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Analysis of lower-hand wrist flexion and twist of the mallet head in a croquet shot

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ABSTRACT

This study investigated the relationship between wrist flexion and the dynamics of the swing of a croquet mallet. Twenty seven subjects participated in a study which used 3D motion capture equipment and high speed and high-definition video to determine if there is a correlation between the lateral twist of a croquet player's swing and the flexion of the wrist during that swing.

The study found a significant correlation between the amount of flexion of the wrist from the start of the stroke to the top of the backswing and the twist of the mallet head at the top of the backswing ($r=0.330$, $p<0.01$).

The methodology and findings are relevant to all sports where minimising wrist flexion is favourable for improving consistency of stroke making. Additionally, reducing wrist motion in stroke-making may reduce the incidence of wrist pain and injury in croquet, further supporting recommendations to reduce the amount of wrist flexion during the croquet swing.

Introduction

Croquet is a game played by 2 or 4 players where the aim is to score points by hitting a ball through a series of hoops in a predefined order using a mallet [1]. The mallet has a shaft which is typically 85-100 cm long ending in a rectangular head which is 22-30 cm long. The mallet is made of wood, or another material which does not give a playing advantage over wood. The ends ("end faces") to the mallet head, which are used to strike croquet balls, are parallel, and the overall mallet weight is 1-1.5 kg.

A shot consists of holding the mallet at the end of the shaft furthest from the head, and swinging the mallet so that the mallet head typically passes backwards between the player's ankles (the "backswing"), then forward to strike the ball. While many players begin a stroke by swinging their mallet back and forth between the ankles prior to driving the mallet forward to stroke their ball, for the purposes of this study the shot is defined to "start" with the mallet resting between the feet.

Like other stationary-ball sports where the ball is struck with the distal end of an implement (e.g. golf, snooker), the game of croquet requires accuracy and consistency, rewarding a controlled and repeatable swing. Similar to the putting

stroke in golf, the croquet mallet is held approximately vertically and gripped near the top, striking a ball which is initially stationary on the ground. Unlike golf Rule 10.1c, [2] croquet is played with a mallet which is swung, for the vast majority of modern players, between the player's legs.

A swing where the mallet is brought back in a perfectly straight line then forward straight along the line of aim has a longer period of time during which the mallet is facing in the desired direction, and therefore requires less precise timing to play an accurate stroke than one where during the path of the mallet's swing the implement twists from left to right, or right to left. Twisting motions mean that the player needs to have fully corrected — and not over-corrected — the alignment of the mallet immediately before impact with the croquet ball. Many international level players twist their mallet in the backswing, however the majority of these players have noted the difficulty of recovering their accuracy during a "bad patch" of play. This includes incidences of the "yips", firmly established in golf [3] and also an affliction of many croquet players. Further, beginner and club level players who do not have a straight swing struggle to develop the ability to consistently hit a croquet ball in the desired direction. In golf, techniques such as various wrist-locking devices [4,5] and motion capture and wearable technology analyses [6,7] have been used to help understand, and correct, wrist rotation and swing inconsistencies. It is therefore of interest to explore mechanisms which may cause the croquet mallet to twist, or to veer off path, in order to optimize competitive performance.

An additional concern is the occurrence of wrist discomfort and diagnosed injuries among croquet players [8]. Of 214 survey participants, 36% reported at least one injury to the 'hand, wrist or forearm' caused by striking a croquet ball [8] (p219). While no specific research has been conducted on the epidemiology of wrist injuries in croquet, a vast body of research demonstrates the prevalence of injury in racquet sports where the wrist is repeatedly forcefully flexed and extended with movement across gliding joints of the wrist, in addition to striking forces which affect the wrist during contact between the striking implement and the ball [9,10]. At 454±7 grams, a croquet ball is significantly heavier than most balls struck in mallet sports.

Reducing the amount of movement in the wrist during a croquet swing, particularly at the moment of impact of mallet with ball, is one mechanism to address wrist injuries. This is particularly relevant when considering the age demographic of typical croquet players. The 7500 croquet players who belong to the UK Croquet Association, for example, have a median age of 70 years old, with an average age of players newly taking up the sport of 66 [11].

The aim of this study is to investigate the relationship between wrist flexion and rotation of the croquet mallet head about the mallet's shaft. In particular, we explore flexion of the wrist on the hand which is grips the mallet most inferiorly, as at the

starting position the wrist is already in nearly full ulnar deviation (flexed towards the ulna), therefore any chances from this position tend to forcefully move the wrist towards the limits of its possible range of motion in that direction. Figure 1 show the standard croquet grip, where the "lower wrist" is defined by the hand in the inferior position.

Figure 1. The croquet "standard grip", with the knuckles of the upper hand, and the palm of the lower hand, facing forward. Both hands are relatively close together. The "lower wrist" is defined as the wrist on the inferior hand in this position. The wrist support shown is used by the injured player, and is not standard equipment.

The present study tests the hypothesis that lateral deviation of the mallet head (i.e. twisting about the long axis through the shaft of a croquet mallet) is correlated with excessive flexion of the lower wrist. This hypothesis is tested through an analysis of 27 croquet players using the standard grip. If this hypothesis is supported, coaching interventions to reduce wrist flexion in croquet players are likely to lead, not only to a swing in which the mallet spends a greater portion of the time of the swing pointing in the desired direction of the stroke, but also to additional benefits in reducing the prevalence of wrist pain in those players.

Results from this study are relevant to ball sports where accuracy in stroke making is optimised with limited wrist flexion and the primary upper limb movement being dominated by larger muscles across the shoulder and elbow joints, such as golf, squash and cricket [10,12]. Additionally, it is noteworthy that wrist injuries through both impact and overuse of the gliding joints in the wrist are prevalent in the aforementioned sports [9,10]. Both the methodology for the data collection and the hypothesis are important to sports where wrist engagement is important as well as sports where wrist injuries are common.

Methods

Twenty-seven croquet players (19 male, 8 female) from the Canterbury Croquet Association (CCA) who satisfied the criteria of using a standard grip and were available during the testing period participated in the study. The participants ranged in age from 21 to 85 years old (M=64.6, SD=9.1), with a mean of 12.6 years' (SD=4.2) playing experience. All participants were fully briefed on the procedures and data collection and handling techniques to be used and all signed an informed consent document.

All players use the standard grip (see Figure 1) with hands either close together or slightly overlapping. A BTS SMART-DX marker-based motion capture system with six infra-red DX100 cameras was used [13]. Thirteen reflective markers were placed on the players and equipment. The critical markers on the players were placed on the tendon of abductor pollicis longus where it crosses the wrist joint, on the head of the second metacarpal on the posterior of each hand, and on the lateral epicondyle of the humerus of each arm. Additional markers were placed at the front and back of the head of the mallet and at the top of the shaft of the mallet. Data was collected at 100 Hz with an accuracy of <0.5 mm.

Each participant took 10 shots hitting a croquet ball with their own mallet in their usual stance and style at a stationary croquet ball which was 4.5m from the striker's ball. This distance was chosen as it optimised the use of available laboratory space and to encourage the players to striker their ball at moderate pace. The five shots with the best marker reconstruction were used for each player. The average flexion of the wrist from the starting point of the swing to the peak of the backswing was determined as well as the rotation of the mallet about its shaft during each shot.

Marker data was reconstructed using the BTS SMART Motion Capture System [13]. IBM SPSS statistics package Version 23.0 [14] was used to carry out quantitative data analysis, with a Pearson correlation used to test the null hypothesis (no relationship between wrist flexion during the swing and lateral deviation of the mallet during the swing). The reconstructed mallet head was projected onto an XY plane parallel to the ground, with the twist angle measured in this plane. Wrist flexion was measured for the bottom hand relative to the starting position. The marker placements are shown in Figure 2. The 3D angle between markers 1, 2 and 3 was used to quantify wrist flexion. Mallet rotation was determined from the change in angle of the vector from marker 4 to marker 5, projected onto the ground, from the starting position of the swing to the top of the back-swing. The wrist angle referred to here is therefore the angle of the lower

wrist from the participant holding the mallet with a "standard grip" measured between the 5th meta-carpal and the ulnar surface of the forearm. While this angular deviation can involve some radio-ulnar deviation, the measurement taken in this study was simplified to measure only the magnitude of the metacarpal-ulnar angular changes and not the specific alignment of the wrist.

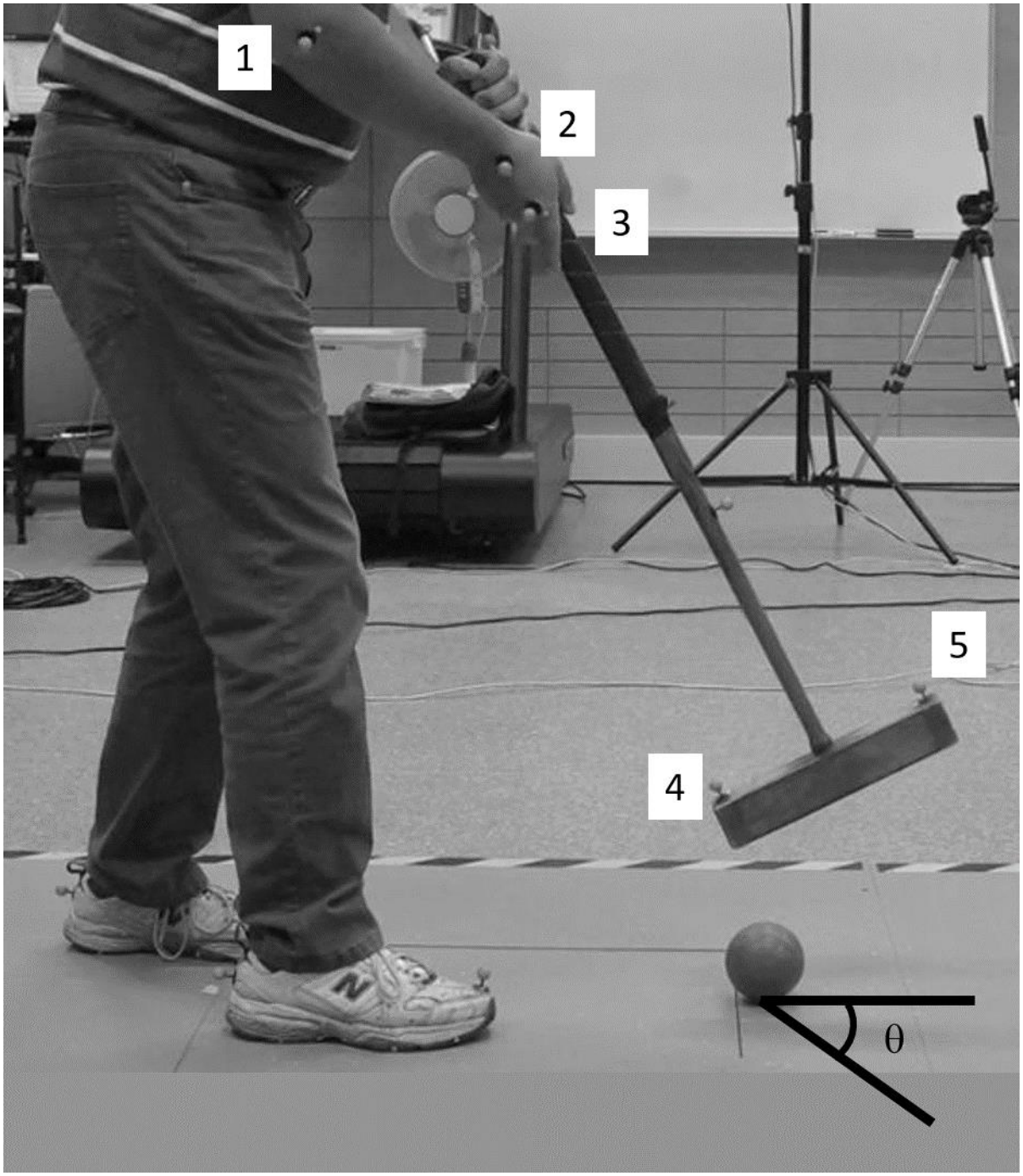

Figure 2. Marker placements shown on study participant. Markers 1, 2 and 3 define the wrist angle used in the study, while markers 4 and 5 are used to quantify rotation of the mallet during the croquet stroke. (Image of participant used with permission.)

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Results

The average flexion in wrist angle from the starting position was 7.1±3.9 degrees, ranging from virtually no bending to a maximum of 19 degrees. Rotation of the mallet head about the shaft varied from 0 to 15.4 degrees, with an average twist angle of 3.6±3.1 degrees.

A scatterplot of wrist angle change compared to mallet deviation is shown in Figure 3 with a fit line superimposed. A Pearson Correlation test showed a statistically significant correlation, moderate relationship between wrist flexion and mallet twist (p<0.01, r=0.33)

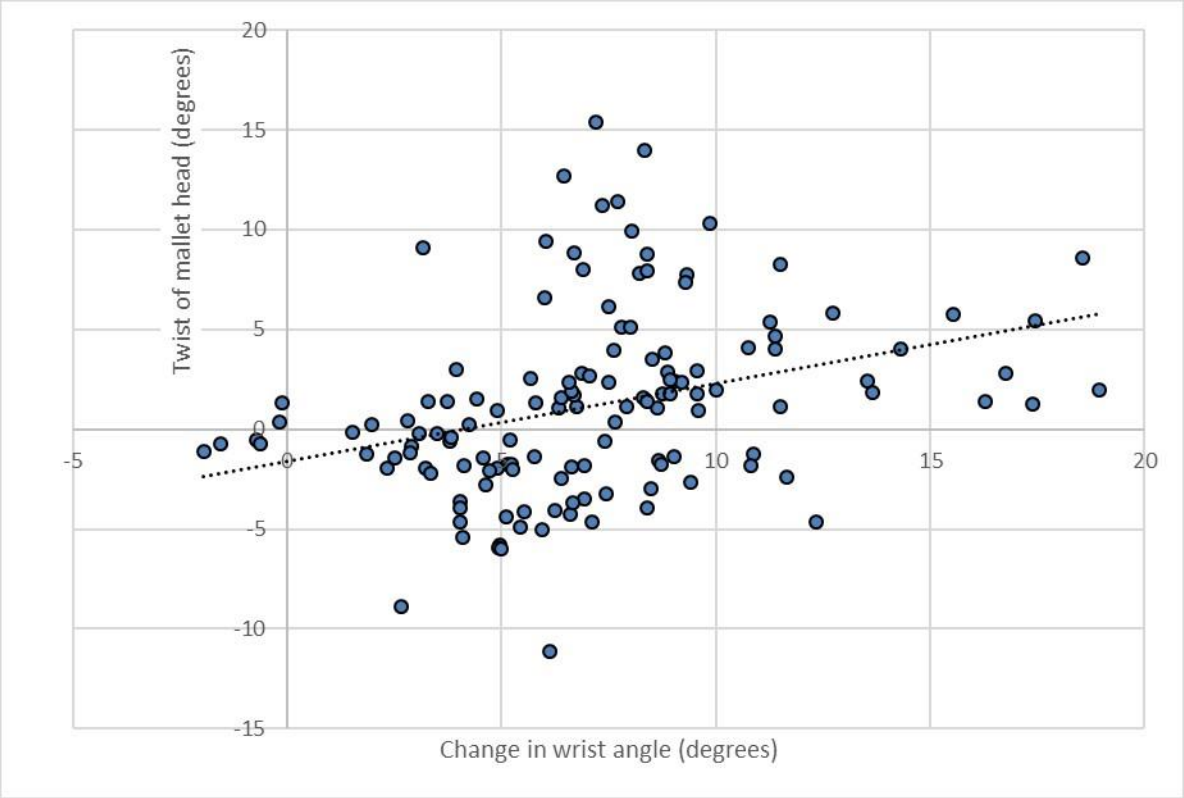

Figure 3. Scatterplot showing comparison of change of wrist angle from address to top of back swing and angle of twist of mallet during a croquet shot. Positive wrist angle change is interpreted as an increase in the angle between the thumb and the radial surface of the forearm, while positive mallet twist refers to rotation of the front surface of the mallet head towards the right, for a right-handed player.

Discussion

The study found a relationship between flexion of the lower wrist of a standard grip croquet player between the start of the back swing and at the peak of the backswing and rotation of the mallet about its shaft.

Numerous patented golf inventions seek to minimise or eradicate wrist flexion to create a consistent putting stroke. While there are few publications relating to the sport of croquet, the similarities to golf, as well as numerous anecdotal evidence collected by the author over a 20 year international croquet playing and coaching career support a conclusion that reducing the flexion of the wrists in a croquet shot is desirable to support players to have a longer period of time during the stroke in which the mallet is pointing squarely towards the target. In addition, a significant proportion of croquet injuries involve wrist pain. Again, reducing wrist flexion during a stroke should reduce torsional impacts on the wrist and reduce the occurrence of wrist injuries in croquet players.

A significant relationship was found between the rotation of the mallet head during a croquet swing and flexion of the lower wrist from the start of the swing to the peak of the backswing. This suggests a strong possibility that a significant mechanism generating the crooked backswing is lower wrist flexion.

Further studies in this area include interventions to reduce wrist flexion, for example visualisation and psychological practice, golf-like wrist supports or strapping to physically prevent motion. Pre- and post-testing would test if wrist flexion reduction alone could produce a more consistent swing. Programmes involving physical practice and mental practice techniques such as visualisation would need to be controlled for general improvement due to practice alone. For physical interventions such as golf-like devices which bind the wrist into a relatively fixed position need to also be tested at intervals after the intervention to establish if their efficacy lasts beyond the period of intervention. It is, however, also notable that strapping and physical devices which limit wrist motion are not forbidden by the Laws of Association Croquet, or the Rules of Golf Croquet [15], therefore suggesting if these physical mechanisms are effective in reducing mallet twist, they could be incorporated into the normal equipment of croquet player. While also not forbidden in golf, it is necessary to have a full range of wrist flexion for shots played away from the putting green. Longitudinal analyses of players who have undergone interventions, plus a control sample, would also be useful in investigating the effect of reducing wrist flexion on controlling wrist pain and reducing the occurrences of wrist injuries.

All methodology, proposed interventions and conclusions from this analysis can be immediately applied to putting in golf, as well as other sports in which limiting or controlling wrist flexion can be desirable.

Conclusion

An imperfect swing has long been associated with inconsistency when putting in golf, and in croquet it similarly limits performance requiring perfect timing to

strike a ball accurately. A player with a perfectly straight backswing and forward swing has a much larger period in which to strike a ball to drive it in the desired direction.

This study has established a relationship exists between flexion of the wrist during a croquet shot and rotation of the mallet about a longitudinal axis through its shaft. This relationship provides a possibility to train croquet players to improve their technique through working to minimise wrist movement.

In addition, one of the few publications to date relating to croquet has identified wrist injury as a significant affliction of croquet players. Reducing wrist movement during a croquet shot could reduce torsional forces on the wrist, thereby reducing the occurrence of repeated impact injuries.

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