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The biomechanical analysis review of rugby place kicking

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Abstract

In order to provide a practical framework of rugby place kicking for coaches and players to implement, this study reviews several studies about the biomechanics of kicking of rugby as well as other different football codes. In spite of that there are few studies analysing rugby place kicking, still many aspects remain undiscovered. Therefore, to deeply review the moving pattern of rugby place kicking, those findings of other football codes are discussed in this study for practical insights. The major content of this study is the discussion about the biomechanical analysis of rugby place kicking and how it works in practice. The rugby place kick will be discussed in turn with the sequential phase description and relevant perspectives from current studies. Though the practical implementations are based on solid and relevant sources, they should be still customised for the kickers instead of fitting them all in a single standard framework.

Keywords: rugby, place kick, performance review, goal kick, conversion kick, penalty kick

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I. Introduction

Rugby Union is undoubtedly a worldwide sport. According to the statistics published by World Rugby in 2016, there are 131 members national unions in the whole world. The current number of registered rugby union players is 2.82 million grew from 2.56 million in 2015 (International Rugby Board, 2018). Moreover, it is estimated that the non-registered rugby union players are up to 4.91 million across six continents (International Rugby Board, 2018).

The fundamental goal for a rugby team to win a game is outscoring the opposition that is possibly comprised of several options which are try scoring and goal kicking. To score a try (five points), the players need to ground the ball past the goal line of the opponent and an opportunity for conversion kick for extra two points will be given. Another way to score points on the board is goal kicking. The kicker has to kick the ball through the posts in certain ways (a place kick or a drop goal) in specific situations (i.e. a penalty is awarded) to score three points.

Although a team can acquire more points through scoring tries, the study of Quarrie and Hopkins in 2015 indicated that the success of place kicking plays a crucial role in total scores. This study analyses 582 international rugby union matches in a time period of 2002 to 2011. The successful rate of place kicks was 72% out of 6769 attempts and those points from place kicks constitute 45% of the total points during these ten years. Furthermore, the success of a place kick determines the result of 33 matches. According to the recorded statistics of the six Rugby World Cup (RWC) finals before 2015, there were only seven tries produced by the finalists whilst 37 penalty goals were made. During the total history of the finals of the RWC, the finalists scored 259 points that place kicks contribute a large proportion (62%) (World Rugby, 2015a).

It is evident that the performance of place kicking is a crucial factor in the outcome of a match. Speaking of the aspect of team success, great place-kicking performance is absolutely the key to winning the games. There is always an excellent place kicker in an outstanding team. It can be observed that a great rugby place kicker usually determines the outcome of tight rugby union matches. Therefore, an understanding of place-kicking technique can bring coaches and players to a further level of performance.

The aim of this case study is to overview current existing researches that are relevant to rugby place kicking. Therefore, an organised framework for improving place kicking performance can be expected to be provided to coaches and kickers for practical implementation.

II. Literature Review

This study aims to provide a practical framework of rugby place kicking for coaches and players. Therefore, the whole analysis of this case study starts from reviewing those findings of current studies and literature. The model of how people, or to be more specific, athletes learn skills or refine skills will be discussed at the beginning. After having a comprehensive understanding of the process of skill acquisition, the indicators of the performance of rugby place kicking need to be discussed since they determine whether a place kick is successful or not. Last but not the least, the relevant biomechanical studies of kicking including other football codes which share similar movement pattern of rugby place kicking will be reviewed in phases.

I. Skill acquisition and refinement of athletes

For human development, the acquisition of perceptual-motor skills is fundamental. Based on a combination of a full understanding of basic components of the movement and a valid perception to determine the best timing to make the moves, athletes are able to exert their full potential. There is always a debate within sport field about that if champions are either born or bred (Tucker & Collins, 2012). For skilled athletes, they spend a great amount of time to improve their athletic performance and skills (Hodges & Williams, 2012). It is a clear point which was provided by Hodges and Williams in 2012 that claims 10,000 hours of training will be taken for transferring a talented athlete/player to an elite one. Approximately three hours a day for a talented athlete/player to spend on training for ten years (Hodges & Williams, 2012). Although this cannot be quantified as a real figure, it still provides a general consensus that reaching certain elite-level performance undoubtedly takes a long-term commitment and practice (Tucker, 2013).

To transfer the result of training into elaborate skills, the deliberate practice, which is defined as directly targeted, highly structured, instructional, highly effortful, is essential for athletes (Ericsson, 2004). There are several phases when training athletes, and they depend on the maturity and skill level of athletes. From fundamental skills acquisition to proficiency and skills honing, different coaching concepts should be applied on corresponding phases and finally the focus of training shifts towards performance outcome (Balyi & Hamilton, 2004; Hendriks, 2012). During the stage that athletes become more proficient, a tailor training process should be implemented instead of focusing on building up the “expert skills”. This may lead to frustration and inefficiency (Ackland, Elliot & Bloomfield, 2009). What coaches or trainers should do is to ensure that their athletes have a full understanding of the movements and this enables the athletes to exert their true potential (Lombard, 2018). For elite athletes, drastically altering their technique may lead regression in their performance outcome (Carson & Collins, 2014). Therefore, refining their technique with a more personalised program will be suggested to utilise (Bartlett, Wheat, & Robins, 2007). Since small alternations could have impacts on the athletic performance outcome, designing or tailoring the program for these elite athletes should be much more careful.

Mentioned in Ericsson's (2004) study, the quality of the provided information and instructions from the coaches or trainers directly affects the process of skill acquisition. In order to efficiently and adequately develop an athlete, the coach or trainer should fully understand the whole process and involved movements (Ackland, et al., 2009). Hamill, Knutzen and Derrick (2015) also mentioned similar point of view in their research that is a thorough understanding of athletic movement brings more effective coaching and training protocols. Based on this, the necessity of the movements analysis of rugby place kicking is crucial as the aim of this study is to provide decent practical implementations of rugby place kicking.

II. Biomechanical analysis of rugby place kicking

Rugby place kicking is a sequential motion composed of several major body segments and described as a "proximal-to-distal sequential pattern" (Putnam, 1993). The operation of this linked system is based on how each segment is moving and how each segment is orientated relative to its adjacent segments (Putnam, 1993). The principles of force summation is one of the most crucial principles to describe the proximal-to-distal pattern according to Putnam's statement (1993). In order to achieve maximum distal speed, the dynamic chain should be passed down from the most proximal segment to the most distal segment (The Performance Lab Inc., 2014). Take throwing movement as an example, if a baseball pitcher wants to throw the ball as fast as he or she can, the movement should be in a sequence from trunk rotation, leg flexion to arm extension. Figure 1 illustrates the relationship between summation of forces and the acceleration in a throw.

To identify key events for focused analysis and make it comparable with other football code, the analysis of a rugby place kick in this study will be generally separated into four sequential phases adopted by Burkett (2010): the approach phase, the kicking phase, the ball contact phase and the follow-through phase. During the approach phase, the kickers start their moves from preparatory position, mostly there is an angle from the left or right depending on the dominance of kicking leg. This phase ends until the kicking foot reaches the top of the backswing and followed by the kicking phase when the kicking leg makes the swing down towards the ball. Due to being reckoned as the main phases of propulsion as well as how affects the motion and direction of the ball, it leaves great space for discussion about movements in these two phases. The ball contact phase commences when the kicking foot initially contacts the ball until it loses contact with the ball which is in-flight. Once the ball is in-flight, the last phase, the follow-through phase starts with the sequential motion. Each phase will be reviewed in turn with relevant researches including different football codes since there are many similarities worth referring.

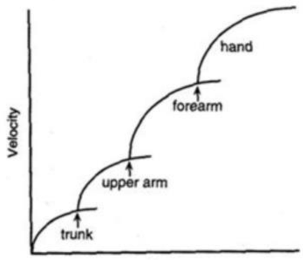

Figure 1. How the principle of summation of force affect the throwing speed. (https://theperformancelabinc.wordpress.com/2014/09/16/the-kinematic-sequence)

a. The Approach Phase

The approach phase is an individualized process of rugby place kicking. It can be observed that current rugby players with different personalized routines. For example, the kicking model of this study, Jonny Wilkinson is well-known for his signature stance that is clasping his hands with dragging of his hip prior to commencing the approach towards the ball.

The length of run-up and the angled approach also vary from kickers. During the approach phase, typically rugby place kickers take several steps approach from an angle behind and to the side of the ball. A general agreement that an angle should be created when kickers approach the ball is mentioned within the rugby coaching literature (Greenwood, 2003). Similar approaching methods can be observed when soccer players kick a stationary ball. Several existing studies of different football codes provide some insights about how approach angle affect kicking performance. De Witt (2002) suggested that with an angle, the further way the kicking foot is placed, the faster velocity of the kicking foot may happen at the initial ball contact because of that providing the joints of the kicking leg more time to rotate for momentum generation. In a research conducted by Scurr and Hall (2009), although there are no significant differences of ball velocity magnitude between amateur soccer players who adopt different approach angles, they found that when greater approach angles are adopted, more longitudinal rotation of the kickers' pelvises occurred.

Another finding from researches is about that how the final step length affects kickers. The study about Australian Rules Football punt (Ball, 2008) indicated that because of the longer final step, greater kicking hip extension and knee flexion at the top of the backswing provide more potential to generate faster kicking foot velocity at ball contact. Atack (2016) also reported that the group of successful rugby place kickers took a longer final step prior to ball contact.

These results above appear to suggest that the longer length of the final step and the angled approach help kickers to produce more ball velocity magnitude. However, most of these suggestions except for Atack's (2016) study are the results without an accuracy constraint.

For determining a successful rugby place kick, the accuracy should be taken into consideration and it is proved to affect kickers movement in other football codes. In research conducted by Lees and Nolan (2002), they observed that when an accuracy constraint is added into soccer kicker's consideration, the final step length becomes shorter. A similar result is observed in another study about female soccer kickers performing curve kicks and in-step kicks (Alcock, Gilleard, Hunter, Baker & Brown, 2012). When taking curve kicks which required greater accuracy, these female soccer kickers adopted shorter final step compared with when they took in-step kicks (Alcock et al., 2012). The accuracy constraint obviously affected how kickers adopt their kicking strategies which means that the whole body and some specific body segments motion may be different.

In addition to the discussion about the length of the final step, the kicker's approaching velocity magnitude is also affected by the accuracy constraint and this is supported by researches. While adding an accuracy constraint, the approaching velocity of the subjects is significantly slower compared with performing the same movement without an accuracy constraint in the study of Lees and Nolan (2002). Alcock et al. (2012) also observed the same situation when female soccer kickers perform curve kicks and in-step kicks.

The position where the support foot is placed appears to be proved that has less relevance to the success of kicking since there were no big difference observed when the testing subjects are already familiar with kicking skills (Baktash, Hy, Muir, Walton & Zhang, 2009; Cockcroft & van der Heever, 2016). However, it is definitely a crucial factor of the kicking performance.

b. The Kicking Phase

The kicking phase commences when the kicking foot reaches the top of the backswing and downswing through the process to contact the ball. The motion of the kicking foot, the kicking legs joints, the torso segments and the support leg will all be put into discussion in turn. Although it is rare to find a study focusing on a comprehensive analysis of a rugby place kick, there are still many of researches about the analysis of soccer in-step kicking. According to Wickstrom's (1975) study of soccer in-step kick, the motion of the kicking leg starts from the forward rotation of the pelvis about the longitudinal axis and followed by the flexion of hip as well as knee. As soon as the deceleration of hip flexion occurs, the knee extends to bring up the kicking foot to initiate ball contact.

Based on this fundamental process, several kicking studies including soccer in-step kicking and rugby place kicking will be discussed to analyse the movement of different segments.

(a) The motion of kicking foot

As mentioned as the end of the “proximal-to-distal sequential pattern” (Putnam, 1993) and the segment contacting the ball, the kicking foot plays a critical role determining the motion of the ball post-contact like flight of the ball as well as the magnitude of the ball velocity (Atack, 2016). This makes the kicking foot motion relatively crucial when investigating rugby place kicking technique. In addition to specific rugby place kicking study, the studies of similar kicking pattern of soccer in-step kicking will be also put into reviewing.

For starters, when performing a soccer in-step kicking, how the linear velocity of the kicking foot changes from the backswing phase to the initial ball contact is widely discussed among several researches. Some of these researches observed one thing in common that is the linear velocity of the kicking foot continuously increased until contact the ball and reached its peak linear velocity at initial ball contact when there is no accuracy constraint (De Witt & Hinrichs, 2012; Dörge, Anderson, Sorensen & Simonsen, 2002; Nunome, Lake, Georgaki & Stergioulas, 2006). Moreover, the relationship between kicking foot’s peak velocity and post-contact of ball velocity was found strong (De Witt & Hinrichs, 2012; Nunome et al., 2006) that motivated more studies to investigate the relationship between the kicking technique and a fast kicking foot velocity. However, like what is mentioned before, the constraint of accuracy still appears to be one critical factor affect the kicking. According to Lees and Nolan’s study (2002) on soccer in-step kicking, the kicking foot velocity was reduced with an accuracy constraint imposed. As performing a successful rugby place kick, the accuracy is definitely a crucial factor that is impossibly ignored. Therefore, for studying a successful rugby place kicking, not only the linear velocity of kicking foot is needed to be focused but also the direction of the velocity vector of the kicking foot should be put eyes on.

The path of the kicking foot basically represents the direction of the velocity vector. In the semi-structured interview with an elite rugby kicking coach, Bezodis and Winter (2014) mentioned that the path of kicking foot is the technical factor that the elite rugby kicking coach highlighted. The coach stated that the path of the kicking foot should travel in a straight line towards the target. Similar perspective is also provided when Jonny Wilkinson (2005) discussed about the path of the kicking foot. There are two different styles of the swing of the kicking foot, the ‘J-shape’© and the ‘C-shape’©. These two shapes are based on the view from above for a left-footed kicker. The differences between these two shapes are the path of the kicking foot after it contacts the ball and through the contact phase. The ‘J-shape’© is the one that is advocated by Wilkinson (2005) because the straighter approach of the foot allows the ball to go towards the desired direction and travel towards the target. In contrast, the ‘C-shape’© style increases the possibility of the ball travelling towards an undesired direction during the downswing phase (Wilkinson, 2005).

Those definitions are now widely implemented in rugby place kicking coaching. However, the path of the kicking foot is still an area with less research support. Atack’s (2016) study helps to clarify that how the path of the kicking foot affects its velocity vector at initial ball contact and the post-contact velocity of the ball. In Atack’s (2016) study, kickers, who were all right-footed kickers were grouped into three different groups: long, wide-left, and short by their testing results. The group of long kickers was those who were able to perform successful rugby place kicks while the wide-left group were the kickers whose kicking result was lack of accuracy and drifted away from the left post but with decent kicking distance. The short group were those kickers with short distance of the kicks. As for the kicking foot motion among these three groups, Atack (2016) observed that the kicking foot of both the long and wide-left kickers was further away from the ball compared with the short kickers. Those two types of kickers also performed faster velocity of their kicking foot than the short kickers. Moreover, the faster lateral kicking foot velocity was demonstrated by the long and wide-left kickers while the slower one was observed from the short kickers.

From the group of successful kickers, the lateral velocity vectors were considered together with the kicking foot at the top of the backswing and those pathways of the kicking foot were more similar to the ‘C-shape’© style which is not advocated by Wilkinson (2005). The assertion that the ‘J-shape’© style of rugby place kicking advocated by Wilkinson (2005) appears not to be supported by Atack’s (2016) study.

(b) The motion of kicking hip, knee and ankle joint

During the kicking phase, the accumulated momentum in the thigh starts to transfer to the shank. This proximal-to-distal sequencing is crucial to maximise the velocity of the ball and is widely mentioned in soccer in-step kicking (Dörge et al, 2002; Lees & Nolan, 2002; Nunome et al., 2002; Putnam, 1991). The elite rugby kicking coach also highlighted that “hips leads the knee, then snaps the shank that snaps the foot through the ball underneath it” Bezodis and Winter (2014). In most studies, the successful or skilled kickers are commonly observed that their ball velocity is a critical indicator to determine the performance of kicking. However, an accuracy constraint should be added when performing the kick since a successful rugby place kick is determined by the accuracy and the magnitude that is powerful enough to propel the ball travelling through the goal posts (Atack, 2016).

Lees and Nolan (2002) have found that with an accuracy constraint, the peak angular velocity of the kicking leg joints of the tested soccer kickers was drastically reduced when compared with performing maximising ball velocity magnitude. These slower joints rotation may have enabled the kickers to acquire better control of the motion of the kicking foot before contact the ball. Also, the research about female soccer players performing in-step and curve kicks observed greater peak knee extension velocity when they performed curve kicks which require a more accurate contact upon the ball (Alcock et al., 2012). The researchers stated that there was a different kicking strategy when the subjects' task needed more control of the ball and they utilised the muscles across the hip joint to acquire more control of the path of their kicking foots then extend their knees for fast kicking foot velocity (Alcock et al., 2012).

In another soccer in-step kicking study conducted by Kawamoto and his colleagues (2007), the kickers were instructed to perform the kick with maximum effort whilst maintaining the accuracy. Though the focus of their study is discussing the difference of techniques between experienced and inexperienced groups, it is still potentially of interest when studying rugby place kicking. The greater peak hip flexion, knee extension and ankle plantar flexion were observed from experienced kickers and these statistics were significantly less than the one recorded in the study of the same subjects performing soccer in-step kicking without an accuracy constraint (Kawamoto, Miyagi, Ohashi & Fukashiro, 2007).

Based on these results and the findings, with an accuracy constraint, Atack (2016) found that the motions of the kicking legs between successful and less successful kickers throughout the downswing were similar. However, there were different strategies adopted by these kickers. Between long kickers and wide-left kickers, these two groups shared similar foot velocities. It is observed that the long kickers employed a knee extensor strategy which with less positive hip flexor contribution but more positive knee extensor work. In contrast, the wide-left kickers adopted a hip flexor strategy to develop a 'tension arc' (Shan & Westerhoff, 2005) which enables the hip flexors to generate more force during the downswing. For the long kickers, through the adjustments to the kicking foot's path from the hip joint, they appear to maintain a more stable trunk when apply the generated power to direct the ball. The short kickers performed both less hip flexor and knee extensor work, and thus were unable to achieve fast velocity of the kicking foot compared with the long and wide-left kickers.

(c) The motion of torso

Trunk segments, which include pelvis and trunk, has been identified important in kicking by Wickstrom (1975). The longitudinal rotation of the pelvis determines the path of the kicking foot (Scurr & Hall, 2009). The greater longitudinal rotation that the kicker's pelvis has means a greater range of motion for the body to employ, and thus the kicking foot is likely to have a longer path to generate a faster foot velocity through the coordination of kicking leg joints (De Witt, 2002). Lees and Nolan (2002) supported this idea by reporting that they observed there was a greater range of the pelvis motion of the kickers when performing maximal speed in-step soccer kicks and a faster kicking foot velocity was achieved compared with the situation with an accuracy constraint. They believed that the approaching angle and the final step length towards the ball both may affect the longitudinal pelvis rotation (Lees & Nolan, 2002). The short kickers in Atack's (2016) research about rugby place kicking were observed that they rotated their trunk and pelvis segments in a more front-on position. Because of this, the pathway of the kicking foot was limited and less room for the short kickers to generate power towards the ball.

Another crucial factor determines the generation of a fast kicking foot velocity in soccer in-step kicking is the relative motion of the pelvis and the trunk. Experienced soccer in-step kickers create a “tension arc” across the torso to generate more power to perform a kick (Shan & Westerhoff, 2005). The “tension arc” is the trunk rotation when the kicking hip reaches the top of the backswing and starts to extend simultaneously with the pelvis longitudinal rotation as well as the maximal horizontal extension and abduction of the non-kicking-side shoulder (Shan & Westerhoff, 2005). This stretch across the torso is also mentioned by the elite rugby kicking coach who identified the non-kicking-side arm position as one of the fundamental components of a successful rugby place kick (Bezodis & Winter, 2014). The “tension arc” can help kickers’ kicking-muscles to contract with more force thanks to the stretch-shortening cycle mechanism (Komi, 1984) for generating faster kicking foot velocity. However, this may potentially sabotage the accuracy of kicking according to Greenwood (2003) indicated that the longitudinal trunk rotation is needed to be controlled before initial ball contact. The idea of the ‘J-shape’© and the ‘C-shape’© that Wilkinson (2005) mentioned supports Greenwood’s perspective by advocating the style of the ‘J-shape’© which involves less trunk rotation compared with the ‘C-shape’©. Researchers also stated that minimal longitudinal trunk rotation can be observed from accurate rugby kickers (Berzodis et al., 2007).

Except for the relative motion of the pelvis and the trunk, a “strong posture” is also a crucial factor that those experts or researchers comment on rugby place kicking.

A "strong posture" is considered as an upright trunk and extended support leg maintaining good balance (Greenwood, 2003). The non-kicking-side arm plays an important role in kickers' body balance. The motion of the non-kicking-side arm counteracts the motion of the kicking leg and those accurate kickers employed their non-kicking-side arm well to maintain their balanced kicking posture (Bezodis et al., 2007).

It can be concluded that the longitudinal trunk rotation has a great influence on the magnitude of the ball velocity and the travelling direction of the ball no matter in rugby place kicking or soccer in-step kicking.

(d) **The motion of support leg joints**

Sharing the similar movement pattern of rugby place kicking, the studies of soccer in-step kicking certainly fill up the gap of the lack of the analysis of rugby place kicking. The joint mechanics of the support leg can be found in several studies. However, when it comes to the discussion of the support leg, there is only the research conducted by Lees and his colleagues (2009) providing complete time-histories of the support leg joints from support foot contact to initial ball contact that will be termed stance phase. During the stance phase, it is found that the support knee flexion contributes 80% of the movement except for the knee extension while the support hip consistently extends. Throughout this stance phase, the support foot contact is sequentially followed by the hip adduction then abduction (Inoue, Nunome, Sterzing, Sinkai & Ikegami, 2014). The support foot's ankle firstly displays plantar flexion, inversion and adduction and then dorsiflexion, eversion and abduction (Inoue et al., 2014).

It is reported that there are two major roles played by the support foot in kicking phase – to resist the ground reaction and decelerate the kicker's body mass and to transfer the momentum of the whole-body centre of mass of the kicker to the kicking leg (Atack, 2016; Inuoe, et al., 2014). Potthast et al (2010) also proposed that a portion of the whole-body impulse could be transferred to the kicking leg by the deceleration of the whole-body centre mass and increases the segment's angular impulse for foot velocity. This appears to explain how the fast approach velocity affects the magnitude of ball velocity. Moreover, it is observed that the successful rugby place kickers positioned their support foot closer to the ball and they also remained further to the left of the ball for the right-foot kickers at initial ball contact (Atack, 2016). It is proved that the ground reaction forces and the support foot both have great influence not only on soccer in-step kicking performance but also the rugby place kicking.

c. The Ball Contact Phase

The ball contact phase is the following phase after the kicking phase. In soccer in-step kicking, this phase lasts approximately 10 ms which only provides the kicker with little time to alter the techniques (Nunome et al., 2006). After the kicking foot made the initial ball contact, a rapid ankle plantar flexion was observed (Nunome et al., 2006). As mentioned previously, how the kicking foot makes the ball contact is determined by the approach phase as well as the kicking phase. Therefore, it is not surprisingly that these two phases are widely discussed in most relevant researches.

d. The Follow-Through Phase

Following the ball contact, it is the phase of follow-through. According to the recording by Berzodis and Winter (2014), *"release mechanism...at the end...to dissipate the energy build up... [due to] the braking forces they're putting on themselves... a hop or a skip, it may be a run, a step on your kicking foot afterwards,* *it may be whatever it is but there needs to be a release".* The motion of the kicker is therefore no interest of affecting the ball. However, based on the consideration of the elite rugby kicking coach (Berzodis & Winter, 2014), the kicker's motion may be an interest of investigation of understanding the injury mechanisms based on the relationship between momentum and impulse.

III. Future Direction of Research

The kicking movements and techniques of different football codes were generally reviewed. As the focus of this study is rugby place kicking, most concerned aspects still remain undiscovered. Although Atack's (2016) study provided a comprehensive discussion of rugby place kicking, most focus was on the approach phase and the kicking phase. The phase of ball contact as well as follow-through still needs further discussion. Whilst the exact moment of the initial ball contact, the processing of the data of the kicking foot's exact movement is possibly much more complicated due to the recording difficulty (Nunome et al. 2006). For discovering further insight of the ball contact phase, the method and the analysis must be more specific, controlled and focused (Atack, 2016).

Another phase of rugby place kicking which also remains much room for further research is the follow-through phase. Most authors of relevant studies believed that as the ball leaves the kicking foot, it will not be affected by the movement of the kicker anymore. As the perspective of the ball itself, it is undoubtedly correct since there is no relevance between the kicker and the ball. However, the follow-through motion of the kicker appears to be strongly influenced by the kicking motion. For example, it can be observed that those kickers who adopt the kicking strategy of more trunk longitudinal rotation have great opportunities to perform the follow-through style with more rotation momentum towards the non-kicking side instead of the target. On the other hand, for those front-on kickers whose kicking strategy is with less trunk rotation but more front-on momentum, it can be found that they close their bodies without full swing path of their kicking legs, and thus demonstrating a completely different style. Apart from that Bezodis and Winter (2014) mentioned in their study about the injury mechanisms and how the longevity of the kicker may be affected, not too many studies discuss about this topic. However, since the strong relevance attached to the kicking movement, I believe that it is a topic deserving further research.

The subjects of current studies no matter which football code it is, mostly performing the kicking with the constraints of maximal distance kicking or accuracy kicking. There is no study or research discussing about the result of that a successful rugby place kicker individually employs different kinds of kicking strategies to make the kick. Moreover, there is no specific study focusing on the relationships between anthropometrics and biomechanical factors of rugby kickers. By conducting these studies, it could possibly provide more valuable findings for discovering a deeper understanding and solid principles for coaches and kickers to evaluate their performance. For example, a systematic framework for determining a suitable kicking style for individual is possibly established based on the range of the different anthropometrical statistics of kicking-relevant body segments of an individual.

Moreover, there are only few researches nowadays discussing about the placing angle, tee height as well as the support foot position. Decades of years ago, it could be observed that the kickers always place the ball slightly leaning towards themselves. However, in recent ten years, less and less kickers adopt this placing strategy when they need to kick a place kick. In contrast, they lean the ball towards the posts instead of themselves. This angle issue might be related with the discussion about the interaction between the ball and the air during the flight phase, how the drag force affects the ball's projectile trajectory and the contacting surface between the ball and kickers' feet as well.

The different heights of the tees used by kickers and how this affect the performance can be another interesting topic to discuss. According to the biomechanical principle, three major factors determining projectile trajectory are release angle, release speed, and release height (Hamil, 2015). Therefore, the height of the tee definitely influences the kicking. However, this still needs further discussions due to the lack of relevant studies.

Also, though most kickers place their supporting foot parallelly right next to the tee, the spaces between the supporting foot and the tee may have great influence on kickers' performance. The different relative positions between the supporting foot and the tee appear to affect the kickers to adopt different kicking strategies and this is another topic that should be covered for the study of place-kicking performance.

All those mentioned above in this section are expected to provide a more comprehensive understanding on place kicking performance.

IV. Conclusion

Through reviewing numbers of studies in different football codes as well as a classic model of place kicking, it can be generally concluded with a practical framework for reviewing the place kicking movement. In this study, several general principles suit most evaluation of rugby place kicking. However, as existing in other sports, there are always special cases adopting the execution strategy that appears to violate some general principles perform excellent outcomes.

As a professional rugby place kicking coach, the coach should be able to instruct the kicker with a base of comprehensive knowledge about the kicking movement. In addition to that, the coach should also thoroughly understand the kicker’s strength, anthropometric and power characteristics that fundamentally affect the kicking strategy and style adopted by the kicker. The coach should be able to observe those situations that may happen during the place kicking. For example, how the kicker’s hip flexors work? Whether there is too much trunk rotation of the kicker that resulting in the missed kick? Is the kicker’s centre of gravity low enough to aid the dynamic balance? Also, kicking techniques refinement is not only the responsibility of the coach, the kickers should provide their feeling every time they perform the kick.

This kind of mutual communication between the coach and the kicker will help the coach to determine those crucial and critical factors influencing the kicking movement of the kicker. The outstanding kicking performance of those elite kickers is not built or modeled by moulding, it is definitely developed through a long process of discussion, training, and thousands of adjustments with the assistance of coaches. And finally, here comes the customised kicking style based on consistency, simplicity, smoothness and rhythmicalness.

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橄欖球射門生物力學分析

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摘　要

此研究主題旨在提供橄欖球教練及選手一省視射門動作之方向和架構。射門動作的細節分析對於教練或是選手在理解掌握動作的過程中十分重要。也因此此研究將橄欖球射門動作分為四個主要階段並依據不同身體部位加以分析討論，並同時參考其他動作模式類似的球類運動研究，期望藉由多方文獻結果的整理，能讓教練及選手在訓練的調整上更有效率。而儘管具參考價值的架構已被提出，由於人體構造的差異，教練在指導選手的過程中仍須依照選手的特質和條件調整，避免有削足適履的情況發生。

關鍵詞：橄欖球、射門、生物力學、動作掌握、罰踢、動作檢視、加踢