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Mechanical Interaction Within Badminton Forehand Shot Technique: A Review Paper

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ABSTRACT

Background: The performance outcome model in qualitative technique analysis can determine the mechanical interactions between a performance outcome and the factors that yield such results in sports techniques. Very little attention has been received for badminton forehand shots for such model work, considering the significance of this technical skill as fundamental to play badminton and as important offensive shots. **Objective:** This study proposes a performance outcome model that associates performance criteria and relevant mechanical variables in the badminton forehand shot technique. **Methods:** Literature review provided the basis of model development. The Literature research in this paper was conducted in the following databases; PubMed, ScienceDirect, Google Scholar Medline, Pedro, and Cinahl. An additional search (including relevant grey literature) was also done on the internet through ResearchGate. Relevant literature research related to the keywords such as biomechanics of badminton, badminton forehand shot, biomechanical analysis, badminton performance, racquet sports, performance indicators, technique analysis and technique models were included and reviewed. **Results:** The results managed to present a synthesis of the literature review and provided constructive discussions as a basis to propose a performance outcome model that illustrates mechanical interactions that contribute to badminton forehand and shot technique performance. **Conclusions:** This model manages to find mechanical relationships and allows for a better grasp of understanding the association between performance criteria and mechanics in the badminton forehand shot technique, which is bases on the kinetic chain principle through the body segmental coordination.

Key words: Badminton, Racquet Sport, Forehand Shot, Technique Analysis, Biomechanics, Sports Performance

INTRODUCTION

In badminton, players are sequentially trading shots with its fast-playing pace and constant interaction between badminton players offensive and defensive shots, constantly struggling throughout the game (El-Gizawy, 2015; Ozgur & Hotaman, 2020). Considering the nature of this sport, it tests the reactive ability of players where players must react quickly under a limited amount of time. While playing offensively, players often concentrate on executing powerful and delicate forehand shots (i.e. smash, clear, drop shots) so that the opponent can be pressured effectively due to the minimal reaction time to intercept the incoming shuttlecock, hence creating a better chance to score a point (King et al., 2020). To execute the high-quality fluidic technique of badminton; forehand shots can be achieved by producing whip-like movement under optimal kinetic energy transfer, utilising efficient kinetic chain, stretch-shortening cycle (SSC), and intersegment coordination and control from proximal (trunk rotation) to distal (arm rotation) part initiated from good body positioning (Ramli et al., 2020). With the execution of exceptional forehand shot technique, this can make a deadly shot (difficult to be returned) with the combination of high post-impact shuttlecock velocity, greater downward flight angle and smaller net clearance height (Zhang et al., 2016; King et al., 2020). An ideal badminton forehand shot technique pattern should also be similar regardless of any shot until the shuttlecock is in contact with the racquet (Grice, 2008), thus emphasises the importance of technical consistency in these shots for its effectiveness in perplexing opponent during the badminton rally.

The dynamic nature of racquet sport is characterised by a handheld racquet being utilised as a sport implement to hit an object or a missile (for instance, a shuttlecock for badminton sport) between two or four players over a net. For this reason, racquet sports seem to share almost biomechanical similarities in their forehand techniques, although to a certain extent. A potential difference lies in, for instance, racquet and missile properties (e.g., weight and dimensions

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of a racquet, shuttlecock and ball). White et al. (2014) reported that in the tennis serve, increased "swing weight" (moment of inertia) of the racquet can significantly affect upper extremity mechanics and impact location, thus requires the technique adjustment to be prioritised. Iino and Kojima (2016) investigated the effect of racquet mass in the table tennis topspin technique and found that the heavier racquet could place a higher demand on wrist dorsiflexion torque but did not significantly affect the racquet speed at ball impact, although the racquet speed tended to be higher for the lighter racquet than for the heavier racquet. Regardless, all racquet shot techniques would exhibit an optimal action of multi-segment, proximal-to-distal sequencing to produce high-quality techniques (Lees, 2002).

Retrospectively, the use of performance outcome or deterministic model in biomechanical analyses was pioneered by Dr James G. Hay where a dissertation on high jumping sport way back in the year 1967 was dealt with whereby the model was constructed to cope with inclusion, redundancy and causality issues of performance parameters in high-jumping (Chow & Knudson, 2011). There are two distinctive features of this model. First, the model is built on appropriate combinations of known mechanical quantities and relationships related to the desired performance. Second, all factors at one level should be determined by the lower-level factors, which makes the model "deterministic". Since the model is outcome-oriented, it would be more suitable to refer to it as a "performance outcome" model. Over several decades, the qualitative approach was becoming more relevant and easier to be done for coaches and sport practitioners to teach and improve important technical skills of their athletes in sports through systematic observation to analyse technique (Hall, 2015) by using performance outcome model as one of the approaches to technique analysis.

Approaches using this model In sports can be seen in works of, for example, triple jump (Hay & Miller, 1985), long jump (Hay et al., 1986), water polo (Sanders, 1999), tennis (Chow et al., 2003), discus throw (Leigh et al., 2008) and soccer (De Witt & Hinrichs, 2012). To date, for similar work, very little attention can be seen on badminton forehand shot, considering the importance of forehand shot skill in badminton. Quantitative biomechanical analysis efforts have been done on overhand shots in badminton (Phomsoupha & Laffaye, 2015; Zhang et al., 2016; King et al., 2020), but these efforts have little direct application for badminton coaches and players, causing the researchers to turn to coaching manual, to identify the critical features in overhand shot technique. However, this literature may not be critically scrutinised and scientifically proven. Therefore, this study will propose a performance outcome model based on a synthesis of previous literature review and discussion, providing the basis of the associations between performance criteria and mechanical rationale in a badminton forehand shot.

METHODS

Literature Search

The literature review provided the basis of model development. Literature search for articles was conducted in April 2018 until June 2021 in the databases such as PubMed, Science Direct, Google Scholar Medline, Pedro, and Cinahl. An additional search (including relevant grey literature) was also done on the internet through ResearchGate. The development of the model was based on an extensive literature review of past work that was relevant with the keywords such as biomechanics of badminton, badminton forehand shot, biomechanical analysis, badminton performance, racquet sports, performance indicators, technique analysis and technique models.

Data Extraction and Analysis

This literature is evaluated with respect to the relevancy and suitability to the context discussed based on the problem statement. For the literature to be included and reviewed in this study, the literature must be available in the English language, including a biomechanical aspect relevant to the aim of this study, and provides information towards improving performance in badminton forehand shot as well as other relevant racquet sports.

RESULTS & DISCUSSIONS

Badminton Forehand Shot Technique

In badminton, a badminton shot is a way of hitting a shuttlecock. Badminton forehand shots are among the fundamentals of badminton and are considered critical offensive shots (Phomsoupha & Laffaye, 2015). These shots include offensive smash, clear and drop shots. For forehand shot to be performed effectively during an offensive situation in badminton gameplay, post-impact shuttlecock velocity, shuttlecock downward flight angle and net clearance height should be highlighted as performance criteria and concentration of this study. Post-impact shuttlecock velocity was shown to be a crucial performance factor, as it has been associated with skill levels (higher-level players produced higher shuttlecock velocity) (Phomsoupha & Laffaye, 2014) and a significant contributor to several points in badminton matches (Phomsoupha & Laffaye, 2020). Effective forehand shots that produce high post-impact shuttlecock velocity would be regarded as an effective weapon ('power stroke') (Zhu, 2013). Post-impact shuttlecock velocity is commonly used to measure performance in badminton shot-related studies (Phomsoupha & Laffaye, 2015), although some studies (e.g. Rambely et al., 2005; Sorensen et al., 2011; Kwan et al., 2011) measured at the racquet velocity at impact instead. Impact position during impact point is also essential. For example, shuttlecock location on racquet head during impact in smash and clear shots were seen higher than drop shots (Huang et al., 2002). Post-impact shuttlecock velocity was found highly correlated with racquet velocity at impact (King et al., 2020). The racquet velocity at impact is expanded to include relevant kinematic factors.

A powerful forehand shot could be delivered effectively under some related basic biomechanical reasonings, which are sequential proximo-distal joint action, use of stretch-shortening cycle, impulse maximisation and racquet deflection mechanism (Kwan et al., 2011; Phomsoupha & Laffaye, 2014). Following these biomechanical reasonings, emphasis should be put on the kinetic chain principle. The principle states that the sequential motion started from the preceding, proximal segments augments and accumulates angular velocities towards the more distal segments within a linked chain of segments (summation of velocity) (Marshall & Elliott, 2000) (schematically displayed in Figure 1). This segment-to-segment sequence (Phomsoupha & Laffaye, 2015; Zhang et al., 2016) started with preparatory body positioning (sideway stance) with weight shift to rear (dominant) leg for readiness and stabilisation purposes. Next, during the backswing, the hip joint rotation starts to rotate towards hitting direction, followed by intervertebral joints' rotation (trunk rotation). The upper arm also initiates an external rotation of the shoulder, in addition to elbow flexion, forearm supination, and wrist extension occurred in sequence. During forward swing, the rotations of hip and intervertebral joints continue towards hitting direction, combined with, occurred in sequence, internal shoulder rotation, elbow extension, forearm pronation and wrist flexion (wrist snap) invoked immediately before the contact point with the incoming shuttlecock. Movement patterns for all forehand shots (smash, clear, drop shots) are pretty similar except for some adjustments during the contact point, such as impact position on racquet head, racquet angle at contact and wrist movement. Finally, the follow-through movement of the upper limb is continued for relaxation (force dissipation) purposes.

This sequential action highlights the significance of the rotational movement of proximal body segment (trunk) to distal body segment (upper limb) with an excellent supporting base of lower limb function for effective Center of Gravity (COG) shift during forehand shot execution. Trunk rotation plays a vital role in power transfer from lower body segments to upper body segments by creating a more significant effective Range of Motion (ROM) during swing action. Hence, this ultimately generates high shuttlecock velocity, which shows that trunk rotation plays a crucial part in maximising the post-impact shuttlecock velocity (Zhang et al., 2016). Shoulder joint movement during the contact point combines shoulder extension and internal rotation in the abducted position (Lo & Shark, 1991). A study by Hussain and Bari (2011) in the forehand smash analysis displayed angular velocity pattern at the impact, being highest at wrist followed by elbow and shoulder, following kinetic chain principle to maximise shuttlecock velocity. Sorensen et al. (2011) found that higher-level badminton players demonstrated better, efficient sequential joint action than lower-level players for a badminton forehand shot. In tennis, coordination strategies for power serve execute similar sequencing pattern, as shown in Table 1 (Elliott, 2006).

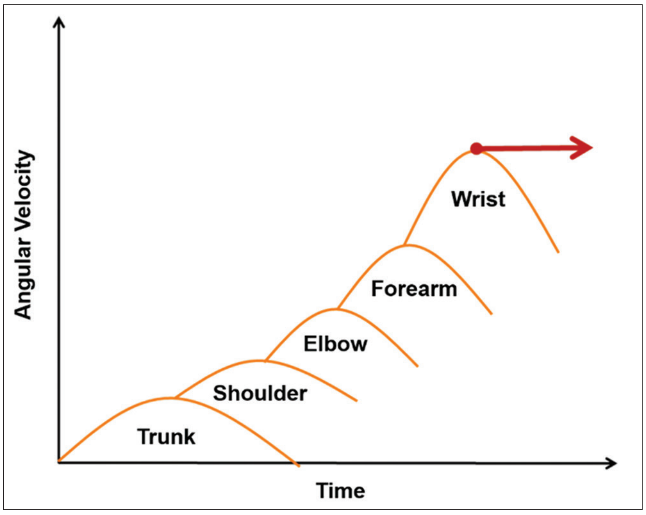

Figure 1. Sequential action of body segment (summation of velocity principle)

With that, racquet velocity at impact is vector summation of the tangential velocity of the wrist, V_{wrist}, and the velocities of each proximal segments at impact, can be found as;

$$V_{racquet} = V_{wrist} + V_{forearm} + V_{elbow} + V_{shoulder} + V_{trunk}$$

Where V_{wrist}, $V_{forearm}$, V_{elbow}, $V_{shoulder}$, and V_{trunk} are the velocity of wrist, forearm, elbow, shoulder and trunk respectively during impact. Velocity at impact can be developed based on angular velocity ω and segment relative positioning r.

Velocity at impact, $V = \omega \times r$

Zhang et al. (2016) emphasised two critical factors that cause maximisation of shuttlecock velocity in forehand shot, which is (1) speed of swing action resulted from the accumulation of velocities of segments in the involved action chain and (2) the respective action chain length. By physics, ideally, a completely extended (longer, higher) action chain will produce faster shuttlecock velocity than a bent (shorter, lower) action chain. Thus, hitting the shuttlecock with a completely extended upper limb is imperative, as high as possible on the racquet. Ramasamy et al. (2021) found that the arm positioning during contact with the shuttlecock is critical and suggested that players/coaches not overextend the elbow when maximising smash speed. However, ex-

Table 1. Coordination strategies for power serve in tennis (Elliott, 2006)

Leg drive and trunk rotations	shoulder speed
(forward/shoulder-over-shoulder/twist)	+ elbow speed
Upper arm elevation and flexion	+ wrist speed and racquet orientation
Forearm extension and pronation and upper	
Arm internal rotation	+ racquet speed
Hand flexion	

tending the elbow is essential for reaching a larger X-factor (trunk rotation) (Zhang et al., 2016), which was found to be one of two key predictors explaining variance in shuttlecock speed besides forward fast swing phase (King et al., 2020). These finding discrepancies may be attributed to factors such as experimental condition in a study (jumping smash versus standing smash) and technique preference, which warrants further work on this area. Angular velocity can then be developed based on segments' ROM and their action times;

Angular velocity, $\omega = \theta/t$

Where an angular displacement θ (range of motion) takes place in a time t, theoretically, to increase angular velocity (thus ultimately increasing post-impact shuttlecock velocity), one needs to either enlarge angular displacement ROM or shorten action time to complete the movement ROM. Lees et al. (2009) have suggested that enlarging the ROM of the body segments thus increases the swing path of the racquet, allowing more muscles to produce forces and accelerate the racquet hence increases the racquet velocity at impact. Phomsoupha and Laffaye (2014) highlighted that to efficiently utilise stretch-shortening cycles and maximise impulse (the product of force and time), there should be no break between phases from preparation until follow-through. King et al. (2020) found that a shorter forward swing phase was significantly correlated to greater post-impact shuttlecock velocity. For the range of motion, at the beginning of badminton forehand shot action, it is very important to set up body positioning in a way that racquet-side segments and joints rotate away from the shuttlecock first and stretched further during backswing phase to take advantage of the muscle elastic characteristics as well as intrinsic kinesthetic reflexes (King et al., 2020).

Regarding the other performance criteria of shuttlecock trajectory (shuttlecock downward flight angle and net clearance height), these criteria are mainly affected by the impact position on racquet head, racquet angle at contact and wrist movement. Huang et al. (2002) found that the shuttlecock location on the racquet head during impact in smash and clear shots were seen higher compared to drop shot. Racquet angle at contact could be affected by body positioning, where Li et al. (2016) suggested that the incoming shuttlecock should be positioned slightly in front of the body (approximately a foot apart) to increase smash shot quality. Also, "slice" movements in badminton forehand drop shot during contact point between racquet and shuttlecock revealed the significance of the ulnar deviation movement (Phomsoupha & Laffaye, 2015). Zhang et al. (2016) found that greater use of wrist flexion (almost triple) was seen among skilful players than novice players for greater downward flight angle and smaller net clearance angle. These findings explain that to ensure better accuracy (targeting) with high post-impact shuttlecock velocity, the coordination and controls of the body positioning and wrist movement are crucial.

Performance Outcome Model

The reviews and discussions provided the foundation of model development. Performance-outcome-model is among qualitative biomechanical approaches to aid observation and analysis of sports techniques for sports performance improvement purposes (Lees, 2002). This model focuses on mechanical variables influencing performance outcome (mechanical relationships) (Chow & Knudson, 2011), and the identified mechanical relationships were associated with relevant biomechanical principles of movement (Knudson, 2007). This performance outcome or deterministic model should be composed of mechanical factors that relate directly to the performance. All factors at one level should be determined by the factors included at the lower level (Chow & Knudson, 2011). Lees (2002) suggested that technique in sports being referred as how the body segments orientate and position relatively in the desired sport task to be effectively performed. This reference highlights that technique should be governed by variables that can be visually observed within a specific period. Kinematic and temporal characteristics are the concentration of the developed model as these characteristics are visually observable and potentially meaningful and practical for technique assessment among coaches and sport practitioners (Hall, 2015). The mechanical interactions are illustrated in the proposed performance-outcome-model (Figure 2).

Limitation of Study

Limitations of the study and the model include the inconsideration of kinetic characteristics, air resistance/gravity and racquet/shuttlecock properties (Chen et al., 2009; Cohen et al., 2015; Kwan et al., 2010; Phomsoupha & Laffaye, 2015) which may be responsible to a certain extent in the variability of performance criteria in these badminton forehand shots. Chen et al. (2009) constructed the motion equation of shuttlecock flight trajectory and found that air drag force is proportional to the square of shuttlecock velocity. Air drag force also depends on drag coefficient C_D, which is varied based on the design of the shuttlecock skirt (Cohen et al., 2015). Findings from a study by Kwan et al. (2010) have shown that the elastic velocity could provide additional speed (approximately 4%) to the racquet speed at impact. In addition, this model explores the biomechanical aspects that meaningfully contribute to the badminton forehand shot technique. Other aspects in performance analysis such as technical, tactical, and match classification indicators (Hughes & Bartlett, 2008) that may affect variability in forehand shot technique and consideration of other mentioned properties can be considered in future work. It is also noteworthy that the study did not discuss the lower body positioning and its contribution to the forehand shot technique thoroughly. Rusdiana et al. (2016) reported that jumping smash produces higher shuttlecock velocity than standing smash. Also, lower body positioning functions as a base in terms of COG for an effective weight transfer during shot execution. While the biomechanical study focused on lower limb characteristics in badminton forehand shots is quite limited (Zhao & Li, 2019), further investigation on this area should be done. Another interest that could be included as future work is how the model can be expanded and applied to young players (Normand et al., 2017), since the biological process of growth and maturation during the

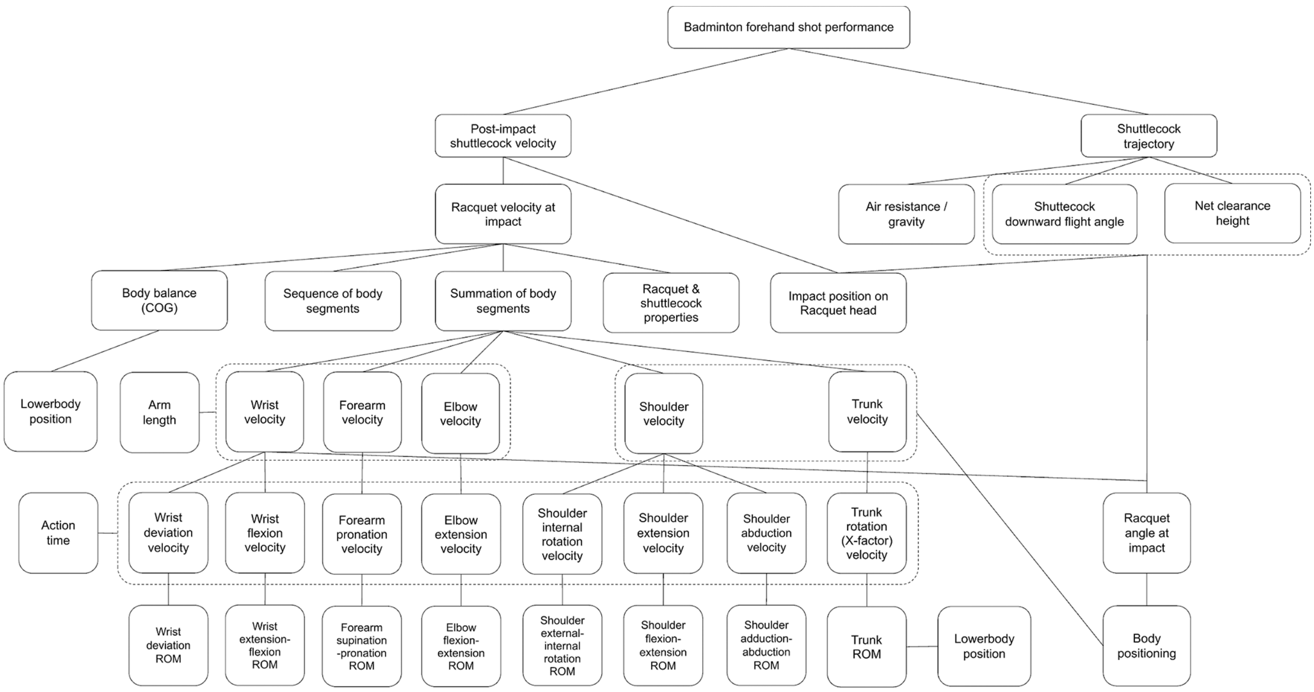

Figure 2. Performance outcome model of badminton forehand shot

adolescence period could have an impact on the technical execution of badminton shot (Ramli et al., 2020; Norjali Wazir & Ramli, 2021).

Strength and Practical Implication of Study

This study is significant since the proposed performance outcome model will help badminton coaches and players better understand the mechanical rationale behind the badminton forehand shot technique from a scientific point of view. In addition, the current system in badminton has changed the game strategy towards a more aggressive side (greater intensity, faster speed of play and longer rally lengths) (Abian et al., 2014), emphasising the effectiveness of badminton shot, specifically overhand shot as a foul shot to win a game. With this study, the analysis model development through existing scientific biomechanical literature and coaching expertise could build the knowledge bridge. The common language could be shared between researchers, coaches and players of all levels in badminton.

CONCLUSIONS

It is essential to appreciate the badminton forehand shot technique from a biomechanical standpoint for systematic observation and learning. From this study, the proposed performance outcome model allows for a better understanding of the essential key features and their mechanical relationship based on the kinematics in the badminton forehand shot technique. Badminton coaches and players should use this suggested model to learn and apply mechanical reasoning behind the badminton forehand shot technique to further train and improve the technical performance of badminton forehand shot during training and competition.

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