APPLYING BIOMECHANICS TO THE QUALITATIVE ANALYSIS OF THE FOREHAND

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The analysis of strokes like the tennis forehand is a demanding skill for coaches because of the complexity, speed, and interrelated biomechanical factors affecting the movement. Coaches will be most effective if biomechanical principles are integrated with other sciences in a comprehensive model of the qualitative analysis process (Knudson & Morrison 2002). This paper illustrates how six principles of biomechanics of tennis strokes can be used in the qualitative analysis of the tennis forehand. A case study is examined using biomechanical principles in the diagnosis of the forehand of a beginner.

KEY WORDS: diagnosis, evaluation, skill, stroke, technique

CHALENGES IN STROKE ANALYSIS: One of the most difficult, yet vitally important skills for tennis coaches is the qualitative analysis of strokes. Player improvement is directly related to the coaches' ability to guide player technique changes through practice and various other forms of training. Major challenges to this stroke analysis ability include the high-speed of tennis movements, variation in player performance, numerous biomechanical factors affecting technique and the interaction of all these factors with the dynamic environment of tennis play. This paper will present two important tools to help coaches with this difficult skill: General biomechanical principles of tennis and a broader vision of stroke analysis. The effectiveness of these two tools is illustrated with an example of forehand stroke analysis.

BROADER VISION OF STROKE ANALYSIS: Many coaches need to expand their vision of stroke analysis beyond the traditional, self-taught versions of visual error detection and correction. A simple visual comparison of the observed technique and the coaches' mental image of correct or "perfect" technique often lead to too much verbal feedback. This "correction complex" can lead to classic "paralysis by analysis." This section will summarize how a simple four-task model of qualitative analysis (Knudson & Morrison, 2002) can be used to help the tennis coach improve their qualitative analysis of strokes.

The four tasks of qualitative analysis are illustrated in Figure 1. The first task of qualitative analysis is preparation, where the coach gathers knowledge about the stroke, player, and environment so they can plan for effective stroke analysis. The two major sources of knowledge that must be combined are experience and the sport science research like tennis biomechanics. Several recent summaries of tennis stroke biomechanics have been published (Elliott et al. 2003; Knudson, 2006; Knudson & Elliott, 2004). An effective strategy for integrating this knowledge on a stroke is the establishment of critical features. Critical features are the key features of a movement that are necessary for optimal performance. Critical features are the most invariant aspects of a movement that are required for safe, efficient, and effective accomplishment of the goal. Tennis coaches should strive to synthesize the hundreds of details and cues they know about a skill into a few critical features with a well-established range of correctness. Critical features are not the details of "perfect" technique because there is no such thing as a perfect way to hit a tennis ball (Groppel, 1992; Knudson, 2006). Critical features are primary foci of teaching and qualitative analysis and must be translated into cues relevant to the specific player.

Observation of the stroke is the second task of qualitative analysis. In observation the coach uses all their senses to gather information about the player's performance. An observational strategy is a systematic plan to gather all the relevant sensory information about the performance of a tennis stroke. A coach feeding balls to a client's forehand can get information on the spin or heaviness of their strokes by volleying or stroking the client's shots back. This kinesthetic information can be easily gathered without disrupting the visual information on the client's stroke technique. Most coaches are well aware of the speed and

spin information in the sound of impact in strokes. The sound of impact or the marks of footwork on a clay court can provide a useful of information for the qualitative analysis of tennis.

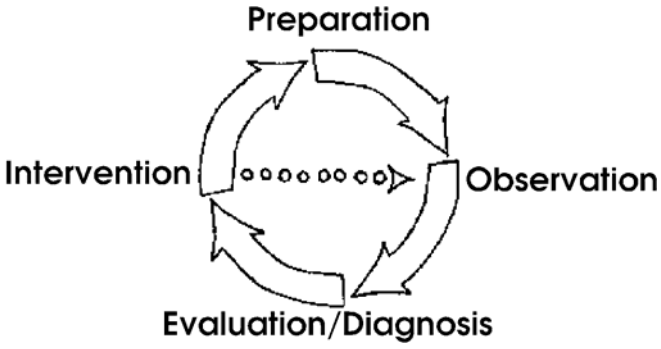

Figure 1. The Knudson & Morrison (2002) model of qualitative analysis. In on-court analysis the coach will return immediately to observation after providing intervention to the player.

Other elements of a good observational strategy are attention to the situation being analyzed, the number of trials observed, vantage points, and the potential need of extended observational power. By planning the situation and exact nature of the task performed the coach can be assured that the performance is as similar as possible to actual competition. Coaches need to plan to observe several trials based on the kind of skill and the skill level of the player. A minimum number of trials to be observed to reduce the risk of focusing on insignificant variations in technique are usually between 5 and 8 (Knudson & Morrison, 2002). The observational strategy should also specify several vantage points since most strokes are three-dimensional. The appropriate vantage point is perpendicular to the plane of motion to be observed. For example, the distance away from the body the ball is contacted in the forehand should usually be observed from behind. Observation sometimes needs to be extended with the use of videotape replay when the movement of interest is fast. The major benefits of videotaping in tennis are the abilities to repeat and slow down the fast actions of strokes. A shutter setting of 1/1000 of a second is usually necessary to prevent blurring of the images. Pause and jog-shuttle controls on the VCR playback or computer programs for digital video allow the analyst to review the movement down to 1/30 or 1/60 of a second. Considerable movement detail beyond live observation can be detected by slow-motion and stop-action review of video.

The third task of qualitative analysis involves two very important steps. First, the coach evaluates the performance, identifying both the strengths and weaknesses. Then the coach diagnoses performance or identifies the likely underlying causes of poor performance. These two steps may be the most difficult parts of qualitative analysis. This task is such a challenge because of the multifaceted nature of the biomechanics of tennis strokes and the need to integrate experience and other sport sciences into in these decisions.

Evaluation involves the careful judgments of identifying the strengths and weaknesses of performance. Evaluation is facilitated when the coach can use a three level range of correctness (too little, within normal range, too much) for each critical feature of a stroke. Diagnosis of the underlying causes of poor performance is achieved by prioritizing the effect of the weaknesses identified. Knudson and Morrison (2002) have noted six different rationale or approaches to diagnosis: Relating actions to previous actions, maximizing improvement, in order of difficulty, in the sequence of the movement, from the base of support up, and critical features first. Some of the rationale can also be combined to form an effective diagnostic approach. Suppose a player has been evaluated as weak in generating racket speed through the contact zone on the forehand. An analyst could combine the relating actions to previous actions and maximizing improvement rationale to diagnosis the performance. He/she first asks themselves if there are previous actions (backswing, forward swing technique, timing, strength) that might be related to the problem (slow racket through impact). If the performer has good timing and adequate strength for this skill, the analyst must decide if intervention on racket preparation, forward stroke, or follow-through technique would be most effective in improving performance.

Intervention is the last task of qualitative analysis and good tennis coaches find many ways to intervene in the learning process to help players improve. Intervention is more than providing the traditional feedback or just corrections. The intervention task of qualitative

analysis involves the administration of any change in training that serves to improve performance. There are a variety of intervention strategies (Knudson & Morrison, 2002) including use of cue words or phrases, exaggeration of corrections, visual modeling, task or practice modification, manual guidance, and conditioning. The best coaches have all these tools at their disposal, but carefully select one intervention strategy for a specific individual or situation to avoid paralysis by analysis. The sport science most useful for stroke diagnosis and selecting the best intervention is biomechanics. The next section will present six simple principles that can be used to summarize the biomechanics of tennis.

BIOMECHANICAL PRINCIPLES OF TENNIS: Biomechanical studies have reported a vast amount of information about the motions, muscle activity, and forces in tennis strokes. What coaches need for qualitative analysis of strokes is a simple theoretical structure for this information. This biomechanical knowledge or "principles" facilitate the stroke analysis process. A new book on the biomechanics of tennis strokes (Knudson, 2006) has proposed simple principles of stroke biomechanics. The author has used common language for these principles to help in creating the critical features and cues that can be understood by players and coaches. This section will show how these principles can be integrated with professional experience and other sport sciences to improve the qualitative analysis of the forehand drive.
The principle of *force and motion* says that stroke or body movement is modified by the application of force(s) over a period of time. So force and timing of force (*force and time* principle) application are critical elements of technique. The principle of *coordination and transfer* is concerned with the origins of the forces that are used to create strokes. The *balance and inertia* principle says that players must strike a compromise between mobility and stability in technique. The *range of motion* principle states that there is a continuum of body motion(s) used between low effort/high accuracy that tend to use simultaneous segment movements, and maximum effort/high speed movements that tend to use sequential motions. The optimal *projection* principle says that there are "windows" of advantageous initial ball trajectories for tennis strokes. The *spin* principle refers to the creation of ball spin to modify shot trajectory or bounce.
A tennis coach planning to qualitatively analyze for forehand of a player could integrate this principles with their experience, knowledge of the research on the forehand (for review see: Knudson & Elliott, 2004), and coaching literature. For example, Knudson (1991) recommended that four critical features be focused on in the qualitative analysis of the topspin forehand drive from the classic square stance. Table 1 shows how these four simple teaching and analysis concepts relate to the biomechanical principles that help explain their importance.

Table 1: Coaching Critical Features and Biomechanical Principles of the Forehand

Critical Feature	**Principle**
Readiness & unweighting	Balance & Inertia, Force & Time
Racket preparation	Coordination & Transfer, Range of Motion
Body rotation & stroke arc	Coordination & Transfer, Spin, Optimal Projection
Follow-through	Range of Motion, Force & Time

Adapted from Knudson (1991, 2006)

The critical feature of readiness and unweighting maximizes the player's ability to intercept the ball. In preparing for a forehand a play hops or split-steps as the opponent strokes the ball. The technique for this favors mobility over stability (Balance & Inertia) and maximizes initial force (Force & Time) in a short amount of time by using stretch-shortening cycle muscle actions in the legs. Early and simple racket preparation fosters adequate range of motion and flexibility in a loop backswing that can transfer energy from the legs and trunk to accelerate the arm and racket. The critical feature of body rotation and stroke path relates to the sequential coordination and transfer of energy used to create high racket speed, and the racket path at impact that creates ball direction (Optimal Projection) and spin. The final critical feature of a high follow-through uses a long range of motion and maximizes the time

of force application to slow the racket which minimizes peak forces on the body, reducing the risk of injury.
These simple cues usually have more extensive descriptions attached to them. The early and simple racket preparation feature includes the traditional unit turn (body rotates sideways to the net) and a small loop backswing pointing the racket to the back fence. This is the beauty of well designed cues. Players can focus on one thing or be reminded of one word, and a flood of related information can be attached to this one cue or phrase. In the analyst's mind, these more extensive descriptions should also include the range of correctness that is appropriate for each critical feature. The next section will examine how these critical features and principles can be used in the qualitative analysis of a forehand drive.

A FOREHAND EXAMPLE: The forehand of a typical beginning player is illustrated in Figure 2. Assume the player using an eastern and the observation of several trials show similar performance as is illustrated. Evaluate these images to determine the strengths and weaknesses of this player's forehand. Following evaluation of the critical features, diagnose the forehand and think about what intervention you think would help this player improve their forehand the most. Compare your evaluation and diagnosis to the suggestions below and discuss this case with fellow coaches.

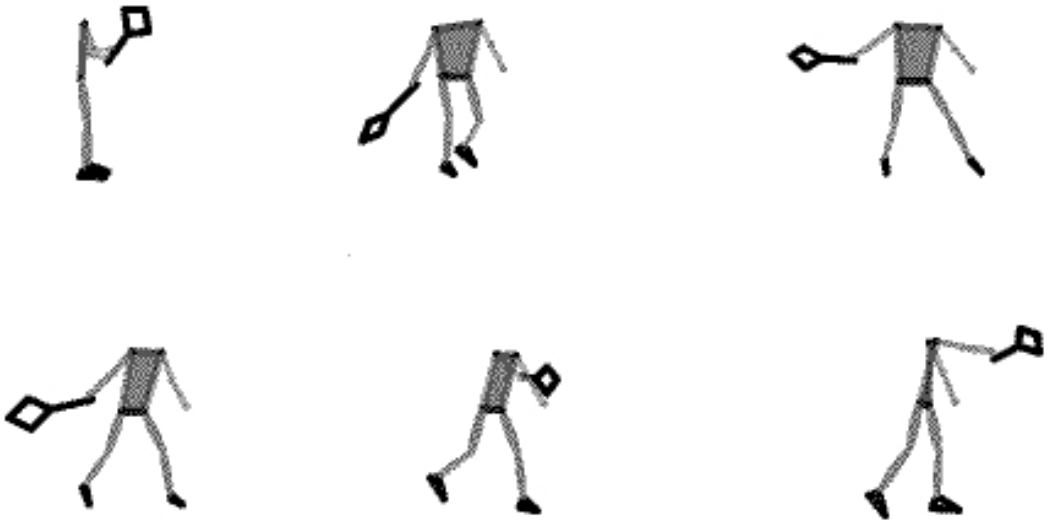

Figure 2. --Animations of key positions in a forehand of a beginning player. The time between images is not uniform.

Evaluation of the forehand illustrated shows several strengths, including an early, simple racket backswing, a well coordinated square stance and weight shift, forward contact with the ball (not pictured) and a slightly upward racket path. Weaknesses are the lack of a split step in the ready position, minimal loop in the backswing, primarily simultaneous coordination in the forward swing, and limited range of motion in the follow-through. To diagnosis this performance these points will be weighed using the biomechanical principles and forehand research to relate action to previous actions and what might maximize improvement.
Assuming the player has the ultimate goal of improvement to intermediate and advanced-level play the coach might diagnose performance this way. The player has a restricted range of motion in the arm (straight arm) and in the stroke that is common in some beginners. The minimal loop in the backswing and flat racket path are also common compromises in early players that increase their change of hitting the ball. The lack of a split step will not likely hurt performance until the level of play increases demands on court coverage. Increasing the range of motion and speed of the racket are likely to help the player develop good coordination and transfer of energy, more optimal projection, and ball spin. Since these are

long-term objectives the coach begins to think about several intervention strategies to work on the forward swing and follow-through.
Immediate intervention during the practice session where these strokes were observed and diagnosed typically would include some verbal feedback. This would be followed up by other appropriate intervention that is coordinated with subsequent qualitative analyses of the strokes observed in the process. The coach might plan a series of different drills to encourage faster racket speeds (faster ball feeds, deeper targets). In this example a coach might "sandwich" the initial cues for improvement between positive reinforcements of the strengths the player exhibited: "Excellent racket preparation and leg drive. On the next few forehands I want you to focus on the image of the racket accelerating up through the ball with racket finishing high above your head. Nice job, I think you are ready to try to hit the ball harder." The coach could then reinforce one or two elements of this intervention strategy with cue words like *high follow-through," "fast stroke," or "sweep up."
As the player practices the drills implemented by the coach, the coach returns to observation and repeats the qualitative analysis process. This monitoring of the intervention is important to fine tuning the instruction and training of players. In this example it might become clear in subsequent observations that the player is not strong enough to use a more sequential coordination in the forward swing. If that were true, the coach could test the player's strengths and suggest conditioning or a lighter racket. It would be a disservice to the player to encourage technique that is not possible given their current equipment or physical development.

SUMMARY: Biomechanics research is clear that there is variability in technique within and between athletes. This is even more prevalent in dynamic-environment sports like tennis. Six principles of biomechanics have been proposed as an effective summary of the biomechanics of tennis. These principles can be integrated with experience and other sport sciences to help coaches improve their qualitative analysis of strokes. This larger vision of qualitative analysis is necessary to maximize player improvement and for truly professional coaching.

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