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Biomechanical insights on Tennis Canada's skill fundamental phases: Ecological dynamics, force generation and reading gameplay

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ABSTRACT

Using an ecological dynamics perspective and informed by a game-based approach to coaching tennis, this paper applies a biomechanical analysis to Tennis Canada's five fundamental skill phases, namely recovery, impact point, set-up, hitting zone and grip, along with tactical concepts of time, space, force, and risk. The intent of this paper is to locate, within the player reading gameplay, the biomechanical principles for force generation in tennis strokes that inform Tennis Canada's five fundamental skill phases. We suggest that these fundamentals can be effectively employed during gameplay so that force can be considered a part of tactical awareness. From a game-based approach we consider gameplay as referring to a player's ability to read the emerging patterns of play, as critical to successful application of biomechanical principles to stroke mechanics. We propose that perception-action coupling ideas from ecological psychology, guided by the 4R model of read, respond, react, and recover for the stroke movement cycle, promotes both novice and advance tennis players ability to play tennis. The goal of this paper is therefore to help the tennis teaching professional combine ideas from sports pedagogy, biomechanics, and motor learning into the coaching of tennis players, so that their tennis players can experience the flow of forces from a well-played point.

Key words: Biomechanics, ecological psychology, percept-action coupling, game-based learning.

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INTRODUCTION

Studying force generation in sports is understood as biomechanics, as in the application of mechanical laws relating to the movement of the human body. By gameplay we refer to the player being able to read and be engaged in the emerging patterns of play as determined by the rules, game intent and other player's actions. The intent of this paper is to locate within the player reading gameplay, the biomechanical principles that inform Tennis Canada's five fundamental skill phases namely recovery, impact point, set-up, hitting zone and the grip, and how these can be effectively employed during gameplay so that force generation can be considered a part of tactical awareness. These fundamental skill phases are used in Tennis Canada's Tennis Professional Association coaching certification courses (Tennis Canada, 2015). In addition, we will apply an ecological dynamic perspective to understand how gameplay context triggers skill application as we develop insight on how the technical cues suggested by Tennis Canada promote skillful gameplay. An ecological dynamics approach views movement as emerging from a self-organizing relationship formed between an individual, the task being performed, and the environment (including the opponent) in which it occurs, creating a movement system (Hopper & Rhoades, 2022a; O'Sullivan et al., 2020). Skills applied effectively in the game are understood as dynamic functional movement solutions that emerge as the player continuously interacts with an array of constraints related to the task and the environment. Therefore, forces generated by the player's actions to execute a successful skill, are adaptive in nature, becoming more efficient based on a holistic engagement that "seeks to encompass physical capacities embedded in perception...memory, anticipation and decision-making learning" (O'Sullivan et al., 2020, p. 452).

Efficiency in motor skill production refers to the ability to perform movements or skills with the least amount of effort and waste of energy, while still achieving the desired outcome (Knudson, 2021). It encompasses factors such as accuracy, speed, fluidity, power, and economy of movement. High efficiency in motor skill production allows for a player's more consistent performance, conservation of energy and movement endurance. In open skill sports like tennis, the repetitive nature of the sport and demands of using an array of strokes for different situations, requires the player to read, responding to the opponent's actions, and then select the most effective stroke to achieve the desired outcome. So, in this paper we unpack the biomechanical principles that inform Tennis Canada's five skill fundamental phases for novice to advanced players, and the capacity of the player to tactically read the situation to effectively respond with biomechanically efficient strokes.

PLAY-PRACTICE-PLAY: TACTICAL CONCEPTS, ATTUNEMENT AND BIOMECHANICS

In line with Tennis Canada's commitment to the play-practice-play approach (Tennis Canada, 2015), related to physical education game-centered ideas promoted by the Teaching Games for Understanding (TGfU) model (Bunker, Thorpe and Almond, 1986), a key premise is to understand skill fundamentals from a play a game first, then practice to re-play the focus game. The goal in this approach is for players to play a game that emphasizes the tactical application of a certain stroke skill fundamental, to then practice this fundamental through a series of progressive game-like tasks framed by a review, by the instructor, of a game related aspect of a stroke skill fundamental. After suitable practice with certain goals achieved, players then return to play the modified game that started the learning process (see video explanations in Hopper, 2022). This return to the game with tactical insights and practiced technical prompts, invites the player to build stroke mechanics in relation to basic game strategies, which in turn leads to the player's ability to read the game and select the appropriate shot.

Strategies refer to ways of playing that enable you to engage successfully in the structure of the game. For example, the International Tennis Federation (ITF) refers to strategic principles of play such as (1) keep ball in play, (2) positioning to cover court area, (3) placement of shot to make the opponent move, and (4) application of force on the ball based on your strengths and opponent's weakness (ITF-Academy, 2021). Tactics are understood as generalized ideas, based on a strategic goal, that can be combined to achieve a certain outcome in a game, to gain an advantage over an opponent in playing a point. As noted by sport pedagogy scholars Mitchell et al. (2021) and Hopper (2011), tactical concepts of Time, Space, Risk and Force can be used to implement strategic principles. These tactical concepts create a lens with which to interpret the demands of the game, the opportunities to gain an advantage, to win points. For example, Tennis Canada (2015) curriculum refers to these tactical concepts in relation to time, space, and risk. The following examples are taken from Tennis Canada module course materials (Tennis Canada, 2019):

1. "Buyback time when under pressure by sending a higher shot to gain time to recover" and "take away time to put the opponent under pressure by taking the ball early or hitting the ball harder" (ball on-rise or volley).
2. "Outlast the opponent by keeping the ball consistently over the net and in the court" and "move the opponent around by directing the ball to open court or the opponent's weakness."
3. The risk tactical concept refers to when to defend to keep the ball in play, when to attack to put pressure on the opponent, and when to play neutral to maintain engagement in the point.

In relation to force, Tennis Canada refers to the five skill fundamental phases that offer technical pointers within the reception and projection stroke movement cycle that involves footwork and body coordination to the trajectory of the ball. This cycle enables the player to generate controlled force on the tennis ball as they develop their ability to play the game, influencing the path, angle, and speed (PAS) of the racket face on the ball based on their intent for the stroke in the game situation. These skill fundamentals are only useful if learned in relation to a game where the player has become attuned to the opportunities to execute a stroke by manipulating time, space, and force at a certain risk level within the process of playing a point. Ecological psychology refers to these opportunities as affordances.

Renshaw and Chow (2019) indicate affordances "consist of environmental properties that afford 'opportunities for action' for each individual" (p. 107). To take advantage of these affordances, a player needs to be able to read the game, to anticipate what the opponent will do next in relation to space, time and force on the ball. As gameplay happens, the player plans their next actions based on the emerging patterns of play, their personal ability to generate force on the ball, and the level of risk they wish to take. This reading refers to a perception action coupling where the "individual is [both] a perceiver of the environment and a behaver in the environment. Hence, what we see in our environment, determines what we do'' (p. 106). Perception-action coupling is the coordination between vision (including time and space) and movement. From dynamics systems perspective this means the player becomes attuned to the relevant affordances (invitations for action) within their environment including the actions of their opponent. In a tennis competition, this perception-action coupling involves many different information forms but essentially, the focus should be on the court, how to manipulate the equipment to direct the ball, the opponent's actions (their strengths and weaknesses), and the score in the game. As noted by Carvalho et al. (2013) these affordances are generated by coach designed practices and games by setting up constraints in tasks "to guide players' attention to relevant informational sources based on their own actions" (p. 10).

TECHNICAL CUES AND BIOMECHANICS

Often when referring to biomechanics coaches and PE teachers think of technique. As noted by Martinez-Gallego (2021) as part of the ITF Tennis Academy program, it is important to understand however, that the two, while related, are not the same. Biomechanics is a sport science which studies the principles which affect human motion. Technique refers to a given player's practical application of these principles in a certain stroke or movement. For example, two players can have very different techniques when serving a ball, yet use the same biomechanical principles (i.e., coordination chain, elastic energy) in such a way that both shots are effective. Therefore, to understand how to apply the biomechanical principles a player needs to understand their own abilities and the gameplay context in which the principles will be applied (tactical understanding). Through game-like, problem-based experimentation in relation to well design constraints and coach guidance (Carvalho et al., 2013), the player can come to appreciate how they can effectively generate the desired force and direction on the ball.

Technical cues are used as a guide to biomechanical principles. They are general in nature to allow for individual interpretation but based on a commitment for the player to generate the effective flow of forces within the tactical demands of the game. To teach the technical cues within a game-based approach, Tennis Canada focuses on four categories to guide a tennis lesson. The first category, "I can play point," encourages players to play different opponents, promoting games with a quick scoring system that causes

players to rotate opponents and typically scoring points for their team (Tennis Canada 2015, p. 13). Tennis Canada then groups strokes into three categories of (1) 'I can rally,' (2) 'I can start a point,' and (3) 'I can play net.' Based on these stroke categories, Table 1 highlights Tennis Canada (2019) five skill fundamental areas to analyze stroke categories: (1) recovery including footwork between shots, (2) impact point where to contact the ball in relation to the body, (3) body set-up before striking the ball, (4) hitting zone based on PAS of the racket face before, during and after impact with the ball (see videos at Hopper, 2022), and (5) how to grip the racket (eastern forehand, backhand grip, continental for the volley and serve).

Table 1

Tennis Canada Five Fundamentals Checklist.*

SKILL PHASES	GROUNDSTROKES	SERVE	VOLLEY
RECOVERY *In an athletic ready position, feet slightly staggered, facing the opponent.*	• Footwork to **'home-base'** in a balanced ready position with head up. • ***Push-off** using* shuffle, crossover or running steps as distance determines	• From serve locate behind baseline or beyond service-line • **Before** the opponent impacts the ball • *Forward balance with weight in motion*	• In a **ready position,** weight forward, *keeping the body in motion.* • **Before** the **ball bounces** on other side • Racket supported by non-dominant hand
IMPACT POINT *Centre of strings. Ball comfortable distance from body*	• At knee to waist height • Slightly **out and in front** • Comfortable distance *in front and to the side of the body*	• Upward **Extended arm** • Slightly **out and in front** • 1 o'clock (right), 11 o'clock (left)	• At **chest height** • Slightly **out and in front** • At a **comfortable distance** • *Body adjusts to ball height*
SET-UP for stroke *Arm and body move as one unit (unit turn) before the ball enters the court on the player's side.*	• **Move** to proper location with **balance** • Get **sideways** by preparing **foot, body & racquet** (unit turn) • *Racket taken back **high*** • **Before** the coming ball **bounces** • *Keep racket in motion during take back*	• Stand **sideways** behind baseline • Coordinate both arms into a **'Trophy Position'** throwing set-up with tossing arm reach up, held high before ball comes down • **Toss** the **ball up & in front** of the body **slightly above impact point** • *Keep racket in motion*	Based on side ball comes: • **Step out** preparing racquet behind impact point making a slight **shoulder turn** • Backhand side **hold** and prepare the racquet with the **non-dominant hand** • Prepare **before** ball **crosses the net** • Step-out/**Catch**/step forward *action to the ball.*
HITTING ZONE *Strings move with stability to the intended target. Laid back wrist*	• **'Extend' the racquet face towards the target** as **long** as possible • Maintain a **stable & laid-back wrist** at the contact • *Low to high path for topspin, high low path for slice*	• **'Throw' the racquet face up at the ball** and towards the target • Use **shoulder rotation** *(from high tossing arm to low racket arm)* and **forearm pronation** (rotate forearm outward)	• Maintain a **'catching'** action to ensure the racquet faces the target before and after hitting the ball • **Keep a stable racquet face** before and after hitting the ball. • *On the ball, from the wrist, use 'chop' action based on the angle of the racket face.*
GRIP (Basic) *Grip changes as the player develops.* • ***Eastern forehand*** • ***Continental*** • ***Eastern Backhand***	• Continental (top/side bevel) • Eastern Forehand (side bevel) One-handed BH: • Eastern Backhand (top bevel) Two-handed BH: • Bottom hand: Continental • Top hand: Eastern grip	• Initial Continental (top/side bevel) • Allows a **stable racquet face at impact** • Extend with **Eastern backhand grip** increase wrist action • Feels like hammering the edge of the racket	• Continental (top/side bevel) • Allows a **stable & open racquet face at contact** • *Eastern backhand if time for grip change*

*Adapted from Tennis Canada (2019) instructor course, April 2019. Italic text added to emphasize key points linked to biomechanical properties.

THE 4RS AND THE STROKE MOVEMENT CYCLE

To analyze the skill fundamental areas it is important to note that every stroke is contained within a stroke movement cycle from striking the ball to recovery, to then reading the situation, responding as the opponent sets up to execute a stroke, then preparing to play a stroke in response by reacting to the arriving ball in order to execute another stroke and then, if needed, repeat the cycle. Hopper (2003, 2007) and ITF-Academy (2019) label this as the 4R model. Figure 1 shows this stroke movement cycle. Note in this diagram how the "Base" positioning either located behind the backline or at the net, refers to a RECOVERY position between shots, that is critical to initiate any stroke. This phase then sets up the player to READ the situation and decide about where to go in the court in anticipation of the opponent's next shot and their potential response. Critically, this decision-making movement is based on how the opponent is shaping up to play their shot. The decision made from the READ phase informs the RESPOND phase where the player selects a shot as the opponent plays the ball, and the player puts their body in motion with a jump or skip step to cover the target area as the opponent strikes the ball. In the REACT phase the player adjusts their positioning relative to the ball arriving in their court and executes the selected shot, but with the ability to make final adjustments, to Respond, to what the opponent does or a mis-bounce. The cycle then moves back to the RECOVERY phase, and the process starts again if the ball is still in play.

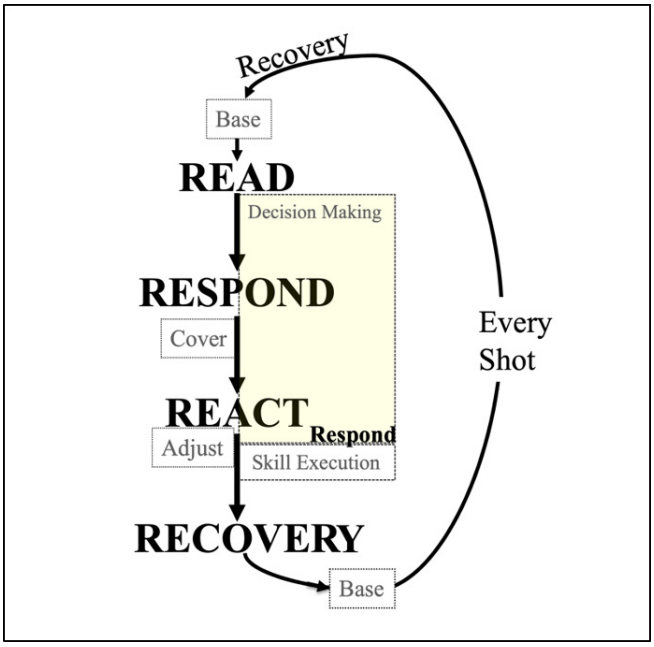

Figure 1. *The 4Rs model for reading play in the stroke movement cycle.*

The 4R model creates a decision-making movement cycle for each stroke. With this in mind, we can now unpack the biomechanics for each skill fundamental area. To do that we adapted Martinez-Gallego (2021) mnemonic BIOMEC framework by adding stability (S) to focus on racket face. Using the BIOMECS framework we then have basic definitions for biomechanical principles applied to tennis outlined in Table 2.

Table 2

Definition of key biomechanical terms for tennis labeled BIOMECS.

Balance (B)
Balance refers to the capability of the player to control and/or manipulate the relationship between their center of mass (CM) and base of support. Creating a wider base of support increases the overall stability. Shifting balance from back to front foot develops linear momentum in the direction of shift. Static balance is the ability to maintain a base of support with minimal movement. Dynamic balance is the ability to perform a task while maintaining a stable position. Additionally, balance is improved by lowering the CM. A lower CM reduces the leverage that the body has and increases the amount of force necessary to move the CM outside of the base of support. However, a higher CM provides a mechanical advantage to move the CM outside of the base of support, by creating a longer lever arm and increasing movement potential.
Inertia linear and angular (I)
Inertia is the tendency of a body at rest to remain at rest or a body in (angular or linear) motion to remain in motion unless disturbed by an external force. Angular inertia is a product of mass and radius (squared) and the amount based on length of lever and the weight of the object. For example, a player chasing down a drop shot will have the tendency to remain in motion (maintaining constant linear inertia) unless acted upon by an outside force. The muscles of the player's lower limbs will help generate a force using the ground to slow the player down and then recover court position.
Opposite force (O)
Opposite force refers to the law that for every action/force there is an equal and opposite reaction/force. Ground reaction force (GRF) refers to force obtained from the ground when the player pushes against it. For example, jumping for a smash has preparatory movements where the player will bend their knees, lowering their body, and in effect push against the ground. In return, the ground reacts and pushes back against the players, which in turn assists the players with their jump. The reason that the player moves, and the ground does not, relate to the difference in weight of the player as compared to the earth.
Momentum (M)
Players wanting to increase their racquet speed need to increase the momentum they generate. It is important to understand that the development of both linear and angular momentum starts with ground forces generated by the players through their footwork. There are two different types of momentum: angular and linear. Linear momentum is the quantity of linear motion that a body possesses (product of mass and velocity) and best seen in closed stance forehand where weight is transferred from back foot to front. Angular momentum is the quantity of angular motion that a body possesses, best seen in the open stance forehand where momentum comes from the rotation of the upper body in relation to the more front facing lower body stance. Impulse refers to the amount and direction of momentum applied at one time, such as the racquet swing in the serve.

Elastic energy (E)
Elastic energy is the energy stored in muscles and tendons because of stretching the muscle (i.e., during the backswing phase of a stroke). This is also known as the passive contractile component of muscle tissue; it requires no active contraction to store or release this energy. The stretched muscles (that are in a higher active muscle state than they were when at rest) and tendons recoil back to their original shape and in so doing a portion of the stored energy is recovered and assists the movement.
Coordination Chain (C)
Coordination can be summarized as the combination of muscle contractions and skeletal leverage system that allow for the efficient performance of different movements, either simultaneously or separately. For example, a coordination or flow of movements from the ground, via the trunk to the racquet-arm is required for effective stroke production. In the volley, where precision is needed, body segments will move more as a unit, while in the serve and drives, body segments will be coordinated sequentially such that high racquet speeds can be generated from optimum timing of the kinetic chain of actions in the body segments.
Stability (S)
Related to balance, stability refers to executing movement or a stroke with resistance to both linear and angular acceleration, or rather, resistance to disruption of equilibrium. Generally, athletes increase stability to prevent unwanted movement, for example in controlling the face of the racket at contact with the ball. The difference between stability and balance is that balance is your ability to control your body without movement against gravity. Stability is your ability to control your body and related body parts during movement. For example, when contacting the ball, the racket swing and hand controls a stable and flat racket face on contact with the ball allowing the player to control the direction, height, speed, and spin of the ball.

In the next section, referring to Table 1, we will apply the BIOMECS framework to each skill fundamental phase, selecting key biomechanical principles implied by the technical prompts. In the final section we will then return to Figure 1, the player reading gameplay, to locate these biomechanical insights for force generation within the 4R stroke movement cycle.

ANALYSIS OF SKILL FUNDAMENTAL PHASES

Applying BIOMECS to each skill fundamental phase in Figure 1 allows us to indicate the biomechanical principles that are implied by the suggested technical cues. For each phase below, we have highlighted at least three biomechanical principles.

Recovery and footwork

The recovery into an athletic position refers to the recovery movements in tennis after completing a stroke. It means moving into a base position either behind the baseline or located just in front of halfway between the service line and the net, to defend the court area, whilst facing the opponent. The key for any stroke is the opposite force push back from the GRF that allows quick movement recovery. Players select between running steps to move quickly back into the court, cross-over steps to cover more ground as they face an opponent, and side-stepping to cover immediate court space. Here stability through dynamic balance is critical as the player moves, observing the opponent's actions and preparing to set-up for the next stroke. The key is to overcome stationary inertia. If a player stops then inertia sets in which takes time and more force to overcome. Therefore, ideally, a player always wants short quick skip steps, in motion, whilst positioning themselves during a point.

Impact point

The impact point refers to the place where the ball is struck in relation to the body. Ideally, the impact point wants to be a comfortable distance from the body, just in front and to the side. The player wants a feeling of poised instability as they contact the ball and then move effortlessly into recovery. The intent for locating the ideal impact point is the coordination of all the body segments to move and adjust in relation to the ball and the selected shot. Key is to anticipate where to go in the court to contact the ball in the ideal place to execute the forces, generated by the body for the stroke, to be released from the racket strings onto the ball with the desired direction, speed and power. For drives, this tends to be at the waist-to-knee height, just in front of the body, at a comfortable distance for the racket arm to extend into the shot. For the serve, this impact point is slightly to the side of the body (see Table 1). The toss is higher than the extended racket and arm and just in front, about a foot or so, from the leading foot, if the ball was to bounce. For the volley, the impact point is ideally around chest height (range from knee to head at times), with legs bending and flexing to adjust body height. And like drives, for the volley a similar distance from the body, but the key is minimal racket swing with a focus on a stable racket face at contact.

Set-up for stroke

This phase focuses on how the body prepares to execute a tennis stroke. In setting up to strike the ball the body needs to be in a static balance, stable with resistance to both linear and angular acceleration, with weight shifted somewhat (but not entirely) onto the back foot in relation to the stroke being executed. Before the ball arrives, the player set-up for volley is “step-out” action; groundstroke (before the ball bounces) is to get sideways somewhat with upper body rotation; and serve is loading on the back foot sideways (at a right-angle) to backline, ready to release forward, as the player prepares to toss the ball. Elastic energy is generated in the body through coiling of the body segments in a unit turn (upper body and hips with legs fixed). This unit turn is minimal for the volley with shoulder turn and racket supported by the non-dominant hand creating all the coil needed for the “step-out/catch/step” forward action. For the groundstroke the unit turn is more pronounced with high racket take back allowing both arms and upper body to create a coil with the lower body, the elbow is bent to create a shorter lever arm that is ready to extend as swing forward. Elastic power is stored up in the rotation stretching of the larger muscles of the shoulders, back and torso (including hips). The high racket when the racket is taken back allows gravity to be used to overcome inertia before swinging forward as the racket head drops when initiating the stroke. In the serve, the “trophy position” noted in Table 1 refers to a slightly rotated upper body and arms with racket hand arm and shoulder lower than tossing arm in the shoulders. This set-up creates a first-order lever (like a seesaw) to release the racket into the hitting zone. Elastic

energy is stored in the hip that pushes forward and bends back from the lower body, with the opposite shoulder pulled back and lower than the front shoulder, ready to release forward to the ball tossed up to the impact point.

Hitting Zone

Hitting zone is an area at the impact point where the stable path of the racket generates an impulse (length force applied) onto the ball. It refers to contact of the racket strings on the ball based on PAS before, during, and after impact with the ball. The key for the player in the hitting zone is to overcome the oncoming inertia of the approaching ball and use the forces generated by their body through the set-up, to generate momentum on their racket swings, which in turn creates racket head speed for force onto the ball. The laid-back wrist noted in Table 1, referred to as wrist lag (Tennis Without Talent, n.d.), plays a critical role in transferring the momentum from the body onto the ball. The laid-back wrist creates a short level lever, meaning that a large force from the body muscles acts over a shorter distance to create a smaller force at the other end of the longer lever of the racket with the racket face generating speed with force. Lagging happens mostly at the wrist; extension happens at the elbow. Most full strokes start with a bent elbow that ends straightening, lengthening the lever arm and increasing leverage as the generated force travels through the forearm to the wrist. In the serve the key is to generate racket head speed and stable racket face contact with the ball. During the acceleration phase of the serve, the racket trails the wrist, creating lag as it is pulled, butt-end first, towards the point of contact. Simultaneous to that motion the elbow extends until the arm is completely straight before the moment of contact at the impact point. By lengthening the lever 'arm', you can optimize leverage, racket head speed and pace. For the volley the “catch” idea is the reaching for the ball with minimal swing. In the volley the hitting zone is focused on resisting momentum on the ball and redirecting the ball back into the court towards the intended target. Stable racket face with “catching” action based on the idea of reaching forward to the ball, and then using a “jab” or “chop” action, to redirect and control spin imparted on the ball for the volley shot.

The longer the strings stay in contact with the ball, flat at contact as in perpendicular to the ground, within the hitting zone, the greater the momentum passed onto the ball. The angle of the racket face influences the trajectory of the ball as it leaves the racket, assuming a stable racket face at contact. In addition, the action of the racket face on the ball, from low to high generates topspin on the ball (trajectory curving down and kick on bounce), or from high to low to generate underspin or backspin (trajectory flat and low bounce). This type of spin is referred to as the Magnus effect. The effect is caused when a ball is propelled forward and rotates clockwise so that the air runs over it and provides resistance by exerting a drag force making the ball curve down as it travels (McKeithen, 2019). As the ball spins, one side moves in the direction of the airflow, while the other side moves against the direction of the airflow creating downward drag so as ball slows it curves down. In contrast, the backspin propels the ball with a backward rotation. To generate backspin a player slices under the ball, sliding the racket beneath the ball after flat contact. The drag generated by the Magnus effect from the backward rotation makes the ball stay lower than the topspin, and the ball travels further. Similarly, for a slice serve the racket string hits the ball from the back to the side, causing the ball to swerve in the direction of the ball rotation and to break in the same direction when it bounces.

Grip

The grip refers to how the hand holds the octagonal shaped racket handle to control the racket face and then direct the forces channeled from the body, through the hand, onto the ball. The basic grips of continental, eastern forehand and eastern backhand enables the tennis player to feel a stable, flat at contact, racket face with the ball. Top of the racket is based on the outside edge of the racket face and bevel refers to the diagonal link from top to the side of the racket. Continental grip means the player can use the same grip (top edge, like knocking a hammer with the edge of a racket) to hit both forehand and backhands. Eastern means the hand grips the racket with a focus on the top side bevel of the racket. In a backhand continental grip a player can add the other hand (double-handed top hand) with an eastern forehand grip to gain more control of the racket face on the ball, and this is the basic double-handed backhand. Key for grip is feeling firm contact of the racket face with the ball to transfer generated forces and redirect ball inertia. The grip controls the racket path onto the ball, as well as angle of racket face for ball height trajectory and the spin generated by the action of the racket strings on the ball. Spin is generated with wrist action, noted in the hitting zone, but can be exaggerated as the player gets stronger with western type grips. These grips focus the side of the racket, increasing the flex of the wrist further (creating more lag), generating more racket head speed and string action on the ball at contact.

THE 4RS, TACTICS AND BIOMECHANICS

How do we locate these biomechanical principles that inform Tennis Canada’s five skill fundamentals into gameplay? The 4R model in Table 1 prompts the player to develop perception-action couplings to guide the force-generation process in emerging situations when playing a point in tennis. As Carvalho et al., (2013) notes, this means that players develop “perceptual attunement to the on-going match characteristics” (p. 11). Figure 2 builds on this model in relation to the Tennis Canada skill fundamental phases. By reading the game we are referring to the player’s ability to anticipate, through perceptual attunement, where the ball will be sent next by the opponent, how well the opponent will send the ball in relation to the biomechanical forces they are generating, and where the player should move next as they select an appropriate stroke to perform.

Key in Figure 2 is the connection between recovery to read and preparation to receive the ball (respond and react) at the impact point. When reading the player needs to be attuned to how the opponent is preparing in relation to their impact point on the ball and applying technical cues like recovery footwork and set-up unit turn. As the ball is struck by the opponent, the player starts their preparatory movements as they select their next shot for the anticipated impact point that they want for an effective shot execution. Note how the 4Rs, located in the space between two eclipse shapes in Figure 4, create a zone of possible adjustment that would allow the player to gain an advantage or stay neutral in the point as they perceive the information flow to make early adjustments. As the player continuously reads, they make decisions, reflected in their recovery footwork from a previous stroke, responding to whether the opponent’s set-up is effective for their impact point on the ball. The perceiving player can either defend by moving back if the opponent looks like they will be able to attack, stay neutral to current positioning (usually just behind the baseline), or move forward to attack an anticipated less

effective stroke. The technical cues within Figure 2 are the indications of the opponent's force generation potential at different stages in the movement cycle. These technical cues work as signposts to biomechanical efficiency for the player, but also as external cues to read to make tactical decisions about the opponent's skill execution to gain a strategic advantage.

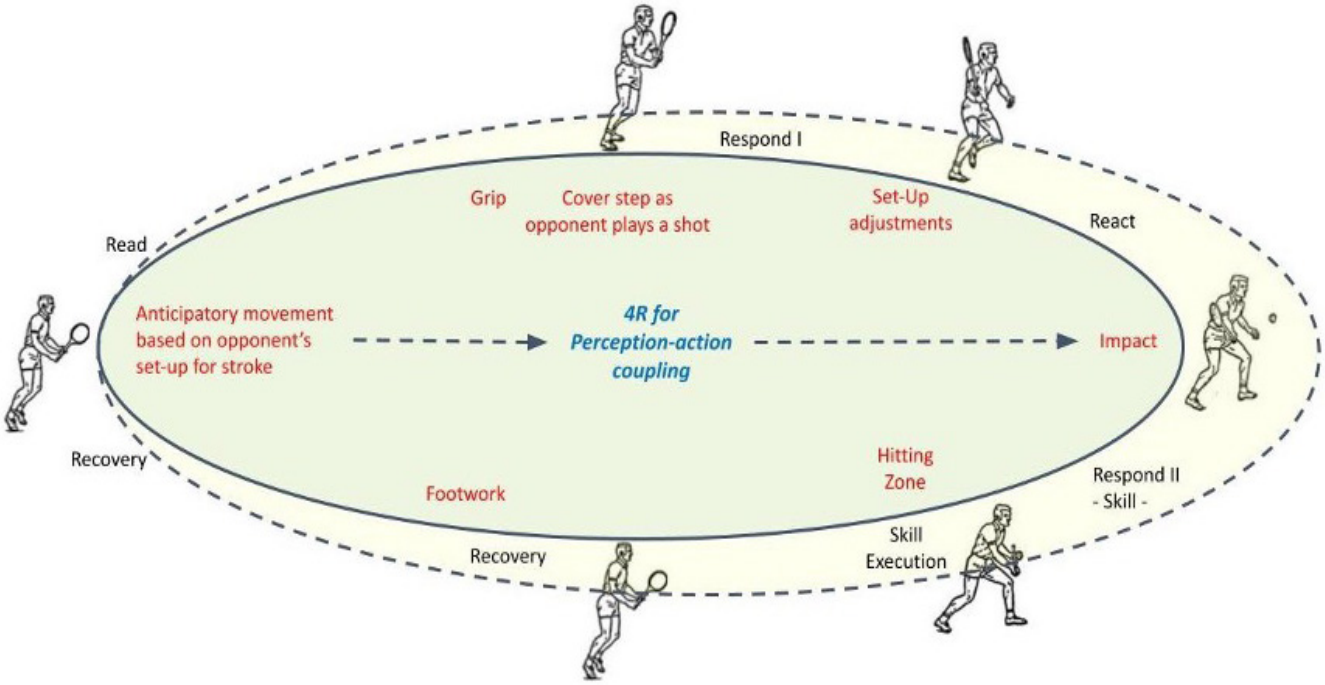

Figure 2. *4Rs combined with the Skill fundamental phases within a stroke cycle.*

CONCLUSION

The player reading gameplay means using technical pointers, such as those in Tennis Canada's five skill fundamental phases, to anticipate the opponent's next shot, but also to adjust and refine their own play. Though the scope of this paper is not on how to teach these fundamental skills and tactical concepts, we have done that in other articles (Hopper and Rhoades, 2022a, 2022b), it is worth noting that when players learn to read gameplay they pick up on what the opponent does well and what they need to do in response. Ecological psychology focuses on generating skillful performance, the gradual efficient and appropriate use of biomechanical processes to generate forces on the ball, by the player learning to adapt to variability (internal and external) promoted by the manipulation of constraints (Carvalho et al., 2013; Renshaw & Chow, 2019). Manipulation of constraints are designed by coach and the player, to promote functional variability that is linked to the complexity of reading the opposing player's stroke performance and adapting your own play in the prevailing conditions.

In Hopper and Rhodes (2022b) we suggest that if the game is close, where both players feel they can influence the outcome of the game, we have observed that often the biomechanical features noted in BIOMECS in Table 2 seem to be mimicked between the players In essence, they become synchronized to each other's successful play where the forces flow between them, creating what sports players have referred to as being in the zone or flow in sports (Jackson & Csikszentmihalyi, 1999). This we feel is critical in a play-practice-play approach advocated by Tennis Canada and therefore compels coaches to consider how to create games that adapt to players to make close encounters. In Hopper and Rhodes (2022a, 2022b) we advocate the use of modification by adaptation games where the outcome of winning a competitive game is that the game structure is adapted to challenge the successful player. For example, court space of the successful play to cover could be increased allowing the losing player to take advantage of the space with an increased target area, or the scoring system (i.e., handicap scoring such as 15-0 lead) could favor the losing player, so they have more scope to take risks. Such games challenge the winning player whilst enabling their opponent to see affordances whilst also noticing what their initially successful opponent is doing to be successful Therefore, to teach biomechanical efficient strokes we need to consider how we create the conditions to teach players to notice, to read the opponent in the situation, to note how they are generating force on the ball in relation to space, time and risk, to become attuned to the affordances in the game that they can exploit.

CONFLICT OF INTEREST AND FUNDING

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