establish both the baseline and the performance following intervention. The ideal situation would have been to probe until a consistent level of performance or consistent level of performance variability was seen before giving the participant the intervention. Time limitations for both the participants and the researcher called for a less robust protocol for evaluating the VPG learning system. Data from one probe took approximately 3hrs to digitize, with 66 probes in the experiment the time spent digitizing was close to 200 hrs. Instead of waiting for stability in each of the variables, the researcher delivered the intervention once stability was observed for the majority of the variables. The assessment was applied individually to the analysis of each of the participants. No extra probes other than what were outlined in the methods were needed based on this performance criterion.

Assessment of the Therapeutic Criterion

Based on the quantitative analyses conducted in this study, the VPG system resulted in a number of changes in the technique of beginner golfers. A qualitative assessment of the intervention suggests that the VPG system is also a practical and relatively efficient method for delivering golf instruction. Students are able to book VPG lessons at their convenience with their choice of instructor. There are several VPG facilities across Ontario and many more facilities using the VPG hardware. This makes it easy for a student to find a nearby location that offers the VPG methodology and/or hardware. The system seems to increase the motivation of the student which will increase the amount of golf the student plays and lead to improved performance. The system is not invasive, the participants in this study were comfortable with the VPG methodology and enjoyed participating in the study.

Conclusions

The results of this research study have contributed to the understanding of how we learn complex motor tasks, how the body behaves during the golf swing and what types of information aid in motor learning. Although learning is not directly observable, learning can be inferred through relatively permanent changes in behaviour. Through the use of repeated probes, the single subject data shows that learning has occurred. As demonstrated by the data, the learning effect can be attributed to the relevance of the information gained from concurrent visual feedback.

While the use of single subject design presented some challenges, the results did highlight the necessity for future research in motor learning to focus on how individuals, rather than just groups, respond in certain learning situations. The following conclusions were drawn from the analysis of the changes in selected kinematic variables:

1. The absolute beginner participants gained distal information from the demonstration. The information from the demonstration was more relevant for these participants because they did not have an already existing movement pattern of the golf swing. The participants did not infer the proximal movements of the VPG model because the demonstration did not have a KSD signature.

2. All participants showed stability across most of the variables after the final intervention. The performance was stable in the absence of augmented feedback for long enough to conclude that the participants did learn a more effective movement pattern. The participants also did not become dependent on the augmented information given during intervention sessions.

3. The inter-participant variability suggests that learning is dependent on the individual and more research on motor learning using the single subject design needs to be conducted to determine whether the findings in the literature can be used to describe individuals.

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Appendix A

Consent Form

I _______________________ have read and understand the cover letter of the study entitled "Analysis of the Change in Golf Swing Kinematics Associated with Learning" being conducted by Peter Lamb and agree to participate. I also understand that I will not be at any risk greater than what is associated with swinging a golf club and the researchers may not be held liable in the event of an injury.

____

Name of Participant Signature Date

____

Name of Witness Signature Date

I have explained the nature of the study to the participant and feel he/she has understood it.

____

Name of Researcher Signature Date

Appendix B

Participant Information

Name: ____

Age: ____________________ Sex: ____________________

Height: __________________ Weight: __________________

Handicap Index: ___________ Years Golfing: ____________

How many times per week do you play or practice golf (average)? ________

How much time do you spend practicing per practice session (average)? ___

____

How often do you exercise? ____

Are you on an exercise program? If so, explain ________________________

____

____

____

Appendix C

Golf Log

Date: ______________________

Current handicap index: ____________

Number of rounds played: ____________ (see scoring sheet)

Time spent practicing - full shots: ________________
- putting: ________________
- chipping: ________________
- other: ________________

____

____

Have you received any additional instruction? ________________

Are there any swing changes you have been trying to make outside of this study?

____

Has there been a significant change in your diet? If yes, explain.

____

____

____

____

____

____

Have you changed your exercise regimen? If yes, explain.

____

____

____

____

____

____

Have you been ill or injured since the last observation session? If yes, explain

____

____

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____

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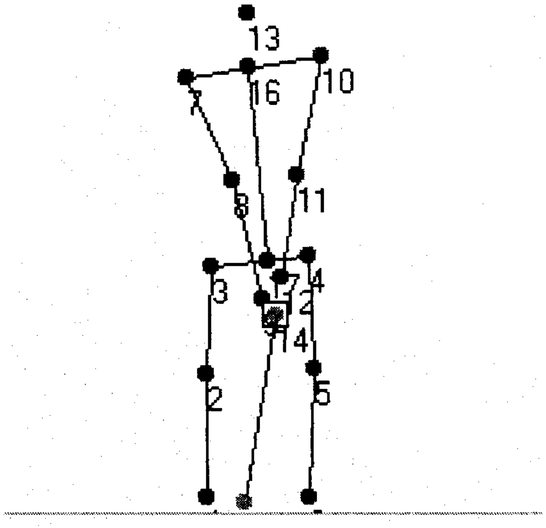
Appendix D

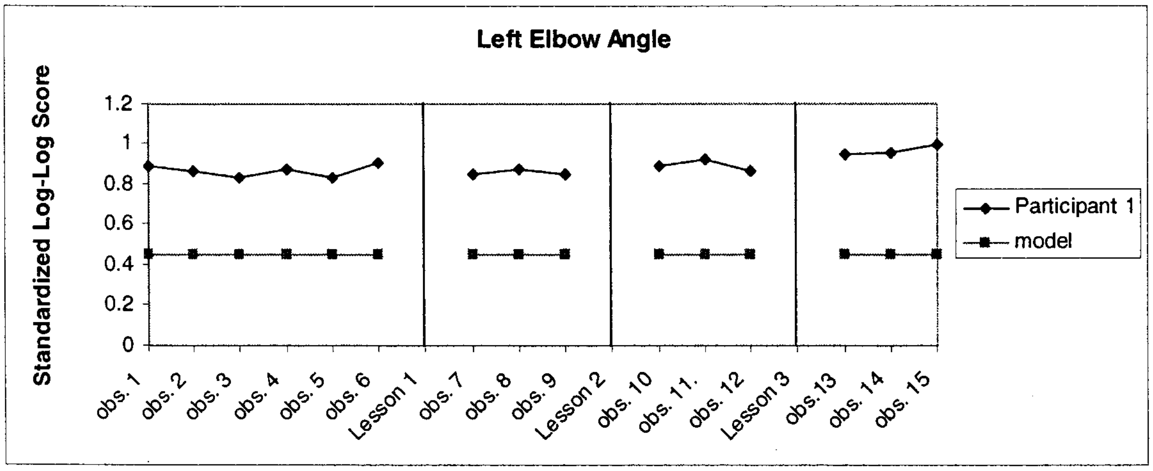
Spatial Model



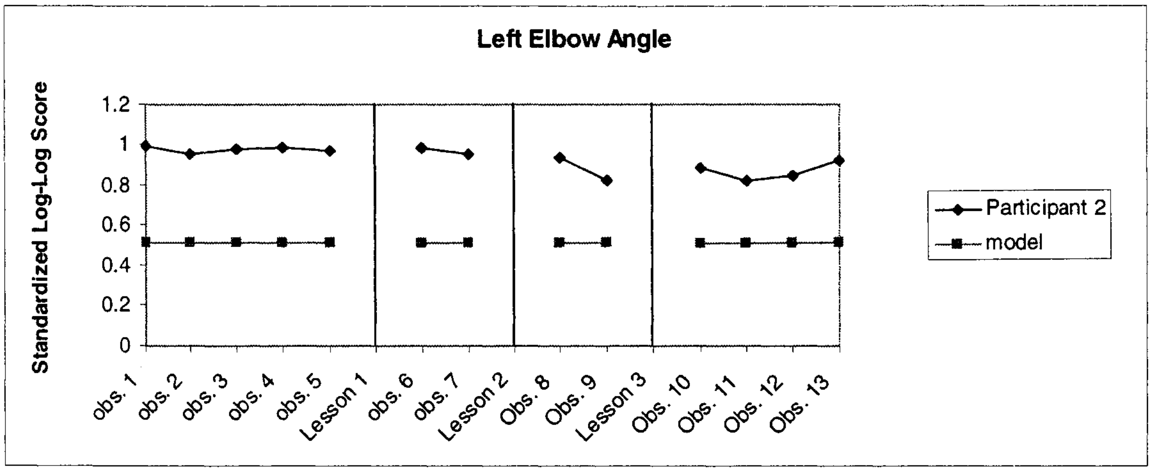
Appendix E

Results

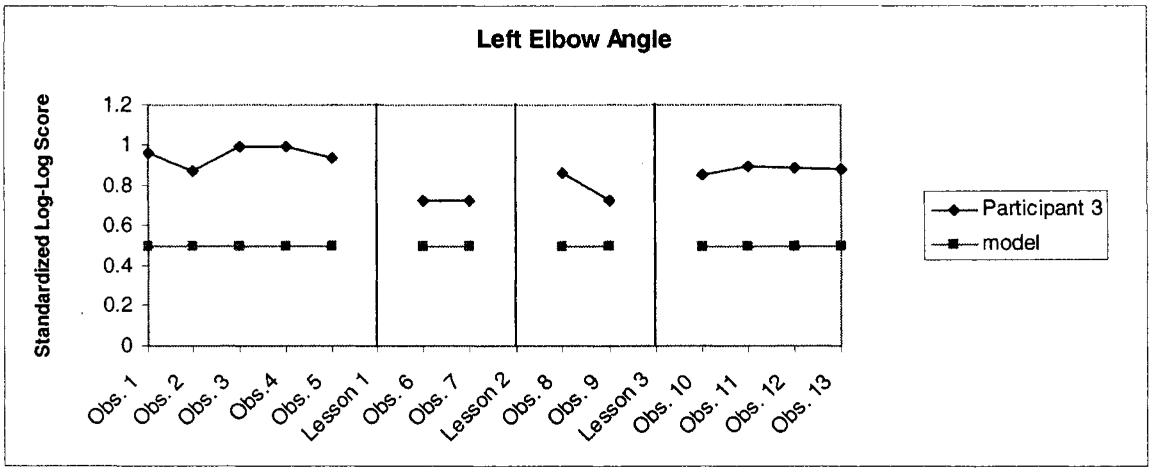
No changes in health or fitness were reported by any of the participants throughout the experiment. None of the participants played or practiced golf at any time outside of the experiment.



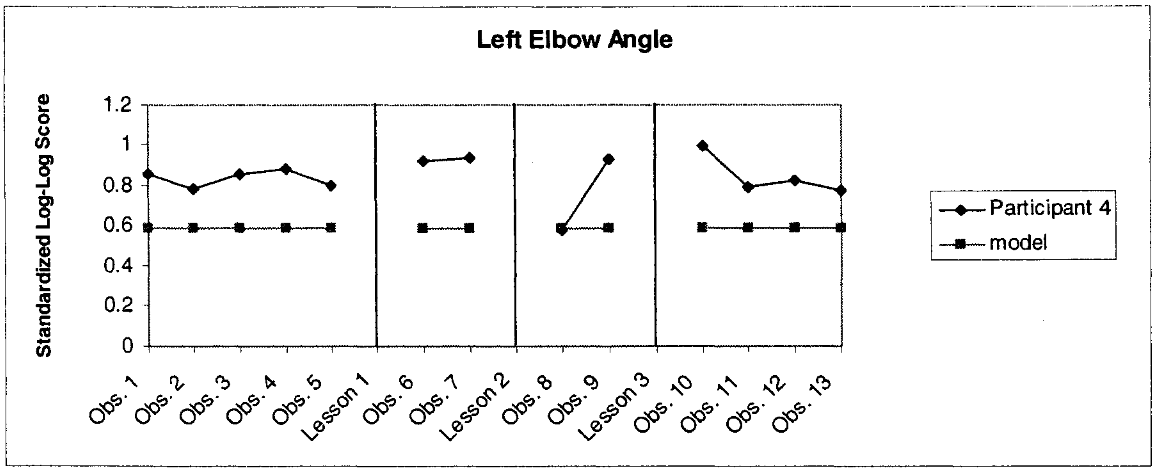
```
Variable      N            Mean          Std Dev     t Value    Pr > |t|
-------------------------------------------------------------------------
 diff1        6     -32.0753333       2.1359163      -36.78      <.0001
 diff2        6     -14.9371667       3.4705142      -10.54      0.0001
 diff3        6      -4.0188333       2.7613874       -3.56      0.0161
 diff4        6     -15.4173333       4.7385069       -7.97      0.0005
 diff5        6     -43.6271667       5.9826124      -17.86      <.0001
-------------------------------------------------------------------------
 diff1        3     -30.8436667       7.9647436       -6.71      0.0215
 diff2        3      -9.0536667       4.7243207       -3.32      0.0800
 diff3        3      -1.1923333       3.1896320       -0.65      0.5837
 diff4        3     -16.8520000       2.1570695      -13.53      0.0054
 diff5        3     -41.9923333       2.7408293      -26.54      0.0014
-------------------------------------------------------------------------
 diff1        3     -23.4860000       4.2634975       -9.54      0.0108
 diff2        3      -8.5706667       0.9612795      -15.44      0.0042
 diff3        3     -12.9266667       8.6696835       -2.58      0.1229
 diff4        3     -21.2930000       4.6100283       -8.00      0.0153
 diff5        3     -41.8313333       2.6652216      -27.18      0.0014
-------------------------------------------------------------------------
 diff1        3     -22.9813333       6.2613965       -6.36      0.0239
 diff2        3     -15.8790000      10.1742409       -2.70      0.1139
 diff3        3     -49.3323333       4.3142462      -19.81      0.0025
 diff4        3     -25.5573333       3.0457305      -14.53      0.0047
 diff5        3     -50.4803333       5.3622069      -16.31      0.0037
```



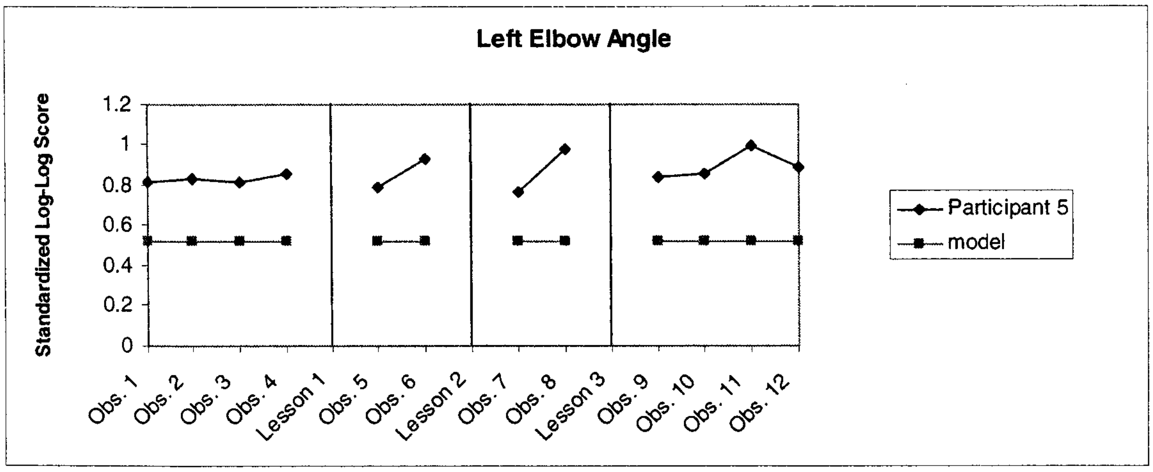
```
Variable      N           Mean          Std Dev     t Value    Pr > |t|
------------------------------------------------------------------------
 diff1        5      0.1140000        6.9612109        0.04      0.9725
 diff2        5    -10.2260000        5.0420693       -4.54      0.0105
 diff3        5    -64.6442000        6.8536162      -21.09      <.0001
 diff4        5    -14.3812000        3.7373108       -8.60      0.0010
 diff5        5    -19.4376000        1.5729794      -27.63      <.0001
------------------------------------------------------------------------
 diff1        2     -1.6355000        2.9196439       -0.79      0.5735
 diff2        2     -9.8980000        6.5110392       -2.15      0.2772
 diff3        2    -72.4600000        8.0511178      -12.73      0.0499
 diff4        2    -13.6375000        1.5068446      -12.80      0.0496
 diff5        2    -18.2060000        3.5185633       -7.32      0.0865
------------------------------------------------------------------------
 diff1        2     -4.4455000        3.8049416       -1.65      0.3465
 diff2        2     -6.9240000        7.6579664       -1.28      0.4225
 diff3        2    -68.0655000        5.4086598      -17.80      0.0357
 diff4        2     -9.0930000        2.3886067       -5.38      0.1169
 diff5        2    -10.6990000        9.6279659       -1.57      0.3608
------------------------------------------------------------------------
 diff1        4     -8.6020000        2.3852241       -7.21      0.0055
 diff2        4     -8.5810000        4.5601065       -3.76      0.0328
 diff3        4    -51.1522500       11.1281878       -9.19      0.0027
 diff4        4     -6.7112500        5.6738037       -2.37      0.0989
 diff5        4    -10.9045000        4.0087871       -5.44      0.0122
------------------------------------------------------------------------
```



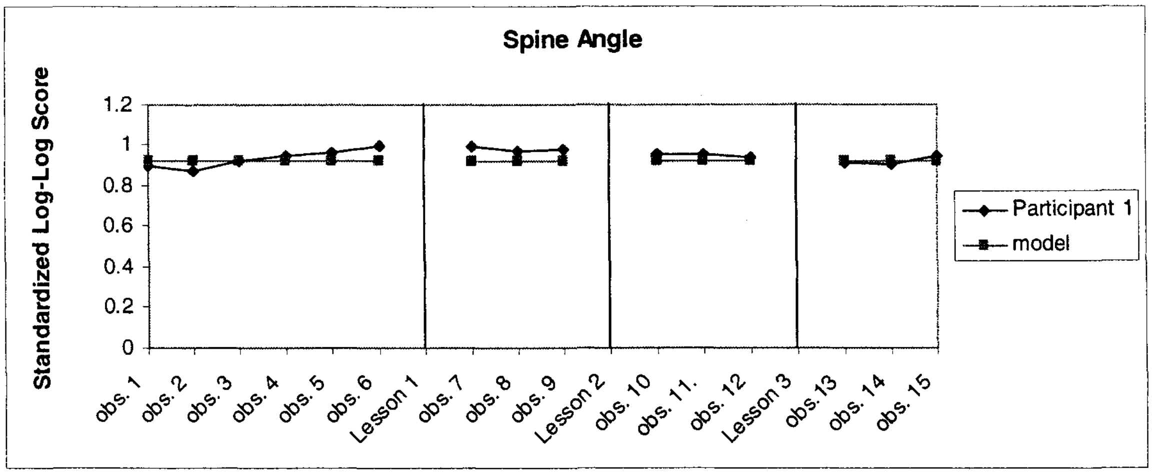
```
Variable      N          Mean          Std Dev     t Value    Pr > |t|
----------------------------------------------------------------------
  diff1       5   -24.9832000        3.8377996      -14.56      0.0001
  diff2       5   -14.3104000        5.0139266       -6.38      0.0031
  diff3       5    -7.5958000        7.2522210       -2.34      0.0792
  diff4       5   -15.3554000        6.7235792       -5.11      0.0069
  diff5       5   -40.4242000        5.8425397      -15.47      0.0001
----------------------------------------------------------------------
  diff1       2    -6.6665000        1.8632264       -5.06      0.1242
  diff2       2     7.0735000        5.0706627        1.97      0.2987
  diff3       2     2.3615000        5.1951135        0.64      0.6363
  diff4       2     0.8945000        3.5885669        0.35      0.7842
  diff5       2   -21.8500000        2.2613275      -13.66      0.0465
----------------------------------------------------------------------
  diff1       2   -10.1490000        7.7993878       -1.84      0.3169
  diff2       2    -0.2520000        2.4494179       -0.15      0.9080
  diff3       2   -46.6400000       11.1666303       -5.91      0.1068
  diff4       2    -1.0025000        6.7196357       -0.21      0.8676
  diff5       2   -11.7520000        4.6923606       -3.54      0.1752
----------------------------------------------------------------------
  diff1       4   -16.7750000        4.2720989       -7.85      0.0043
  diff2       4    -5.7005000        3.9826846       -2.86      0.0644
  diff3       4   -35.0335000       13.0695064       -5.36      0.0127
  diff4       4    -6.5947500        1.9686859       -6.70      0.0068
  diff5       4   -19.2262500        4.9171625       -7.82      0.0044
----------------------------------------------------------------------
```



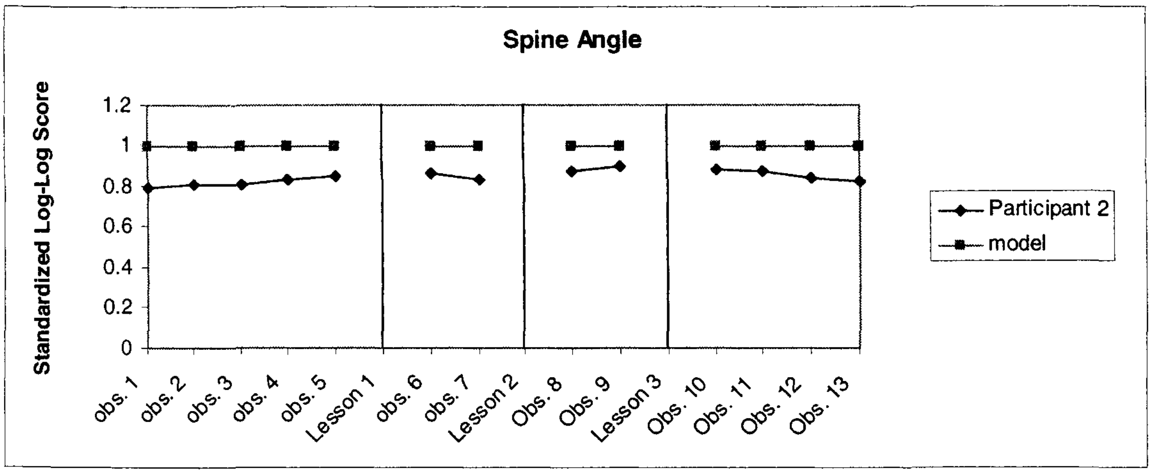
```
Variable      N            Mean          Std Dev      t Value      Pr > |t|
-----------------------------------------------------------------------------
diff1         5       9.1314000        1.0295564        19.83        <.0001
diff2         5       7.4092000        3.0901621         5.36        0.0058
diff3         5     -15.8184000        3.1558637       -11.21        0.0004
diff4         5      -1.1576000        2.0929487        -1.24        0.2838
diff5         5      -8.0916000        2.2357865        -8.09        0.0013
-----------------------------------------------------------------------------
diff1         2       9.7315000        1.1518769        11.95        0.0532
diff2         2       1.3390000        1.2346084         1.53        0.3678
diff3         2     -12.1080000        4.6414489        -3.69        0.1685
diff4         2      -2.5730000        3.3700709        -1.08        0.4756
diff5         2     -14.1165000        0.2849640       -70.06        0.0091
-----------------------------------------------------------------------------
diff1         2       5.8065000        1.0839947         7.58        0.0836
diff2         2       5.3000000        5.5578593         1.35        0.4062
diff3         2     -13.2800000       18.3211367        -1.03        0.4921
diff4         2      -8.6460000        3.3743136        -3.62        0.1714
diff5         2      -5.8255000        9.1365267        -0.90        0.5329
-----------------------------------------------------------------------------
diff1         4       5.7970000        2.3300551         4.98        0.0156
diff2         4      10.0927500        4.1866001         4.82        0.0170
diff3         4     -13.0335000        8.2651874        -3.15        0.0511
diff4         4      -1.6362500        4.1696674        -0.78        0.4898
diff5         4     -12.9055000        2.8612716        -9.02        0.0029
-----------------------------------------------------------------------------
```



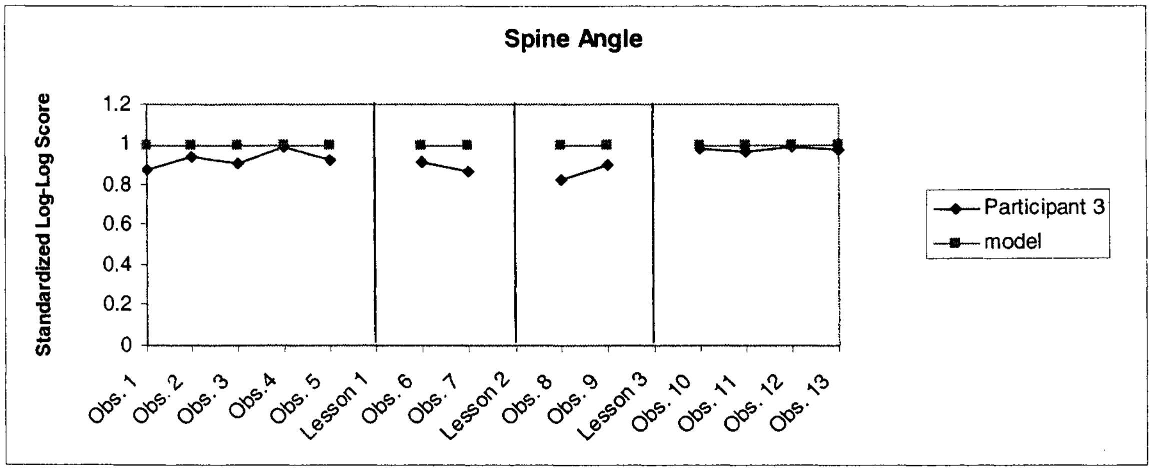
```
Variable     N          Mean         Std Dev     t Value     Pr > |t|
---------------------------------------------------------------------
diff1        4     8.2737500       0.8848730       18.70       0.0003
diff2        4     6.4420000       2.8354965        4.54       0.0200
diff3        4   -44.2920000      13.3053089       -6.66       0.0069
diff4        4   -11.2600000       2.1003963      -10.72       0.0017
diff5        4    -6.9462500       1.8944152       -7.33       0.0052
---------------------------------------------------------------------
diff1        2    -0.0955000       0.1746554       -0.77       0.5810
diff2        2    -0.8505000       3.1162196       -0.39       0.7655
diff3        2   -34.5820000      20.5570083       -2.38       0.2533
diff4        2    -8.5715000       9.4886659       -1.28       0.4228
diff5        2   -10.2595000       3.8657528       -3.75       0.1658
---------------------------------------------------------------------
diff1        2    -1.6085000       9.3896709       -0.24       0.8487
diff2        2    -1.2780000       5.4178522       -0.33       0.7950
diff3        2   -45.3840000      14.2609296       -4.50       0.1392
diff4        2    -5.9870000       2.8991378       -2.92       0.2100
diff5        2   -13.7370000      13.2002694       -1.47       0.3799
---------------------------------------------------------------------
diff1        4    -1.2540000       4.7115930       -0.53       0.6314
diff2        4    -1.9440000       3.8115617       -1.02       0.3828
diff3        4   -54.2807500       8.3269304      -13.04       0.0010
diff4        4    -5.9232500       4.9049851       -2.42       0.0946
diff5        4    -3.7010000       6.7507620       -1.10       0.3530
---------------------------------------------------------------------
```



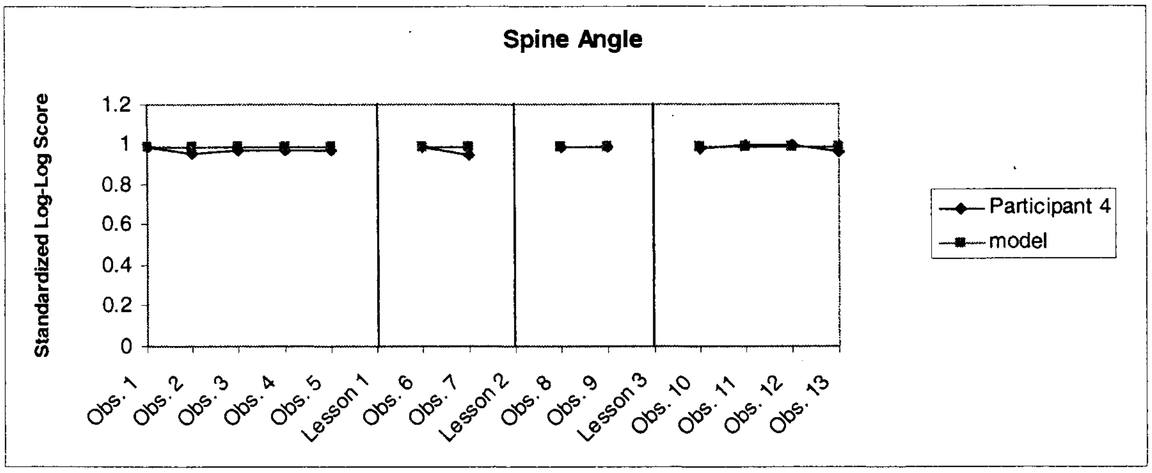
```
Variable     N          Mean         Std Dev     t Value     Pr > |t|
-----------------------------------------------------------------------
diff1        6     4.6925000       2.3244800        4.94       0.0043
diff2        6     7.0925000       5.9844435        2.90       0.0337
diff3        6     4.8380000       7.4992496        1.58       0.1749
diff4        6    -1.7663333       6.5732664       -0.66       0.5395
diff5        6    -8.3218333       5.2697187       -3.87       0.0118
-----------------------------------------------------------------------
diff1        3    -0.8370000       1.4635628       -0.99       0.4263
diff2        3     0.1286667       1.3252235        0.17       0.8819
diff3        3    -0.3760000       3.1273036       -0.21       0.8543
diff4        3   -10.4263333       2.8334815       -6.37       0.0237
diff5        3   -15.6406667       2.7400833       -9.89       0.0101
-----------------------------------------------------------------------
diff1        3    -1.4073333       1.4978372       -1.63       0.2452
diff2        3     0.6290000       2.3274770        0.47       0.6858
diff3        3    10.6913333       2.8502864        6.50       0.0229
diff4        3    -4.4196667       1.7239401       -4.44       0.0472
diff5        3   -14.6426667       3.2542496       -7.79       0.0161
-----------------------------------------------------------------------
diff1        3     2.1776667       0.6742509        5.59       0.0305
diff2        3     6.6763333       2.2687090        5.10       0.0364
diff3        3    14.1040000       4.9694258        4.92       0.0390
diff4        3    -2.9903333       2.0284709       -2.55       0.1252
diff5        3    -9.8580000       0.8477576      -20.14       0.0025
-----------------------------------------------------------------------
```



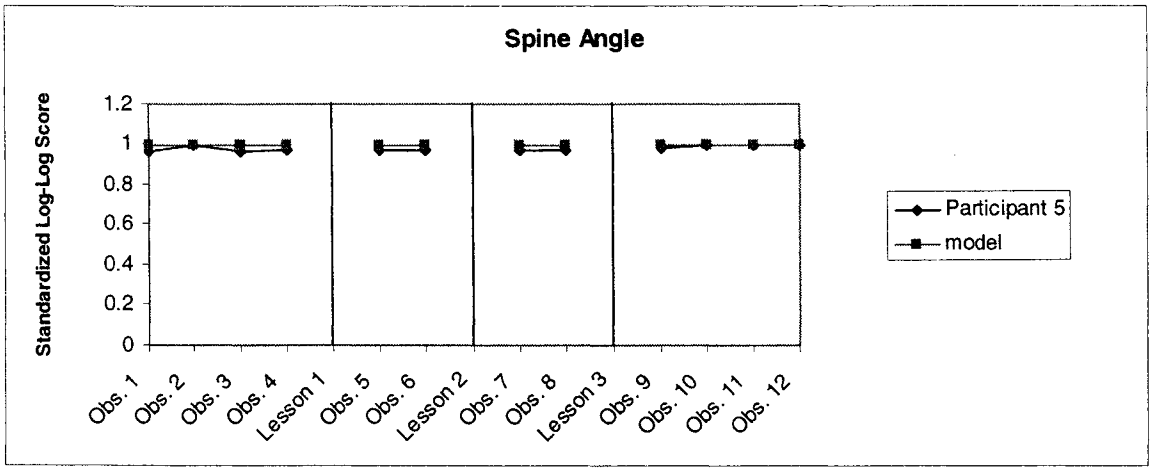
```
Variable      N          Mean        Std Dev    t Value    Pr > |t|
---------------------------------------------------------------------
diff1         5    13.6500000      1.1695114      26.10      <.0001
diff2         5    22.1874000      1.9370934      25.61      <.0001
diff3         5    29.0348000      1.0109385      64.22      <.0001
diff4         5    13.2712000      2.0898176      14.20      0.0001
diff5         5     5.9486000      1.9280547       6.90      0.0023
---------------------------------------------------------------------
diff1         2    12.0965000      1.4347197      11.92      0.0533
diff2         2    18.7825000      0.4292138      61.89      0.0103
diff3         2    29.1485000      0.7304413      56.43      0.0113
diff4         2    10.4180000      1.0394470      14.17      0.0448
diff5         2     4.3315000      0.9835855       6.23      0.1014
---------------------------------------------------------------------
diff1         2     9.5850000      3.3573430       4.04      0.1546
diff2         2    17.5080000      2.1580899      11.47      0.0553
diff3         2    25.9350000      0.3450681     106.29      0.0060
diff4         2     8.2870000      0.1032376     113.52      0.0056
diff5         2    -0.8155000      2.1319269      -0.54      0.6843
---------------------------------------------------------------------
diff1         4     9.2922500      1.4240530      13.05      0.0010
diff2         4    18.4930000      1.4236280      25.98      0.0001
diff3         4    25.3725000      3.1643812      16.04      0.0005
diff4         4    11.8720000      1.7672504      13.44      0.0009
diff5         4     4.7500000      1.8950356       5.01      0.0153
---------------------------------------------------------------------
```



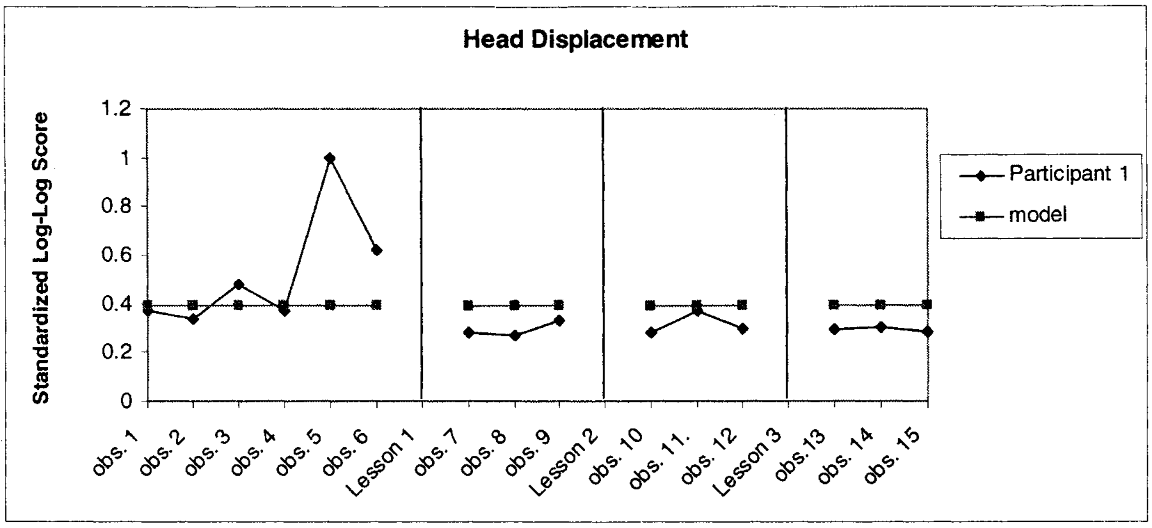
```
Variable     N           Mean        Std Dev    t Value    Pr > |t|
---------------------------------------------------------------------
diff1        5      5.0760000      4.1626159       2.73      0.0526
diff2        5     15.3216000      3.9909906       8.58      0.0010
diff3        5     15.2940000      4.4779293       7.64      0.0016
diff4        5      8.1080000      4.6251993       3.92      0.0173
diff5        5     -0.7642000      5.5601421      -0.31      0.7739
---------------------------------------------------------------------
diff1        2      5.7625000      3.9972746       2.04      0.2903
diff2        2     12.9410000      2.5993245       7.04      0.0898
diff3        2     17.9455000      3.7766573       6.72      0.0940
diff4        2     13.1290000      3.6500852       5.09      0.1236
diff5        2      4.4195000      1.6638223       3.76      0.1656
---------------------------------------------------------------------
diff1        2      8.0105000      1.0769236      10.52      0.0603
diff2        2     14.5800000      1.7309974      11.91      0.0533
diff3        2     25.0165000      6.1101097       5.79      0.1089
diff4        2     13.0735000      3.5206847       5.25      0.1198
diff5        2      3.0625000      2.6410438       1.64      0.3486
---------------------------------------------------------------------
diff1        4      6.6235000      2.1996870       6.02      0.0092
diff2        4      7.3422500      2.1770494       6.75      0.0067
diff3        4     15.0712500      3.8388167       7.85      0.0043
diff4        4      0.5065000      2.3630464       0.43      0.6971
diff5        4     -6.0827500      3.3637239      -3.62      0.0363
---------------------------------------------------------------------
```



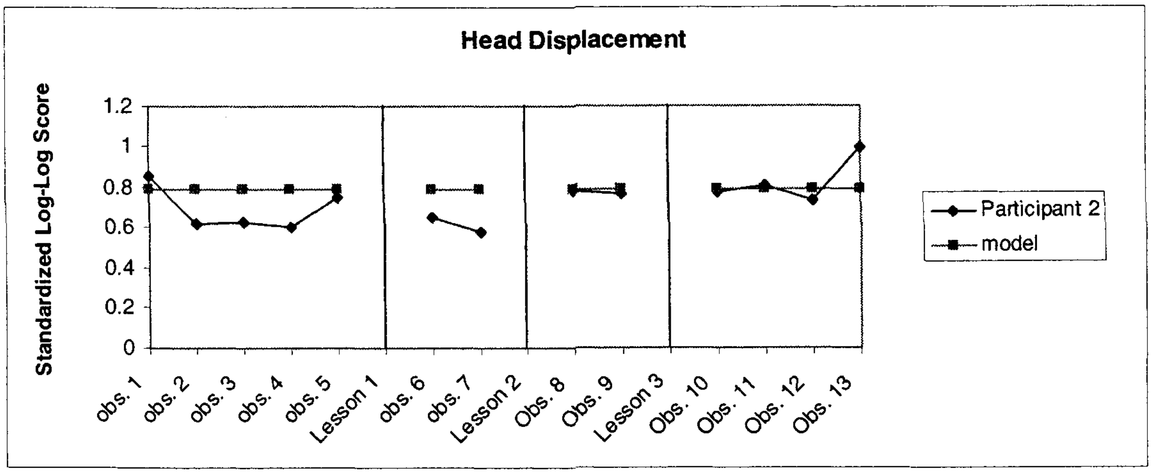
```
Variable      N          Mean        Std Dev    t Value    Pr > |t|
--------------------------------------------------------------------
diff1         5     1.7370000      1.0389959       3.74      0.0202
diff2         5     2.4862000      1.2272991       4.53      0.0106
diff3         5     5.3860000      1.6340763       7.37      0.0018
diff4         5     2.8580000      1.3232815       4.83      0.0085
diff5         5     0.2122000      1.6651320       0.28      0.7898
--------------------------------------------------------------------
diff1         2     2.5970000      2.0124259       1.83      0.3191
diff2         2     0.0760000      2.2146584       0.05      0.9691
diff3         2     3.4235000      2.6014458       1.86      0.3139
diff4         2     2.7195000      3.4330034       1.12      0.4639
diff5         2     1.9050000      3.7900923       0.71      0.6066
--------------------------------------------------------------------
diff1         2    -1.6705000      1.0953084      -2.16      0.2764
diff2         2    -0.3165000      0.7969093      -0.56      0.6742
diff3         2     2.2130000      0.7707464       4.06      0.1537
diff4         2     0.4260000      1.0210622       0.59      0.6606
diff5         2    -1.2575000      0.3429468      -5.19      0.1213
--------------------------------------------------------------------
diff1         4    -0.2177500      0.8659205      -0.50      0.6496
diff2         4    -0.8497500      0.4482896      -3.79      0.0322
diff3         4     3.6015000      2.2162898       3.25      0.0475
diff4         4    -0.0800000      2.5643691      -0.06      0.9542
diff5         4    -0.3077500      2.8949966      -0.21      0.8453
--------------------------------------------------------------------
```



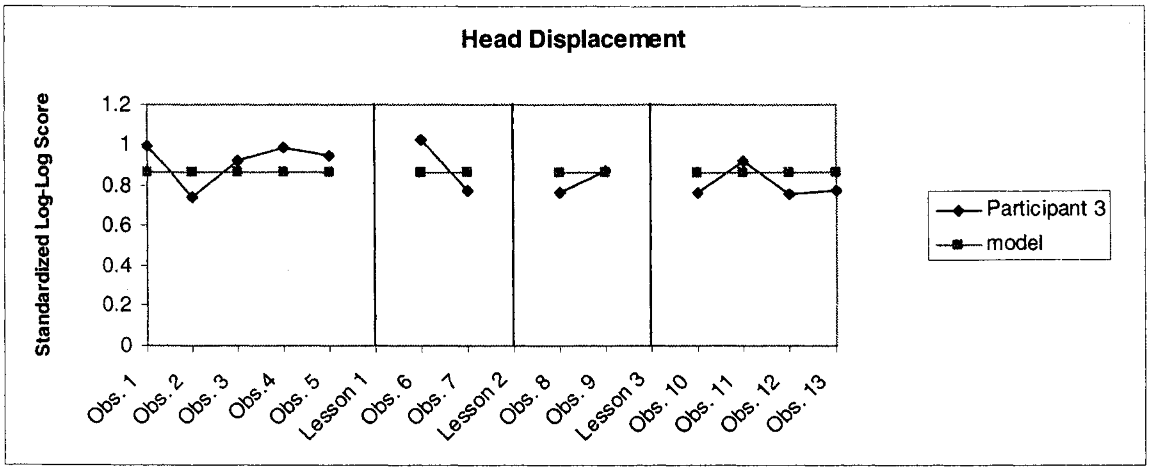
```
Variable      N          Mean        Std Dev    t Value    Pr > |t|
--------------------------------------------------------------------
diff1         4     5.8340000      1.7838320       6.54      0.0073
diff2         4     6.2140000      0.9852638      12.61      0.0011
diff3         4     3.8635000      0.7369046      10.49      0.0019
diff4         4     3.4782500      2.0650984       3.37      0.0435
diff5         4     1.4152500      2.1277493       1.33      0.2755
--------------------------------------------------------------------
diff1         2     6.7800000      0.4553768      21.06      0.0302
diff2         2     5.6025000      2.2662772       3.50      0.1774
diff3         2     3.2735000      1.9933340       2.32      0.2588
diff4         2     3.9205000      0.9383307       5.91      0.1067
diff5         2     2.6985000      1.0514678       3.63      0.1712
--------------------------------------------------------------------
diff1         2     4.3055000      0.6045763      10.07      0.0630
diff2         2     3.9275000      1.1631907       4.78      0.1314
diff3         2     4.0360000      0.9644936       5.92      0.1066
diff4         2     2.9790000      0.6632662       6.35      0.0994
diff5         2     2.1430000      0.4200214       7.22      0.0877
--------------------------------------------------------------------
diff1         4     3.1877500      2.4303154       2.62      0.0788
diff2         4     2.5682500      1.1152774       4.61      0.0192
diff3         4     2.3437500      1.3210045       3.55      0.0381
diff4         4     1.1057500      1.5648470       1.41      0.2525
diff5         4    -0.7475000      1.8090610      -0.83      0.4692
--------------------------------------------------------------------
```



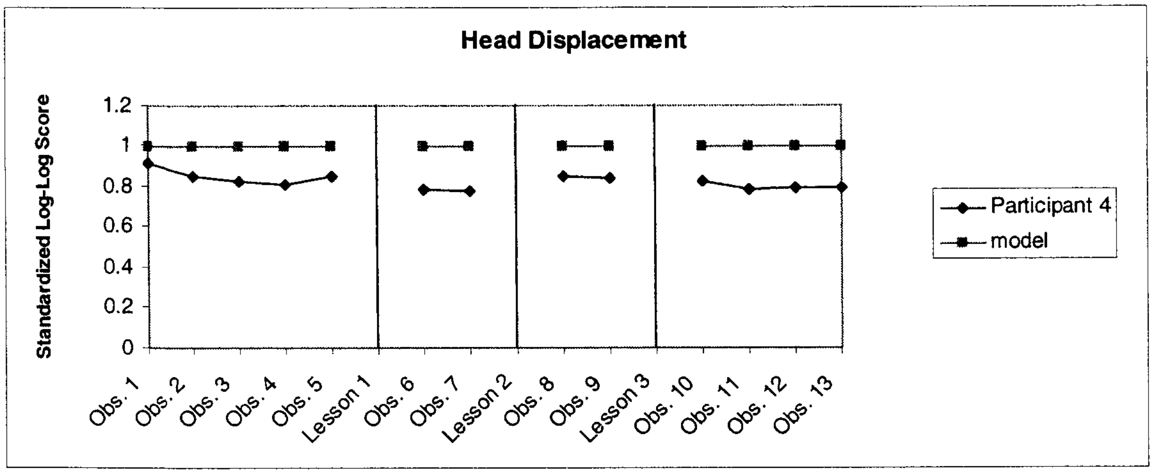
```
Variable      N           Mean        Std Dev    t Value    Pr > |t|
------------------------------------------------------------------------
diff1         6              0              0          .           .
diff2         6     -0.0225000      0.0112205      -4.91      0.0044
diff3         6      0.0248333      0.0255923       2.38      0.0634
diff4         6      0.0205000      0.0351611       1.43      0.2126
diff5         6      0.0265000      0.0387853       1.67      0.1551
------------------------------------------------------------------------
diff1         3              0              0          .           .
diff2         3     -0.0936667      0.0316439      -5.13      0.0360
diff3         3     -0.0810000      0.0317648      -4.42      0.0476
diff4         3     -0.0476667      0.0221886      -3.72      0.0652
diff5         3     -0.0170000      0.0225167      -1.31      0.3211
------------------------------------------------------------------------
diff1         3              0              0          .           .
diff2         3     -0.0586667      0.0120968      -8.40      0.0139
diff3         3     -0.0593333      0.0765789      -1.34      0.3117
diff4         3     -0.0386667      0.0177858      -3.77      0.0638
diff5         3     -0.0116667      0.0153731      -1.31      0.3192
------------------------------------------------------------------------
diff1         3              0              0          .           .
diff2         3     -0.0800000      0.0269072      -5.15      0.0357
diff3         3     -0.1300000      0.0329697      -6.83      0.0208
diff4         3     -0.0363333      0.0077675      -8.10      0.0149
diff5         3     -0.0100000      0.0105357      -1.64      0.2419
------------------------------------------------------------------------
```



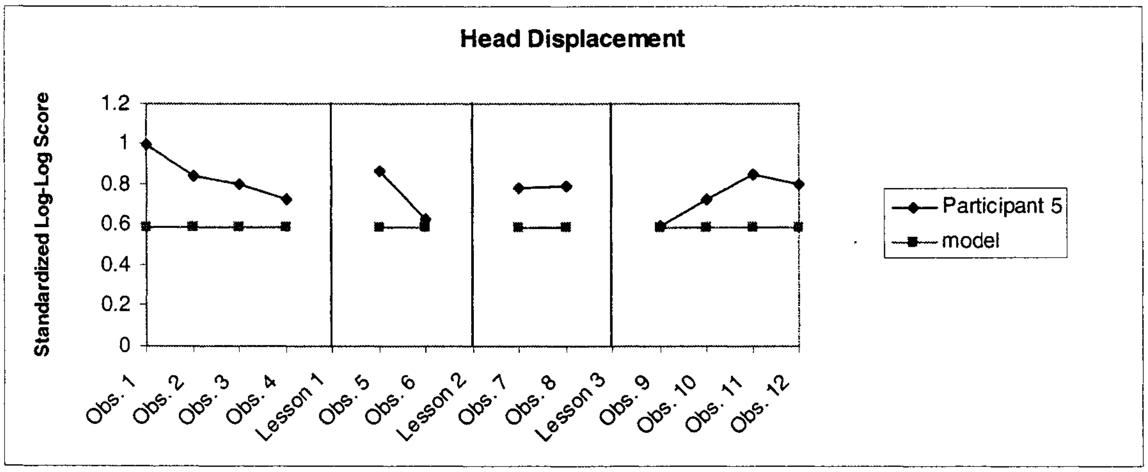
```
Variable     N            Mean          Std Dev     t Value      Pr > |t|
-------------------------------------------------------------------------
diff1        5               0                0           .             .
diff2        5      -0.0656000        0.0143631      -10.21        0.0005
diff3        5      -0.0960000        0.0284341       -7.55        0.0016
diff4        5      -0.0178000        0.0197408       -2.02        0.1140
diff5        5       0.0116000        0.0249860        1.04        0.3578
-------------------------------------------------------------------------
diff1        2               0                0           .             .
diff2        2      -0.0410000        0.0254558       -2.28        0.2634
diff3        2      -0.0980000        0.0339411       -4.08        0.1529
diff4        2      -0.0435000        0.0190919       -3.22        0.1916
diff5        2      -0.0135000        0.0162635       -1.17        0.4492
-------------------------------------------------------------------------
diff1        2               0                0           .             .
diff2        2      -0.0180000        0.0183848       -1.38        0.3982
diff3        2      -0.0210000        0.0113137       -2.62        0.2317
diff4        2      -0.0020000        0.0098995       -0.29        0.8228
diff5        2       0.0160000        0.0113137        2.00        0.2952
-------------------------------------------------------------------------
diff1        4               0                0           .             .
diff2        4      -0.0115000        0.0158008       -1.46        0.2415
diff3        4      -0.0222500        0.0148633       -2.99        0.0579
diff4        4     0.000750000        0.0168399        0.09        0.9346
diff5        4       0.0200000        0.0190438        2.10        0.1265
-------------------------------------------------------------------------
```



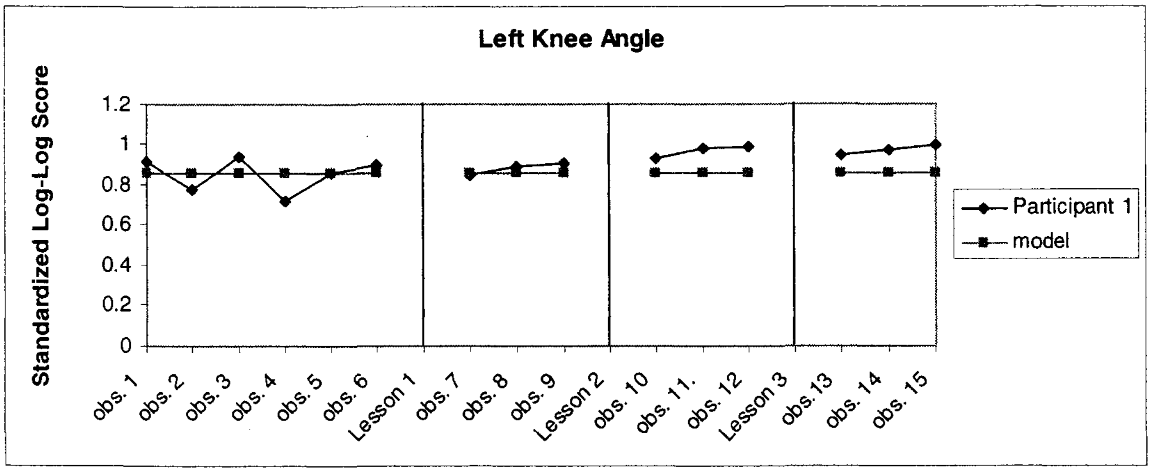
```
Variable     N             Mean          Std Dev     t Value    Pr > |t|
-------------------------------------------------------------------------
diff1        5                0                0           .           .
diff2        5       -0.0210000        0.0109316       -4.30      0.0127
diff3        5        0.0034000        0.0227112        0.33      0.7546
diff4        5      0.000800000        0.0199048        0.09      0.9327
diff5        5        0.0244000        0.0317616        1.72      0.1610
-------------------------------------------------------------------------
diff1        2                0                0           .           .
diff2        2       -0.0445000        0.0106066       -5.93      0.1063
diff3        2       -0.0325000        0.0162635       -2.83      0.2165
diff4        2       -0.0170000        0.0169706       -1.42      0.3913
diff5        2        0.0360000        0.0197990        2.57      0.2361
-------------------------------------------------------------------------
diff1        2                0                0           .           .
diff2        2       -0.0670000        0.0014142      -67.00      0.0095
diff3        2       -0.0885000        0.0120208      -10.41      0.0610
diff4        2       -0.0285000        0.0219203       -1.84      0.3171
diff5        2        0.0375000        0.0091924        5.77      0.1093
-------------------------------------------------------------------------
diff1        4                0                0           .           .
diff2        4       -0.0662500        0.0041130      -32.22      <.0001
diff3        4       -0.0925000        0.0045092      -41.03      <.0001
diff4        4       -0.0215000        0.0081854       -5.25      0.0134
diff5        4        0.0322500        0.0105317        6.12      0.0088
-------------------------------------------------------------------------
```



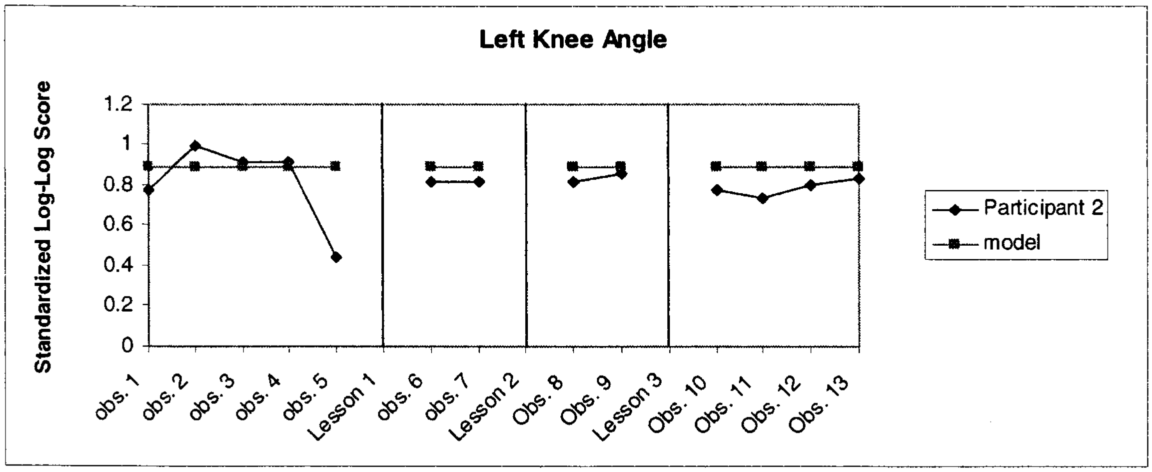
```
Variable      N            Mean          Std Dev      t Value      Pr > |t|
---------------------------------------------------------------------------
diff1         5               0                0            .             .
diff2         5      -0.0304000        0.0039749       -17.10        <.0001
diff3         5      -0.0516000        0.0049800       -23.17        <.0001
diff4         5      -0.0280000        0.0103199        -6.07        0.0037
diff5         5      -0.0040000        0.0107935        -0.83        0.4539
---------------------------------------------------------------------------
diff1         2               0                0            .             .
diff2         2      -0.0365000        0.0063640        -8.11        0.0781
diff3         2      -0.0665000        0.0049497       -19.00        0.0335
diff4         2      -0.0490000                0            .             .
diff5         2      -0.0215000        0.0106066        -2.87        0.2137
---------------------------------------------------------------------------
diff1         2               0                0            .             .
diff2         2      -0.0325000      0.000707107       -65.00        0.0098
diff3         2      -0.0505000        0.0049497       -14.43        0.0441
diff4         2      -0.0310000        0.0014142       -31.00        0.0205
diff5         2      -0.0035000        0.0049497        -1.00        0.5000
---------------------------------------------------------------------------
diff1         4               0                0            .             .
diff2         4      -0.0390000        0.0037417       -20.85        0.0002
diff3         4      -0.0530000        0.0061644       -17.20        0.0004
diff4         4      -0.0385000        0.0033166       -23.22        0.0002
diff5         4      -0.0217500        0.0065000        -6.69        0.0068
---------------------------------------------------------------------------
```



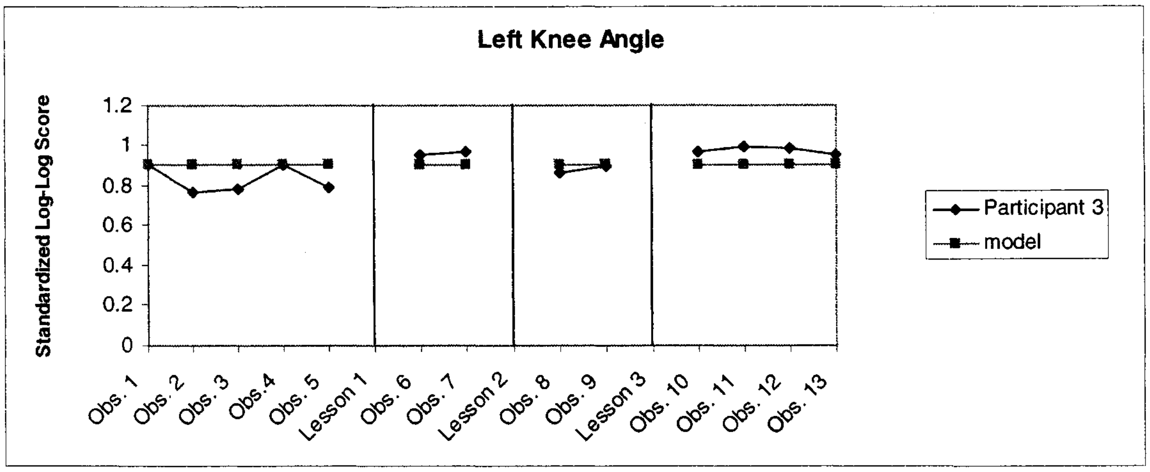
```
Variable      N            Mean         Std Dev      t Value      Pr > |t|
--------------------------------------------------------------------------
diff1         4               0               0            .             .
diff2         4      -0.0112500       0.0118708        -1.90        0.1543
diff3         4       0.0090000       0.0180370         1.00        0.3919
diff4         4       0.0735000       0.0120692        12.18        0.0012
diff5         4       0.0700000       0.0094868        14.76        0.0007
--------------------------------------------------------------------------
diff1         2               0               0            .             .
diff2         2      -0.0100000       0.0070711        -2.00        0.2952
diff3         2      -0.0025000       0.0233345        -0.15        0.9043
diff4         2       0.0485000       0.0332340         2.06        0.2872
diff5         2       0.0480000       0.0367696         1.85        0.3160
--------------------------------------------------------------------------
diff1         2               0               0            .             .
diff2         2      -0.0160000       0.0014142       -16.00        0.0397
diff3         2       0.0030000       0.0028284         1.50        0.3743
diff4         2       0.0865000       0.0049497        24.71        0.0257
diff5         2       0.0790000       0.0042426        26.33        0.0242
--------------------------------------------------------------------------
diff1         4               0               0            .             .
diff2         4      -0.0815000       0.0972197        -1.68        0.1922
diff3         4      -0.0257500       0.0134009        -3.84        0.0311
diff4         4       0.0482500       0.0138173         6.98        0.0060
diff5         4       0.0400000       0.0123558         6.47        0.0075
--------------------------------------------------------------------------
```



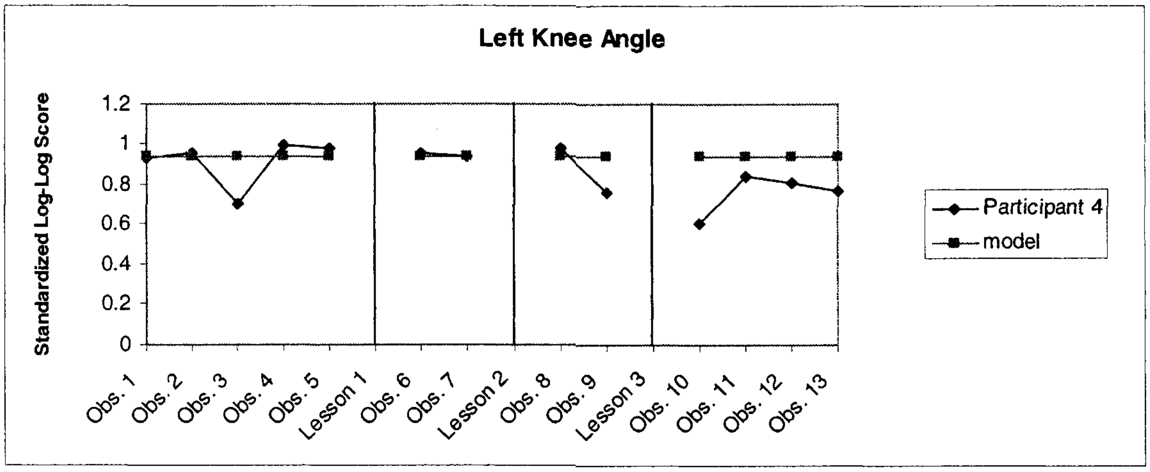
```
Variable     N          Mean         Std Dev     t Value     Pr > |t|
---------------------------------------------------------------------
diff1        6      4.2705000       5.6216416       1.86       0.1219
diff2        6    -12.5708333       7.7023410      -4.00       0.0103
diff3        6     -7.8320000       5.9901447      -3.20       0.0239
diff4        6     -5.1510000       5.9123220      -2.13       0.0860
diff5        6      5.6885000       7.5348396       1.85       0.1237
---------------------------------------------------------------------
diff1        3     -5.3953333       6.1377890      -1.52       0.2673
diff2        3      0.1903333       4.3720249       0.08       0.9468
diff3        3      6.1473333       2.4164638       4.41       0.0478
diff4        3     -6.8376667       0.4814482     -24.60       0.0016
diff5        3     -4.3390000       3.8477458      -1.95       0.1900
---------------------------------------------------------------------
diff1        3     -3.9060000       4.5207562      -1.50       0.2732
diff2        3    -16.3366667       3.0820682      -9.18       0.0117
diff3        3    -14.3916667       3.1233915      -7.98       0.0153
diff4        3    -14.0803333       6.6188309      -3.68       0.0664
diff5        3     -6.4330000       2.2100156      -5.04       0.0372
---------------------------------------------------------------------
diff1        3    -10.3630000       2.3219735      -7.73       0.0163
diff2        3    -22.3266667       2.6723206     -14.47       0.0047
diff3        3    -11.6550000       3.3096361      -6.10       0.0258
diff4        3    -15.1543333       4.2803704      -6.13       0.0256
diff5        3     -7.7200000       3.6590705      -3.65       0.0674
---------------------------------------------------------------------
```



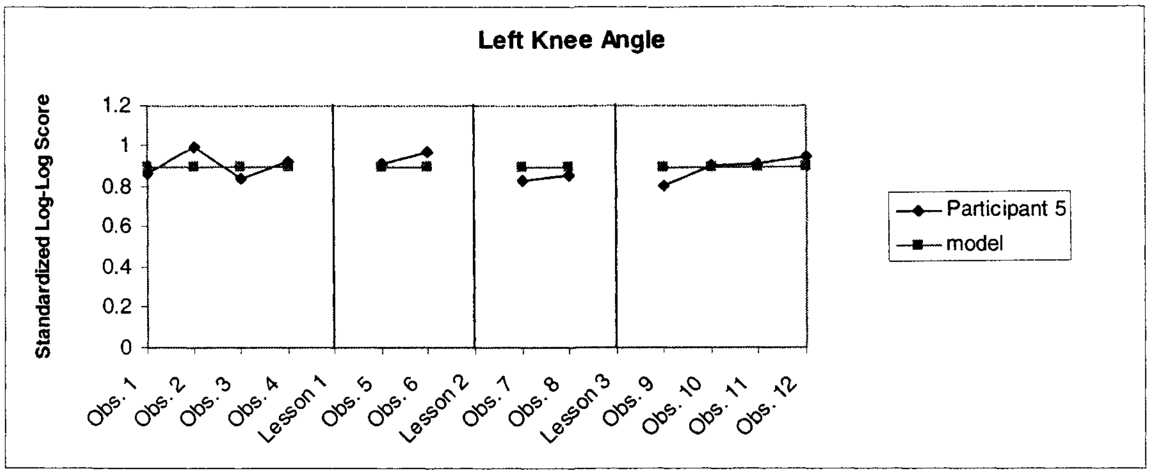
```
Variable      N            Mean         Std Dev    t Value    Pr > |t|
-----------------------------------------------------------------------
diff1         5       8.6926000       1.5803836      12.30      0.0003
diff2         5      -7.9020000       4.9559682      -3.57      0.0235
diff3         5       4.0786000       3.9072310       2.33      0.0799
diff4         5      11.4392000       2.8731639       8.90      0.0009
diff5         5      18.1296000       6.0828800       6.66      0.0026
-----------------------------------------------------------------------
diff1         2       3.5475000       4.5940728       1.09      0.4720
diff2         2     -10.1000000       3.5864456      -3.98      0.1566
diff3         2      -1.9615000       5.1823856      -0.54      0.6871
diff4         2       0.9990000       0.6321535       2.23      0.2678
diff5         2      13.1165000       1.6171532      11.47      0.0554
-----------------------------------------------------------------------
diff1         2       3.7870000       2.8835815       1.86      0.3144
diff2         2      -7.9205000       1.6935207      -6.61      0.0955
diff3         2      11.7675000       1.6609938      10.02      0.0633
diff4         2       0.5560000       2.0081833       0.39      0.7624
diff5         2       5.0730000       2.8793388       2.49      0.2430
-----------------------------------------------------------------------
diff1         4       4.1862500       4.0076945       2.09      0.1279
diff2         4      -5.1082500       4.0198604      -2.54      0.0846
diff3         4      13.7307500       2.8046994       9.79      0.0023
diff4         4       1.7340000       4.1682076       0.83      0.4664
diff5         4       9.2317500       1.9440849       9.50      0.0025
-----------------------------------------------------------------------
```



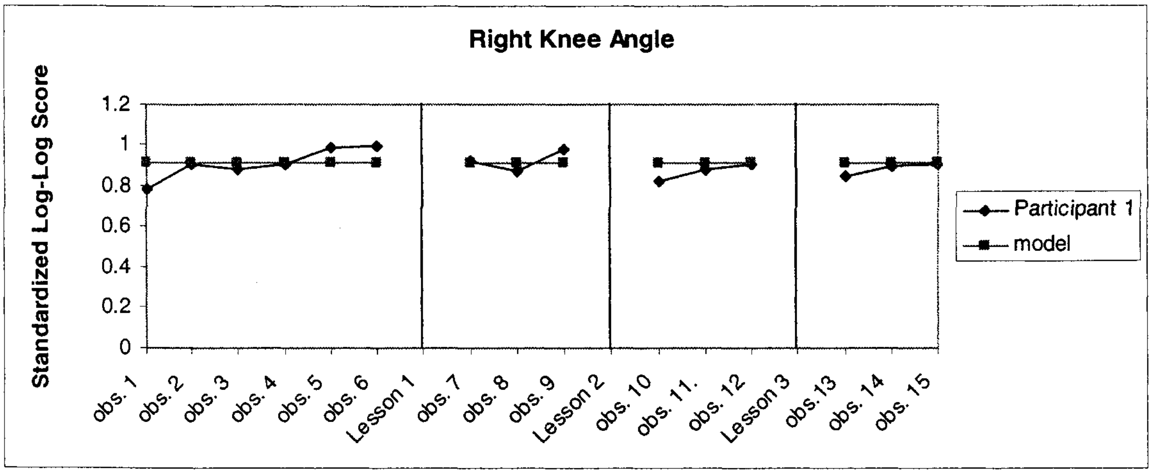
```
Variable      N          Mean         Std Dev     t Value     Pr > |t|
------------------------------------------------------------------------
diff1         5    11.2084000       5.3629148        4.67       0.0095
diff2         5     4.1810000       3.9924243        2.34       0.0792
diff3         5    16.4424000       6.0834091        6.04       0.0038
diff4         5     0.7136000       5.4350848        0.29       0.7837
diff5         5     1.2620000       5.0590664        0.56       0.6067
------------------------------------------------------------------------
diff1         2    -5.7240000       6.7104434       -1.21       0.4406
diff2         2    -8.4855000       0.1124300     -106.74       0.0060
diff3         2    10.7255000       4.2376909        3.58       0.1734
diff4         2    -9.2810000       3.0363165       -4.32       0.1447
diff5         2   -11.0245000       4.5007347       -3.46       0.1789
-------------------------------------------------------------------
diff1         2    -5.7240000       6.7104434       -1.21       0.4406
diff2         2    -8.4855000       0.1124300     -106.74       0.0060
diff3         2    10.7255000       4.2376909        3.58       0.1734
diff4         2    -9.2810000       3.0363165       -4.32       0.1447
diff5         2   -11.0245000       4.5007347       -3.46       0.1789
------------------------------------------------------------------------
diff1         4   -18.6717500       1.3608726      -27.44       0.0001
diff2         4   -14.9365000       2.2237603      -13.43       0.0009
diff3         4     1.9765000       3.6642630        1.08       0.3597
diff4         4   -10.4892500       3.7560192       -5.59       0.0113
diff5         4    -5.7807500       3.0338706       -3.81       0.0318
------------------------------------------------------------------------
```



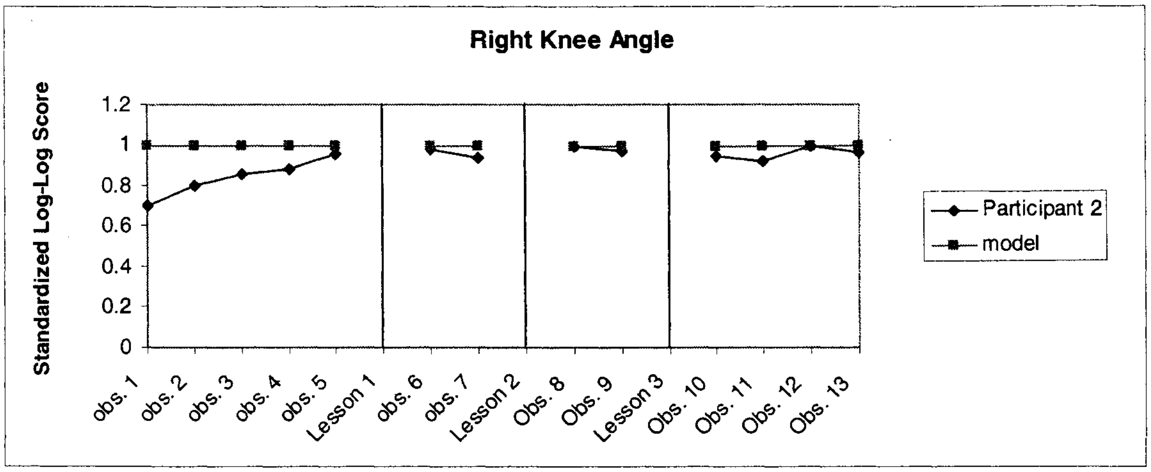
```
Variable      N           Mean          Std Dev     t Value     Pr > |t|
--------------------------------------------------------------------------
diff1         5     -0.4528000        6.2336310       -0.16       0.8788
diff2         5     -3.6614000        6.9640456       -1.18       0.3049
diff3         5    -15.6574000        7.0971967       -4.93       0.0079
diff4         5     -1.5906000        3.4914526       -1.02       0.3660
diff5         5      5.7870000        6.1718898        2.10       0.1040
--------------------------------------------------------------------------
diff1         2      3.0205000        6.2571879        0.68       0.6187
diff2         2     -2.6710000        3.4393674       -1.10       0.4702
diff3         2     -9.6780000        0.3139554      -43.59       0.0146
diff4         2     -4.3375000        0.1463711      -41.91       0.0152
diff5         2      4.8450000        0.4299209       15.94       0.0399
--------------------------------------------------------------------------
diff1         2      0.3090000        5.2594602        0.08       0.9472
diff2         2     -0.2665000        5.5161400       -0.07       0.9566
diff3         2    -17.2385000        7.4734116       -3.26       0.1894
diff4         2      0.9210000        7.0738962        0.18       0.8841
diff5         2      9.3590000        8.0200051        1.65       0.3468
--------------------------------------------------------------------------
diff1         4      7.8612500        2.7896950        5.64       0.0111
diff2         4      5.3980000        1.9372291        5.57       0.0114
diff3         4     -8.7142500        1.6869790      -10.33       0.0019
diff4         4      2.3465000        3.1802506        1.48       0.2365
diff5         4     14.4897500        2.2974974       12.61       0.0011
--------------------------------------------------------------------------
```



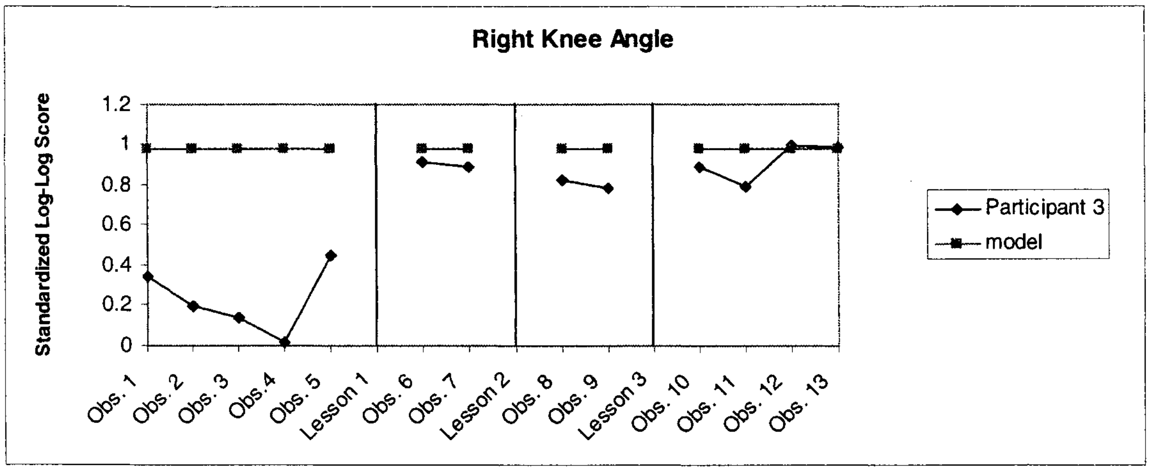
```
Variable      N           Mean          Std Dev     t Value     Pr > |t|
------------------------------------------------------------------------
diff1         4      3.4460000        4.4302582        1.56       0.2176
diff2         4     -2.1440000        5.5062227       -0.78       0.4929
diff3         4    -20.2892500        3.2995105      -12.30       0.0012
diff4         4     -2.9105000        5.5601314       -1.05       0.3721
diff5         4      3.7477500        7.1335914        1.05       0.3706
------------------------------------------------------------------------
diff1         2     -0.7240000        4.0828346       -0.25       0.8436
diff2         2     -4.5220000        2.1496046       -2.98       0.2064
diff3         2     -9.3055000        6.8709566       -1.92       0.3063
diff4         2     -4.7275000        3.9887894       -1.68       0.3425
diff5         2     -2.9520000        3.1381399       -1.33       0.4104
------------------------------------------------------------------------
diff1         2      5.6405000        2.5576052        3.12       0.1975
diff2         2      1.0455000        0.6017479        2.46       0.2461
diff3         2     -6.9350000        4.7432723       -2.07       0.2868
diff4         2      4.9815000        0.4080006       17.27       0.0368
diff5         2      6.2240000        1.0988439        8.01       0.0791
------------------------------------------------------------------------
diff1         4      3.5930000        2.8691224        2.50       0.0874
diff2         4     -1.4782500        5.9773294       -0.49       0.6548
diff3         4     -8.3102500        7.9539685       -2.09       0.1278
diff4         4     -1.4270000        4.9114698       -0.58       0.6020
diff5         4      3.0245000        3.7539567        1.61       0.2055
------------------------------------------------------------------------
```



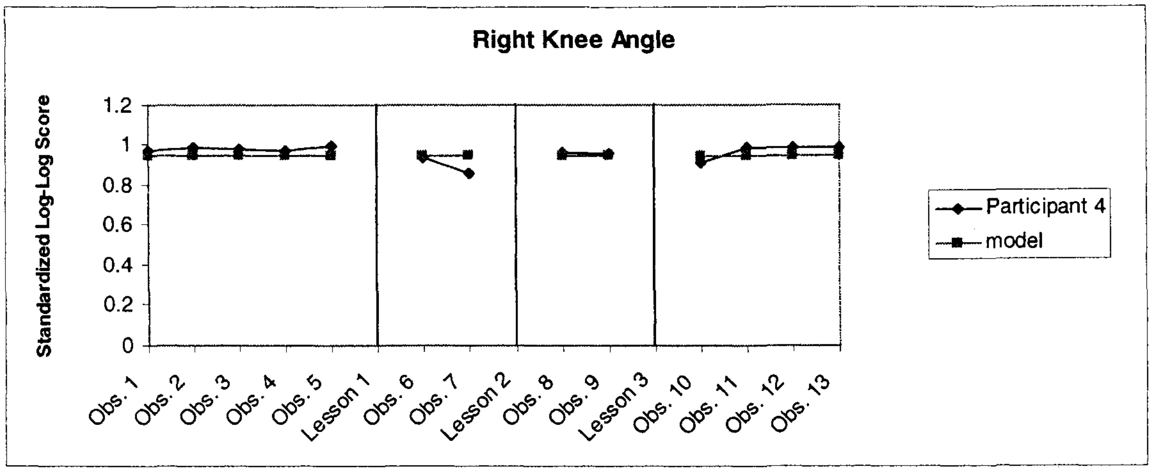
```
Variable      N           Mean         Std Dev     t Value    Pr > |t|
----------------------------------------------------------------------
diff1         6      5.7158333       3.5556105        3.94      0.0110
diff2         6      6.3558333       2.9534942        5.27      0.0033
diff3         6     -2.6688333       5.7538816       -1.14      0.3074
diff4         6     -0.3111667       6.7729228       -0.11      0.9148
diff5         6     -2.2008333       7.4054557       -0.73      0.4993
----------------------------------------------------------------------
diff1         3      2.5306667       4.5486889        0.96      0.4369
diff2         3     -1.0970000       5.8459438       -0.33      0.7760
diff3         3     -6.6586667       5.0652418       -2.28      0.1505
diff4         3      3.5066667       3.8051847        1.60      0.2515
diff5         3      1.5910000       1.9866623        1.39      0.2998
----------------------------------------------------------------------
diff1         3      7.3960000       2.4420942        5.25      0.0345
diff2         3      6.5466667       1.1885707        9.54      0.0108
diff3         3     -0.5410000       1.2472754       -0.75      0.5309
diff4         3      2.9100000       4.8662802        1.04      0.4091
diff5         3      4.3913333       5.5517556        1.37      0.3042
----------------------------------------------------------------------
diff1         3      7.1220000       3.7251863        3.31      0.0804
diff2         3      6.8643333       2.9951672        3.97      0.0580
diff3         3      0.0286667       2.8713510        0.02      0.9878
diff4         3      0.7313333       5.4303461        0.23      0.8373
diff5         3      1.3100000       4.0850561        0.56      0.6344
----------------------------------------------------------------------
```



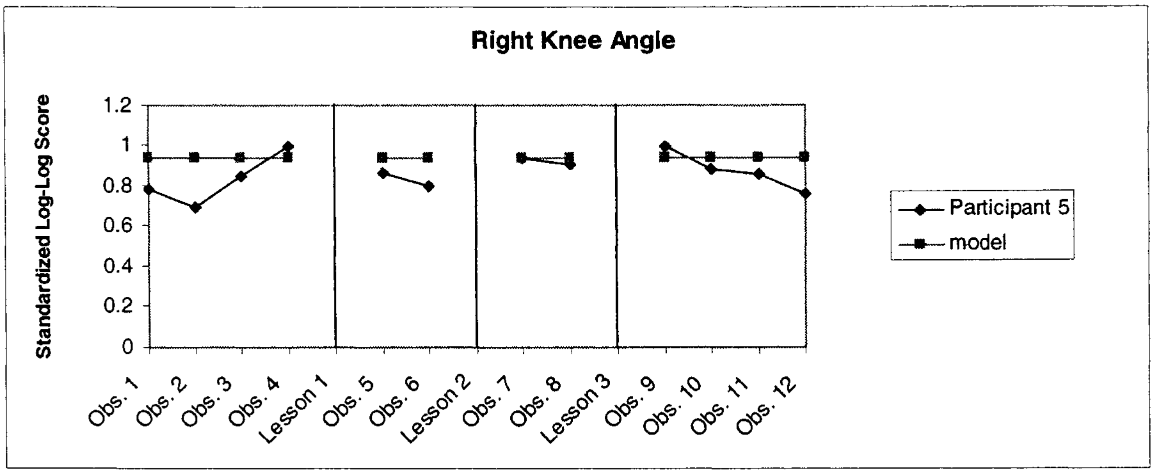
```
Variable      N           Mean          Std Dev     t Value    Pr > |t|
-----------------------------------------------------------------------
diff1         5     13.9884000        3.0774613       10.16      0.0005
diff2         5      9.9560000        4.5016021        4.95      0.0078
diff3         5      3.7974000        4.1839650        2.03      0.1123
diff4         5      6.3980000        4.7276131        3.03      0.0389
diff5         5     11.0916000        3.0638985        8.09      0.0013
-----------------------------------------------------------------------
diff1         2     12.6260000        3.5058354        5.09      0.1234
diff2         2      6.3715000        1.9183807        4.70      0.1335
diff3         2     -4.7790000        1.5047232       -4.49      0.1395
diff4         2      1.4925000        2.0272751        1.04      0.4872
diff5         2     11.4295000        2.2521351        7.18      0.0881
-----------------------------------------------------------------------
diff1         2      8.5340000        1.9685853        6.13      0.1029
diff2         2     -1.7065000        1.2522861       -1.93      0.3047
diff3         2     -7.7990000        2.7152900       -4.06      0.1537
diff4         2      2.6895000        0.0360624      105.47      0.0060
diff5         2      9.2150000        2.6021530        5.01      0.1255
-----------------------------------------------------------------------
diff1         4      9.6262500        1.9233936       10.01      0.0021
diff2         4      4.9775000        1.1029387        9.03      0.0029
diff3         4     -4.9192500        2.1845917       -4.50      0.0204
diff4         4      3.1942500        1.5053833        4.24      0.0240
diff5         4      7.9980000        2.7549186        5.81      0.0102
-----------------------------------------------------------------------
```



```
Variable      N            Mean         Std Dev     t Value    Pr > |t|
-----------------------------------------------------------------------
diff1         5      16.4496000       2.1442745       17.15      <.0001
diff2         5      18.2170000       2.1659717       18.81      <.0001
diff3         5       9.0336000       2.1755582        9.28      0.0007
diff4         5      22.0680000       2.7897762       17.69      <.0001
diff5         5      26.5448000       3.0398615       19.53      <.0001
-----------------------------------------------------------------------
diff1         2       0.1180000       3.4902791        0.05      0.9696
diff2         2       5.7330000       0.5543717       14.62      0.0435
diff3         2       1.2735000       2.7555951        0.65      0.6315
diff4         2      10.3940000       1.5075517        9.75      0.0651
diff5         2       0.5210000       1.6178603        0.46      0.7279
-----------------------------------------------------------------------
diff1         2      -0.2690000       0.3507250       -1.08      0.4742
diff2         2       6.9265000       0.7728677       12.67      0.0501
diff3         2       2.2030000       0.0339411       91.79      0.0069
diff4         2      15.0445000       1.0882373       19.55      0.0325
diff5         2      11.9805000       3.1232907        5.42      0.1161
-----------------------------------------------------------------------
diff1         4      -7.8430000       4.5336808       -3.46      0.0406
diff2         4       0.7507500       4.1913328        0.36      0.7439
diff3         4       0.4642500       3.2685309        0.28      0.7948
diff4         4       5.7490000       7.0941475        1.62      0.2035
diff5         4       5.4372500       6.3258455        1.72      0.1841
-----------------------------------------------------------------------
```



```
Variable     N           Mean          Std Dev     t Value     Pr > |t|
-----------------------------------------------------------------------
diff1        5      4.7814000        0.1462662       73.10       <.0001
diff2        5      6.1184000        1.2542704       10.91       0.0004
diff3        5     -0.3690000        0.6949629       -1.19       0.3008
diff4        5     -9.3732000        1.0493487      -19.97       <.0001
diff5        5     -4.9242000        1.9638344       -5.61       0.0050
-----------------------------------------------------------------------
diff1        2     12.6365000        3.5744248        5.00       0.1257
diff2        2     11.1090000        5.5861436        2.81       0.2175
diff3        2      4.1035000        2.8998449        2.00       0.2950
diff4        2     -5.9890000        1.8893893       -4.48       0.1397
diff5        2     -0.3875000        0.1605132       -3.41       0.1814
-----------------------------------------------------------------------
diff1        2     11.1190000        7.1092516        2.21       0.2703
diff2        2      8.8050000        1.3420887        9.28       0.0684
diff3        2      0.9480000        0.1159655       11.56       0.0549
diff4        2     -8.8325000        3.7766573       -3.31       0.1869
diff5        2     -3.9720000        0.7608469       -7.38       0.0857
-----------------------------------------------------------------------
diff1        4     12.3032500        2.9179668        8.43       0.0035
diff2        4      6.5742500        1.9684189        6.68       0.0068
diff3        4     -0.6075000        2.3868454       -0.51       0.6458
diff4        4     -6.8050000        2.9154774       -4.67       0.0186
diff5        4     -3.0297500        5.4011727       -1.12       0.3436
-----------------------------------------------------------------------
```



```
Variable      N           Mean         Std Dev     t Value    Pr > |t|
----------------------------------------------------------------------
diff1         4     12.0295000       1.9401494       12.40      0.0011
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diff3         4     11.4545000       2.1281931       10.76      0.0017
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----------------------------------------------------------------------
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diff2         2     11.9335000       0.6767012       24.94      0.0255
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----------------------------------------------------------------------
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----------------------------------------------------------------------
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----------------------------------------------------------------------
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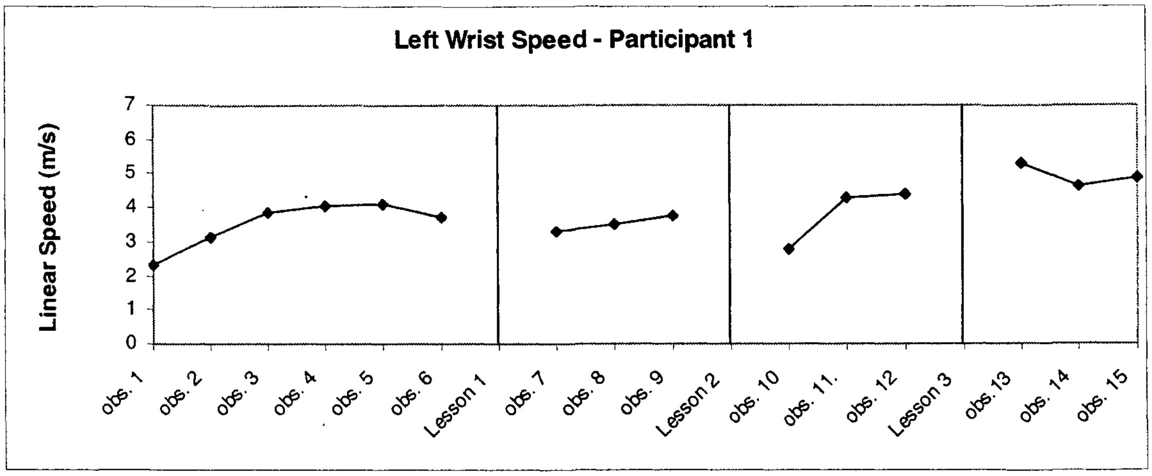
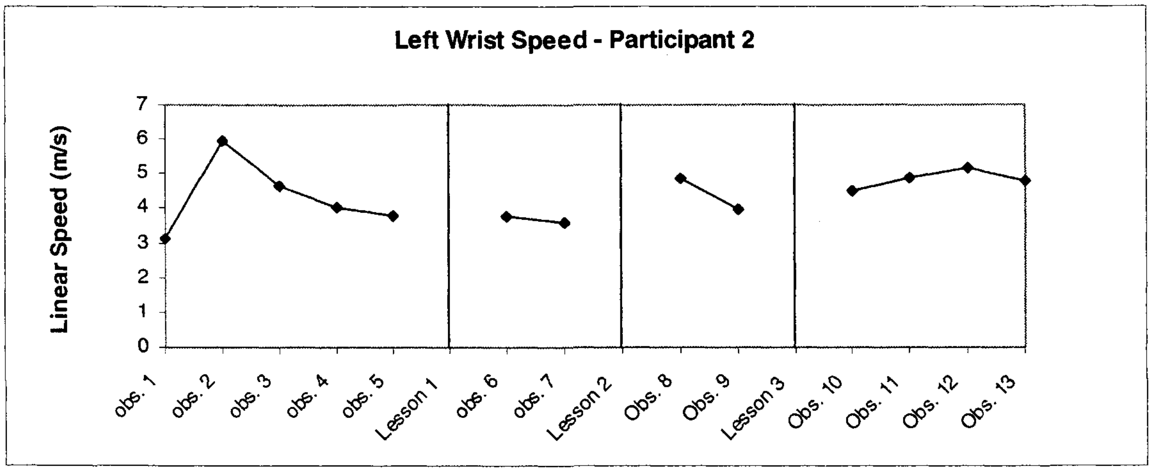
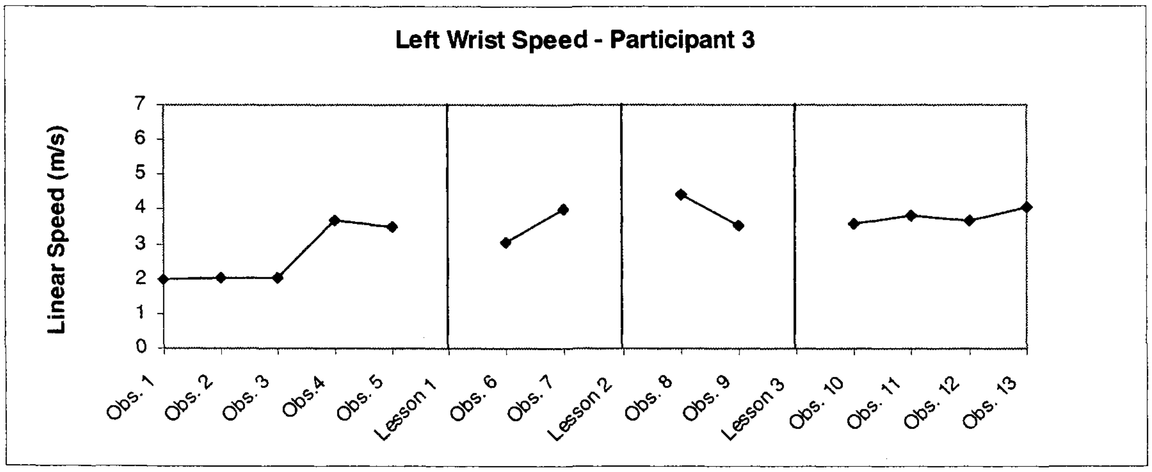
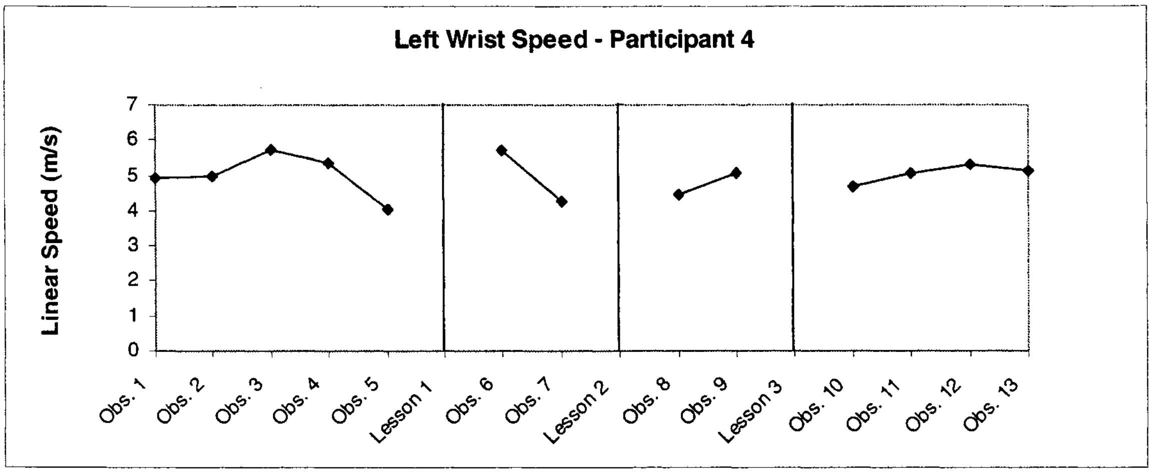
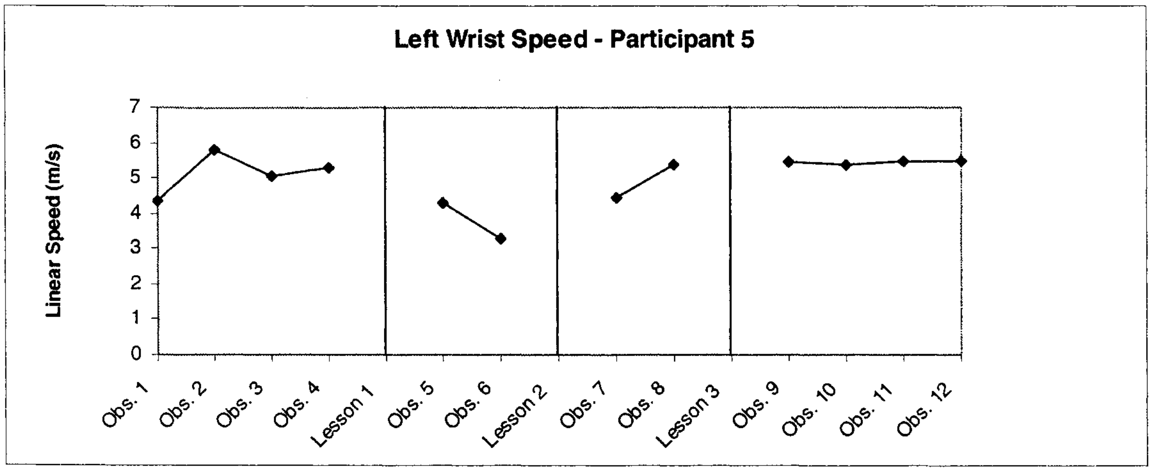

Left Wrist Speed - Participant 1
Linear Speed (m/s)
0
1
2
3
4
5
6
7
obs. 1
obs. 2
obs. 3
obs. 4
obs. 5
obs. 6
Lesson 1
obs. 7
obs. 8
obs. 9
Lesson 2
obs. 10
obs. 11.
obs. 12
Lesson 3
obs.13
obs. 14
obs. 15


Left Wrist Speed - Participant 2
Linear Speed (m/s)
0
1
2
3
4
5
6
7
obs. 1
obs. 2
obs. 3
obs. 4
obs. 5
Lesson 1
obs. 6
obs. 7
Lesson 2
Obs. 8
Obs. 9
Lesson 3
Obs. 10
Obs. 11
Obs. 12
Obs. 13


Left Wrist Speed - Participant 3
Linear Speed (m/s)
0
1
2
3
4
5
6
7
Obs. 1
Obs. 2
Obs. 3
Obs.4
Obs. 5
Lesson 1
Obs. 6
Obs. 7
Lesson 2
Obs. 8
Obs. 9
Lesson 3
Obs. 10
Obs. 11
Obs. 12
Obs. 13



Left Wrist Speed - Participant 4



Left Wrist Speed - Participant 5

Appendix F

Discussion

Left Elbow Angle

The model's left elbow angle at event 1 was approximately 8°. The angle increased until it reached a maximum of about 20° at the top of the backswing (event 3). From event 3 the angle decreased to the final critical event of contact where it was 1°. This motion pattern resembles the symmetrical load and unload of the left elbow angle. The golf literature indicates that the left elbow angle should remain fairly straight from starting position to contact. This data shows that the angle does not change dramatically during this time but there is a slight increase which likely exists to increase muscular potential energy at that joint or to allow for more body rotation about the spine.

Participant 1

Left elbow angle for Participant 1 before intervention was greater than the model at event 1 and event 5. The difference was likely caused by a physical end of range rather than poor golf swing fundamentals. Event 3 resembled event 3 of the model until after the final intervention. The final intervention was intended to increase body rotation and the height of the hands at event 3. This was accomplished as the height of the right wrist at event 3 increased from 0.238 m above the starting position in probe 1 to 0.699 m above starting position in probe 15. Many top golf teachers point out that allowing the left elbow to bend to increase range of motion in the backswing is acceptable for individuals with limited range of motion (Reinmuth, 2003; Flick, 1997). Although the angle of the left elbow was much greater than the model for all events after the final intervention, Participant 1 did achieve the proper motion pattern where the angle increased to a maximum at event 3 and returned nearly to the starting position at contact.

Participant 2

Participant 2 displayed an elbow angle greater than the model for all events in baseline observations. Event 3, in particular, was much greater than the model as it often exceeded 90°. The mean difference between Participant 2 and the model for event 3 decreased from 64° (baseline), 72° (after 1st intervention) and 68° (after 2nd intervention) to 51° after the final intervention. Movement variability of the left elbow angle also increased after the final intervention which is indicative of a changing coordination pattern. Participant 2 showed a motion pattern similar to the model although the angle was greater across all events.

Participant 3

Left elbow angle for Participant 3 approached the model after the first intervention. After the second intervention the angle at event 3 increased an average of 46° higher than the model. This increase was likely similar to the change seen at event 3 by Participant 1 after the final intervention. The height of Participant 3's right wrist at event 3 increased from 0.446 m above starting position in baseline observations to 0.708 m above starting position at probe 8 (following second intervention) and 0.705 m above starting position after the final intervention. After the second intervention the left elbow angle showed a negative change but allowed a more complete range of motion for the backswing. Participant 3 also showed a similar motion pattern to the model.

Participant 4

Participant 4 showed very little change in left elbow angle throughout the experiment. The difference seen in the log-log data may misrepresent the difference between Participant 4 and the model during the golf swing. The model's left elbow angle at event 1 is slightly bent, however, it is acceptable for this angle to be straight if the performer is flexible. Participant 4's elbow angle at event 1 was close to straight throughout the duration of the experiment. Event 3 was higher than the model by 12-15° throughout the experiment. This participant also showed a motion pattern consistent with the model.

Participant 5

At event 1 and 2 the angle of the left elbow was less than that of the model, this difference disappeared after the first intervention when the participant adjusted his hand position to match the model's starting position. Event 3 was consistently greater than the model, like all participants, throughout the experiment. A proper motion pattern was recorded for all observation periods.

Summary

None of the participants achieved the left elbow angle of the model at event 3 by the end of the experiment. This may be explained two ways: a straight left arm at event 3 is uncomfortable and will not yield positive feedback without practice. To achieve the flexibility required to swing with a relatively straight left arm requires the participant to practice a great deal to train the golf specific muscles. This angle may be important for increasing clubhead velocity but also may be considered an advanced swing characteristic. Since the lessons emphasized the importance of body rotation over a straight left arm, the alternative explanation for the angle at event 3 is that the participants only gained visual information from the portion of the model's swing that they focused their attention on. The participants increased body rotation at the expense of keeping a straight left elbow. A proper motion pattern was displayed by all participants after the final intervention.

Spine Angle

The model's spine angle stays fixed during the first three events of the swing at approximately 40°. During events 4 and 5, the spine angle decreases (becomes more vertical) to resist centrifugal force of the swinging club. The decrease in spine angle is not created by the head moving superior or posterior, rather, the pelvis moves anteriorly to generate a posterior ground reaction force to resist the angular momentum of the swinging club. During the final two events the angle decreases to a minimum of 29°.

Participant 1

Participant 1 showed an improper motion pattern throughout the experiment. The spine angle reached its minimum at event 3 and returned to near starting position. This is considered a negative change in movement kinematics as changing the spine angle in the first three events when the body is rotating relatively slowly increases the difficulty of returning the club to starting position for contact. Overall, posture was close to that of the model although the motion pattern was incorrect. Movement became less variable after the first intervention which may indicate that the participant was beginning to develop error detection and found a coordination pattern that was providing positive feedback.

Participant 2

Participant 2 showed the same motion pattern as Participant 1. The spine angle reached a minimum at event 3 and increased until event 5. Spine angle for all events were too low (vertical) during baseline observations. After the final intervention, spine angle during all events increased and approached the model. However, the spine angle was still more vertical than the model and the motion pattern was still incorrect.

Participant 3

During baseline observations, Participant 3 showed very little change in spine angle between events and spine angle was too vertical. After the first intervention the spine angle and range of motion increased. The increases in mobility after the first intervention lead to an incorrect motion pattern. Participant 3 showed a similar motion pattern to Participants 1 and 2. The spine angle decreased at event 2 and reached a minimum at event 3. Participant 3 did not establish a correct motion pattern during the experiment.

Participant 4

The spine angle and motion pattern for Participant 4 matched the model throughout the experiment. No change was seen after any intervention because the movement was already correct.

Participant 5

During baseline observations the spine angle was close to the model but the motion pattern was incorrect. Instead of staying constant, the spine angle increased during event 2 and 3 and returned to a correct position at events 4 and 5. The more horizontal position of the spine during events 2 and 3 is likely related to over flexion of the left knee at event 3. After the second intervention a correct motion pattern was established for three of the seven remaining probes. It is important to note that the change in spine angle during events 2 and 3 that creates an incorrect motion pattern is because the top of the spine moves anteriorly and inferiorly. The change in spine angle for the model is caused by movement of the pelvis rather than the top of the spine.

Summary

The three beginner participants showed similar, incorrect motion patterns. During the backswing the spine angle became more vertical. This change was caused by the head moving superiorly rather than a pelvic movement. The decrease in spine angle was likely caused by the attempt to increase body rotation. The final lesson indicated that proper body rotation should allow the hands to reach or exceed head height. The beginner participants lifted their heads in an attempt to increase the height of their hands at event 3. This motion pattern makes it difficult to return the golf club head to the starting position. The more advanced participants did not show the same incorrect motion pattern. Participant 5's spine angle increased during events 2 and 3 which is opposite to the beginner participants. Participant 5 started to correct this error after the second intervention.

Lateral Head Displacement

There is a very specific lateral motion pattern of the head of expert golfers that is illustrated by the model. From event 1 to event 3 the head of the model translates about 6.5 cm to the right. As the weight shifts from the right leg to the left the head moves about 2 cm left at event 4. To maintain balance and resist angular momentum of distal segments the head moves to right again, about 1 cm at event 5. This motion pattern is a reaction to high clubhead velocity.

Participant 1

Participant 1 showed a correct motion pattern during three of the first four observation periods but, overall, showed high movement variability during baseline observations. After the first intervention, and especially after the final intervention, body rotation of Participant 1 increased which caused head displacement to increase. Head movement should be higher for Participant 1 than for the model because of Participant 1's large base of support. To transfer body weight to the right leg more lateral motion was required by this participant. The motion pattern did not match the model; this was likely because club head momentum was not high enough relative to the body to require a centre of mass manipulation to remain in balance.

Participant 2

Participant 2 showed much more head displacement than the model at event 3 during baseline observations. After the second intervention the mean difference between the participant and the model decreased by almost 8 cm. The motion pattern was incorrect throughout the experiment as the head did not displace away from the target at contact. After the second intervention however, the head displacement at event 4 and event 5 did become much closer, indicating that the participant was resisting the motion of the club to stay in balance. A positive change was shown by Participant 2 after the second intervention since head displacement approached the model and the motion pattern improved.

Participant 3

Participant 3 showed high variability and an inconsistent motion pattern during baseline measurements. After second intervention Participant 3 showed a more consistent, yet incorrect, motion pattern. After the second intervention, when mobility increased, the head displacement at event 3 increased past what the model demonstrated. The motion pattern for all three beginner participants was similar.

Participant 4

Head moved approximately 5-6 cm further to the right than the model throughout the experiment. Participant 4 showed a similar motion pattern to first three participants before final intervention. After final intervention the difference between event 4 and event 5 became smaller and approached the correct movement pattern.

Participant 5

Participant 5 showed the correct motion pattern throughout the experiment, however, the displacement from event 3 to event 4 was too high. The participant's head was left of its starting position at both events 4 and 5. This is indicative of a lateral translation of the centre of mass passed where resistance should have been applied to maintain balance. When the head is left of its starting position during contact many coordinative manipulations are necessary achieve the desired outcome which cause an increase in movement variability. After the final intervention the displacement from event 3 to event 4 became smaller and approached the contact position of the model.

Summary

All three beginner participants showed a similar motion pattern for head displacement after the first intervention. They likely do not show the head movement to the right at impact to maintain balance because the club is not travelling fast enough to require a centre of mass manipulation. Since none of the participants lost their balance after contact it is likely that they manipulated their balance in an appropriate way to keep their centre of mass within their base of support, although it was a different movement than the model.

Left Knee Angle

The left knee of the model showed a similar motion pattern as the left elbow angle. The angle increased from approximately 16° until event 3, where it reached a maximum of approximately 33°, then returned to near the starting position at contact. The increasing angle allows the hips to rotate during the backswing.

Participant 1

During baseline measurements there was high movement variability for the left knee angle and the angle tended to be too small. After the second observation period the left knee angle at the starting position and contact began increasing. The increase did not appear to be from intervention because the change started before the first intervention; the change may be attributable to discovery learning. The seventh and eighth observation periods showed angles that were closest to the model. The left knee angle increased passed the model's in following observation periods. An explanation for this large change in left knee flexion across observation periods is that the participant was searching for a proper movement in early observation periods, the angle increased passed what it should have as the participant attempted to increase body rotation and range of motion.

Participant 2

During baseline observations, the left knee angle of Participant 2 was straighter than the model at events 1, 3, 4 and 5 while it was more flexed than the model at event 2. The large difference between event 2 and 3 can be attributed to the length of the backswing. The length of this participant's backswing is extended by excessive elbow and wrist flexion just before the change in direction of rotation. The lower body began rotating toward the target before the upper body was finished the backswing; this is why the left knee angle straightened more than expected at event 3 while most other participants and the model show similar angles from event 2 to event 3. After the first intervention the angle at events 1, 4 and 5 increased and became closer to the model. After the second intervention, the angle at event 3 straightened, even more so than in baseline, while the angle at event 5 increased and further approached the model.

Participant 3

The left knee angle of Participant 3 in the first three events during baseline measurements was lower than the model indicating that the left leg was too straight. After the first intervention the angle at these events increased so that events 1 and 2 had passed that of the model. After the final intervention the angle at these events increased further; events 1 and 2 became even more flexed than the model while event 3 approached the model. The angle at event 5 was correct during the baseline; after the first intervention it became more flexed than the model. After the final intervention the angle at event 5 straightened to once again approach the model. Movement variability decreased after the final intervention compared to the baseline. Like Participant 1, this participant shows great change from intervention to intervention with angles increasing and decreasing above and below the model as the participant tries to increase range of motion and still follow the instructions of the intervention.

Participant 4

Throughout the experiment, Participant 4 showed a correct motion pattern and angles close to the model with the exception of event 3. The left knee was flexed more than the model at event 3 during baseline observations. After the final intervention the angle at event 3 decreased slightly an approached the angle of the model.

Participant 5

The data for left knee angle for Participant 5 were similar to the data for Participant 4. The angle changed with the correct motion pattern. In the starting position the left leg was straighter than the model, the angle increased passed the model's angle in events 2, 3 and 4 and became straighter than the model at event 5. The angle at event 3 decreased and approached the model after the first intervention. Movement variability at event 3 increased after the final intervention.

Summary

The three beginner participants showed similar movement patterns for left knee angle. In baseline measurements all three participants left knee angle was straighter than the model at the starting position and contact position. The angle at event 3 for participants 1 and 2 was greater than the model showing that the angular displacement of the left knee during the golf swing for these participants was too high. Participant 2 did not show the same angle as the other two participants because of the length of the backswing which caused the left leg to be very straight at the start of the downswing. Following intervention the angle at starting position and contact became more flexed to match the model; however, the angle at event 3 did not approach the angle of the model. Participants 4 and 5 showed similar data to the beginner participants but not to the same degree and the data did not show them "searching" as much for the correct movement in response to intervention. Unlike left elbow angle and head displacement the participants had to learn the proper leg movement to be able to increase body rotation. As a result, when body rotation increased the leg movement pattern improved.

Right Knee Angle

The motion pattern for right knee angle for the model is opposite to the motion pattern of the left knee angle. The starting position angle is approximately 28°, the angle decreases to a minimum of 11° at event 3 and returns to the starting position (±1°). The difference between starting position angle for right and left knees is because of perspective error created by the shape of the lens. The curved lens is used so the cameras can be situated close to the participant while maximizing the field width. The perspective error in the model is constant in observation periods and throughout the experiment and thus does not threaten validity of the data.

Participant 1

Participant 1 showed the correct motion pattern throughout the experiment. During baseline measurements the right knee was very straight at event 3. A straight right knee at the start of the downswing can drastically reduce the performer's ability to shift his weight properly. After the first intervention, the right knee angle increased passed the angle of the model; the participant over-corrected while in search of the correct movement. After the second intervention the participant matched the right knee angle of the model at event 3.

Participant 2

The motion pattern for Participant 2 was inconsistent and incorrect for most observation periods. Instead of the simple load and unload motion of the model, Participant 2 rarely reached the minimum right knee angle at event 3 and a maximum at event 1 and/or 5. Aside from the motion pattern, the angle of the right knee was much straighter than the model at event 1 and 2. After the second intervention, the right knee angle at event 1 and

2 increased and became closer to the model, but did not reach the value of the model. In the final three observation periods the participant showed a correct motion pattern.

Participant 3

Participant 3 showed and inconsistent motion pattern and right knee angles that were too straight compared to the model. After the first intervention, the angles and the motion pattern became much closer to the model. The mean difference from the model in the final intervention at event 1 decreased from 16.4° in baseline to -7.8°. The mean difference from the model at event 2 decreased from 18° in baseline to 0.8° after the final intervention; from 9° to 0.4° at event 3, from 22° to 5.7° at event 4 and from 26.5° to 5.4° at event 5.

Participant 4

Participant 4 showed angles and a motion pattern close to that of the model. The motion pattern however was inconsistent. In probes 3, 4, 6, 8, 10 and 12 the right knee angle at the final event was less than the angle at event 4. This is indicative of the hips translating too far to toward the target at contact. No change was seen as a result of interventions.

Participant 5

During baseline observations, Participant 5 showed an incorrect motion pattern. Like Participant 4, the right knee angle at event 5 was straighter than event 4. The angles at event 2 and 3 were less than the model and the angles at events 4 and 5 were greater than the model.

Summary

There is a synergistic relationship that must exist between the right knee and left knee angles during the golf swing. As the left knee bends to allow hip rotation the right knee straightens slightly to achieve a position where the pelvis can rotate on the head of the femur. During the downswing the right leg generates a ground reaction force that rotates the hips toward the target. At impact the left leg straightens to decelerate the hips and transfer momentum to more distal segments. Most participants showed a correct motion pattern for left and right knee angles during the golf swing however, in some cases the maximum and minimum angles were not achieved at the proper event. When timing the change of angle of both knees is incorrect achieving a high club head velocity becomes more difficult. Participants 4 and 5 showed angles that were very close to the model for both legs but the angle of the right knee at impact straightened slightly which indicates that they did not effectively decelerate their hips. The axis of rotation of the hips translated linearly toward the target more than the model. Participant 1 showed a correct motion pattern for the right and left knee angles but the center of mass did not translate to the left leg during baseline measurements. Participant 1 eventually produced a full body rotation finishing with his center of mass over his left leg by the end of the experiment.

Participant 2 showed synchrony between right and left knee angles but not between upper and lower body in baseline measurements. The participants improved the motion pattern of both legs as their body rotation increased.

Linear Velocity of Left Wrist at Contact

There is no prescribed velocity for the wrists during the golf swing due to variability among participants and physical constraints. The speed of the model is adjustable to the model to the participant. The participants' left wrist velocity was not compared to the model. Linear velocity of the left wrist was used instead of clubhead velocity because of the amount of noise in the motion of the club head.

During baseline observations Participant 1's left wrist velocity averaged 3.53 m/s at contact. After the final intervention the left wrist velocity at impact increased to 4.95 m/s. The average left wrist velocity of Participant 2 before intervention was 4.31 m/s. After the final intervention the average velocity was 4.82 m/s. Participant 3's average left wrist velocity before intervention was 2.65 m/s and 3.80 m/s after the final intervention. Average left wrist velocity for Participant 4 before the first intervention was 5.02 m/s and 5.05 m/s. The average left wrist velocity for Participant 5 before intervention was 5.12 m/s. After the final intervention the average left wrist velocity was 5.46 m/s.

Recommendations for Virtually Perfect Golf

VPG Methodology

Concurrent visual feedback as used by Virtually Perfect Golf offers more information than retroactively viewing a visual display of the performance. Viewing visual feedback retroactively supplies the learner with visually encoded information whereas visual feedback while performing the golf swing offers visually and physically encoded information. Other teaching methods use different types of visually encoded information or different types of physically encoded information but I have not found any other teaching devices that supply the user with knowledge of performance about their movement and intrinsic proprioceptive movement feedback concurrently. According to Adams' closed loop theory, viewing the model gives the learner a reference of correct movement and viewing him/herself gives the learner perceptual trace. Using the VPG methodology should reduce time spent in the verbal-motor stage and accelerate learning.

Model

Since the model is a composite of more than one swing and was altered further to demonstrate the VPG swing more accurately the model does not have a KSD signature. The model could supply more relevant information to the user if a performance by a real person was used. For novice golfers a slow motion KSD demonstration would increase visually encoded information and for an advanced learner a normal speed or frame by frame KSD demonstration that illustrated key positions of the golf swing would maximize important information. Using a KSD demonstration in this situation is thought to supply the learner with additional information about how to stabilize his/her body against rotational and gravitational forces.

Instruction

When the instructor offers transitional information an external focus should be used rather than an internal focus. Since most of the information gained from a demonstration is from external limbs a learning advantage can be created by focusing the learner's attention on external components of the movement. The VPG instructors do not physically manipulate the learner's limbs to teach new movements. Having the student move through the range of motion on his/her own keeps the level of constraint of the task consistent with a playing situation.

Feedback

When the golf swing or the golf swing change is a very novel movement the learner should gain more from verbal instructions and from viewing a demonstration. Discovery learning has only been shown to benefit performers of less specific and demanding tasks and tasks with a higher degree of constraint. As the learner becomes more competent in performing the task, he/she should be given less movement feedback to increase the development of error detection and correction. Even in the early stages of learning, extrinsic information should not be offered in a way that inhibits the retrieval of stored information.