THE LATERAL REACTION STEP IN TENNIS FOOTWORK

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Anecdotal evidence suggests that the key to quickness in tennis is the "reaction step", or the first step in response to the ball. There are three possible lateral reaction steps towards a wide and difficult shot: 1) step first with the outside foot towards the ball (jab step); 2) pivot on the outside foot while turning the hips towards the ball (pivot step); 3) bring the outside foot towards the body away from the ball, allowing gravity to assist the motion (drop step or gravity step). A controlled study of 10 participants showed that when a player used the gravity step to reach a lateral shot requiring a quick response, the player was 52% more likely to reach the ball ($p < 0.05$) and 100% more likely to control the return shot ($p < 0.05$) when compared to the jab step. A simple experiment utilizing a 9-marker motion analysis system provided further evidence to support these findings.

KEY WORDS: tennis, footwork, quickness, reaction, biomotion, motion analysis

INTRODUCTION: Quickness in tennis often seems to be an elusive attribute obscured by terms such as agility and grace. This elusiveness is apparent in the scientific literature in that there has not been a quantitative scientific study to date on the biomechanics of tennis footwork and its relationship to quickness. It has been anecdotally suggested by McLennan (1993, 1995) that the key to quickness in tennis is the first step in response to the ball, or the "reaction step" (Figure 1).

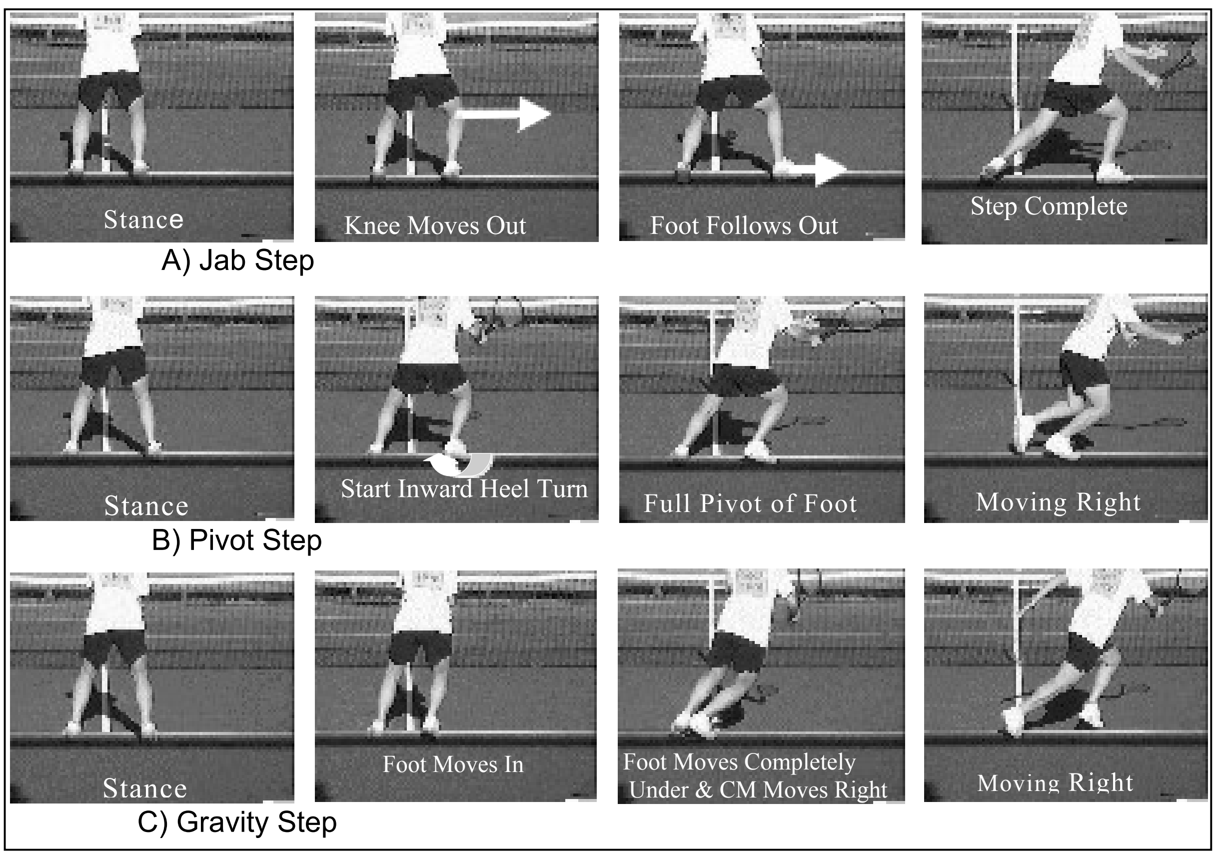


Figure 1 - The three lateral reaction steps.

There are three possible lateral reaction steps (Figure 1) that can be used to move towards a wide and difficult shot, each distinguished by the initial movement of the foot on the side of the body that is closest to the ball (McLennan, 1993). The first is the jab step, and is the most intuitive of the three. It consists of stepping first with the lead foot in the direction of the ball (Figure 1A). The second is the pivot step, and involves pivoting on the lead foot while turning the hips towards the ball and then making the first step towards the ball with the opposite leg (Figure 1B). The third is the gravity step, and involves bringing the lead foot in towards the body away from the ball as the hips turn (Figure 1C). This moves the center of mass (CM) of the body outside the base of support, allowing gravity to assist the motion towards the ball (Figure 1C). While the jab step is most often taught as "proper" footwork, it has been suggested that the gravity step represents the quickest and easiest way to get to a wide and difficult shot (McLennan, 1993, 1995). Boris Becker, Stefan Edberg, and Monica Seles, who are particularly known for their quickness, have been observed to use the gravity step.

Despite the lack of research on tennis footwork in the scientific literature, studies on the mechanics of starting motions in other sports may still serve to provide relevant insight. For example, there have been many studies on the biomechanics, economy, and efficiency of the explosive start in sprinting. Two of the keys to a good sprint start are reaction time and body positioning. While reaction time can be improved by performance feedback (Martinez & Ona, 1999), body positioning can be improved with a greater forward lean, which moves the center of gravity of the body to a position in front of the feet (Mero *et al.*, 1992; Harland & Steele, 1997). This imbalance may be similar to that exhibited at the beginning of the tennis gravity step presented here.

The purpose of this study was to determine the relative effectiveness of each type of reaction step using two separate approaches. The first approach was to examine the footwork of ten tennis players on the court to look for a correlation between their footwork and their ability to both reach and return the ball on wide and difficult shots. The second approach was to compare the kinematics of the reaction steps using a quantitative motion analysis system.

METHODS: Performance Study: Ten participants were recruited from a local tennis club, all of whom had been previously coached to use the gravity step (unrelated to the study). They were not informed of the purpose of the study, and they were instructed to use whatever means necessary to return each shot. Each participant was asked to return a total of 30 shots, consisting of 10 shots from each of three court positions: 1) standing centered with both heels on the baseline, 2) standing centered at the "T" formed by the two service boxes, and 3) running in from the baseline to the "T". The tennis balls were shot from a Playmate tennis ball machine located on the opposite side of the net from the participant at a centered position approximately 3 m inside the baseline. The ball speed was calibrated such that a ball shot from the machine would bounce twice before reaching the back fence behind the participant. The ball direction was calibrated such that a shot to either side of the participant would pass directly over the corresponding back corner of the singles court (if not struck by the participant). The specific corner to which each successive ball was shot was random. A video camera was positioned directly behind the participant to record his/her footwork.

The video data were then analyzed by recording four observations of each shot: 1) whether the shot was to the forehand or the backhand of the participant, 2) whether the participant was able to reach the ball with their racket, 3) whether the participant was able to return the ball in a "controlled" manner, and 4) what type of reaction step was used to reach the ball. A participant was said to be able to return the ball in a "controlled" manner when their return either went into or over the net. Shots that went forward but failed to reach the net, or shots that hit the participant's racket but went to the side or behind the participant were not considered to be "controlled" returns. This classification of a return being "controlled" is admittedly ad-hoc, but was necessary to objectively distinguish between shots in which the participant could barely reach the ball from shots in which the participant reached the ball with time to spare. The type of reaction step was classified by examining the position on the court of the lead foot at the instant the ball was shot from the machine and comparing it to the position of the lead foot on the court when the opposite foot left the ground. If the second position of the lead foot was closer to the ball than the first, the step was recorded as a jab step. If the second position was farther from the ball, it was recorded as a gravity step. If the second position was within approximately 3 cm of the first position, it was considered a pivot step (although some times this was not exactly a pivot, but instead a situation in which the participant picked up the lead foot and placed it back down in the same position). The results were then analyzed to determine the likelihood of reaching or returning a given shot by using a given reaction step and whether the shot was a backhand or forehand. Statistical significance between groups was determined using the test of binomial proportions.

Motion Analysis Study: To provide a biomechanical insight into the different reaction steps independent of the tennis environment, a single participant familiar with all three types of footwork was analyzed in a motion analysis laboratory and used as his own control. The participant was marked with nine retro-reflective markers that were tracked in three-dimensional space using a Qualisys motion analysis system. The nine markers were placed over relevant anatomical landmarks that completely specified the 3-D position of the right foot and approximated the 3-D positions of the right knee and hip joints, the torso, and the left foot. The center of mass of the entire body was approximated from the 3-D position of the torso. Each of the reaction steps were then performed moving to the right, the motion data were recorded, and the procedure was repeated a total of six times for each type of reaction step. Motion to the left was assumed to be biomechanically similar, and was not recorded.

RESULTS AND DISCUSSION: Performance Study: Of the 100 shots that were attempted by the participants starting at the baseline, all 100 were reached and 96 were controlled. With these high success rates, the reaction step clearly made little difference. However, those returns attempted from the other two court positions (starting at the "T" of the service box and charging from the baseline) were more difficult, requiring a significant effort and a quick initial response to reach the shot. Table 1 shows the combined results of these shots.

Table 1 Returns Requiring Quick Initial Movement

	Attempted	***Reached***		***Controlled***	
Gravity Step	**85**	**44**	**0.518***	**34**	**0.400****
Pivot Step	**65**	**32**	**0.492**	**23**	**0.354**
Jab Step	**50**	**17**	**0.340***	**10**	**0.200****
TOTALS	**200**	**93**	**0.465**	**67**	**0.335**

Significant differences ($p < 0.05$) between groups are marked with * and **.

These findings show that when a player used the gravity step, (s)he was 52% more likely to reach the ball, and 100% more likely to control the return, when compared to the jab step. Interestingly, whether a shot was a forehand or a backhand had no significant effect on the results (data not shown).

Motion Analysis Study: Figure 2 shows the position of the center of mass of the participant with respect to its starting position as a function of time for a typical trial of each type of reaction step. These results demonstrate that during both the pivot step and jab step, motion towards the ball starts rather slowly, but increases more rapidly around 0.3 seconds, with the jab step increasing more rapidly than the pivot step. The jab step resulted in about 20 cm greater distance moved towards the ball over the time period shown. Using the gravity step technique, it seems that although it starts with the lead foot moving away from the ball, significant motion of the overall body center of mass towards the ball occurs almost immediately. This progression towards the ball then remains relatively constant for the duration of the first 0.7 seconds, resulting in about 10 cm greater distance covered than for the jab step, and almost 30 cm more than for the

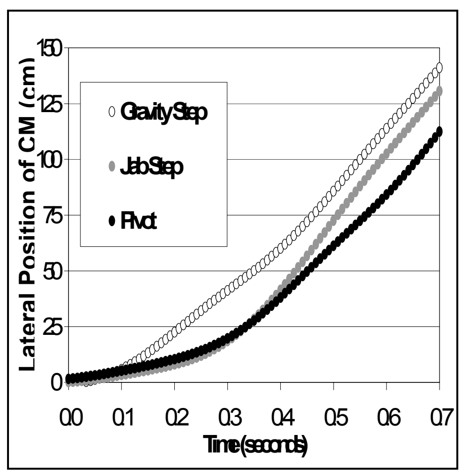
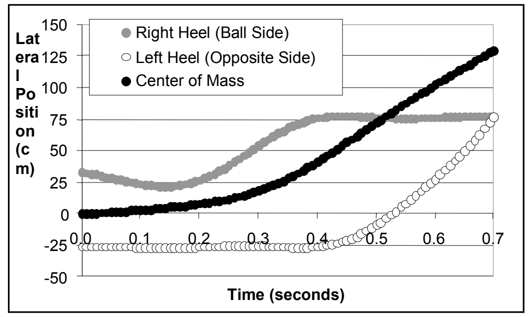


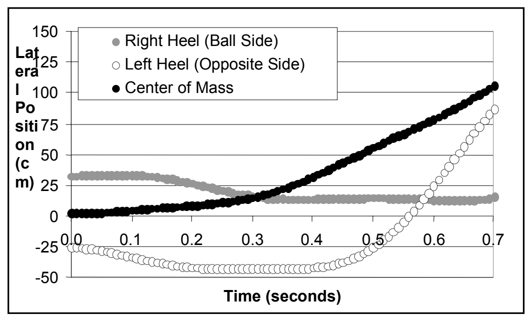
Figure 2. Lateral motion of body center of mass (CM).

pivot step over the time period shown.

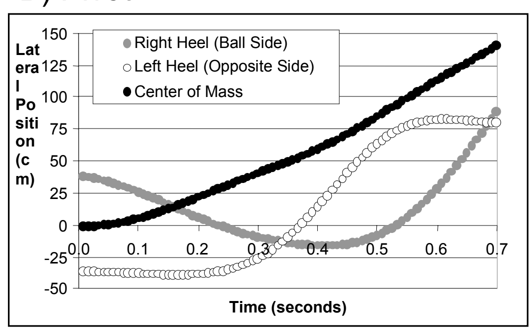
These results can be further explained by taking into consideration the positions of the feet relative to the body center of mass during the different reaction steps (Figure 3). In the jab step (Figure 3A), the center of mass of the body remains between the feet, and thus above the base of support, for about 0.5 seconds. Since the sharp increase in overall lateral motion occurs at around 0.3 seconds, this motion must be driven almost entirely by forces in the legs. In the pivot step (Figure 3B), the center of mass passes outside the base of support at about 0.3 seconds. In this case, the decreased performance may be explained by the fact that the lead leg must generate forces in the direction of motion over a smaller range of motion than in the jab step. Finally, in the gravity step (Figure 3C), the center of mass moves outside the base of support much sooner (~0.15 seconds). It seems likely that, in the latter case, the participant quickly moves into a position of “dynamic imbalance”, in which motion towards the ball is aided by gravity as well as the muscle forces in the opposite leg. In addition to the immediate positive effects that the gravity step footwork may have in getting to the ball most quickly, the possibility that it may also require less muscle action than the other methods may also be significant in terms of endurance. If a player were to consistently use the gravity step footwork over the course of a long match, it is possible that the decrease in muscle use would delay the onset of fatigue and the resulting decrease in performance.



A) Jab



B) Pivot



C) Gravity

Figure 3. Relative position of feet respect to body center of mass for of the three types of reaction

CONCLUSION: The most important implication of these findings is that, contrary to conventional wisdom and accepted practice, it seems that the gravity step should be taught by coaches as the preferred reaction step to reach a wide and difficult tennis shot. Ultimately, these results could also be applied to other sports where quick, lateral movement is critical, such as baseball (base stealing and fielding) and soccer (goaltending).

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