Biomechanical determinants of placekicking success in professional Rugby Union players

Kim Hébert-Losier[a]*, Peter Lamb[b], and C. Martyn Beaven[a]

[a]*Division of Health, Engineering, Computing and Science, Te Huataki Waiora School of Health, University of Waikato, Tauranga, New Zealand;* [b]*School of Physical Education, Sport and Exercise Sciences, University of Otago, Dunedin, New Zealand*

*Corresponding author e-mail: kim.hebert-losier@waikato.ac.nz, Telephone: +64 7 837 9476, Fax: +64 7 838 4504

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The ability to score from placekicks discriminates winning from losing Rugby Union teams. We aimed to identify which biomechanical variables related to successful placekicking in professional Rugby Union players, and use self-organising maps (SOM) to determine whether meaningful sub-groups existed. Three professional placekickers performed 10 kicks outdoors. Placekicks were categorised into '*best*', '*worst*', and '*typical*' performances based on outcomes and coach and player perceptions. Seven 3D biomechanical variables consistently and meaningfully (moderate Cohen's effect size) discriminated *best* from *worst* placekicks in all players. The three-cluster solution from SOM on these seven variables highlighted differences between players rather than *best*, *worst*, and *typical* attempts. Within-clusters, however, the *best* and *worst* placekicks tended to be represented in separate map regions. The seven variables identified using standardised effect sizes can be useful for group-level coaching of placekicking skills in absence of individual data, and translated in an applied setting using verbal and visual cues to promote overall placekicking performance. However, players' idiosyncrasies formed the main SOM boundaries, indicating that optimising placekicking success would benefit from an individualised approach and numerous effective movement templates may exist.

Keywords: 3D motion analysis; artificial neural network; biomechanics; self-organising map; sport performance

Introduction

Forty-five percent (45%) of points scored during international Rugby Union matches are from placekicks, with 6% of match outcomes relying on placekicking attempts (Quarrie & Hopkins, 2015). In fact, the ability to score points from kicks is a trait discriminating between winning and losing teams at the Rugby Union World Cup (van Rooyen, Lambert, & Noakes, 2006) and in Super Rugby (Lim, Lay, Dawson, Wallman, & Aanderson, 2009). The overall success rate of placekicks in international Rugby Union is ~75% (Pocock, Bezodis, Davids, & North, 2018), with individual success rates ranging from 36 to 93% (Quarrie & Hopkins, 2015). Clearly, improving success of placekicks can alter match outcomes and should represent a key focus in training and coaching of rugby skills.

In light of the importance of placekicking, the lack of in-depth biomechanical analyses on placekicking accuracy in professional Rugby Union players is surprising (Atack, Trewartha, & Bezodis, 2019). Until recently, coaching of placekicking skills mainly relied on practical experience or scientific findings of kicking from other sports more extensively researched, such as soccer (Lees, Asai, Andersen, Nunome, & Sterzing, 2010), with limited relevance to placekicking in Rugby Union. Indeed, there are few published papers on technical and biomechanical models for Rugby Union (Atack, Trewartha, & Bezodis, 2018; Atack et al., 2019; Green, Kerr, Olivier, Dafkin, & McKinon, 2016; Padulo, Granatelli, Ruscello, & D'Ottavio, 2013).

The few 3D biomechanical studies on Rugby Union placekicking are from a mix of playing standards (Atack et al., 2019; Baktash, Hy, Muir, Walton, & Zhang, 2009; Bezodis, Trewartha, Wilson, & Irwin, 2007; Cockcroft & Van Den Heever, 2016; Flemmer & Flemmer, 2015; Koike, Ishikawa, Willmott, & Bezodis, 2019; Sinclair et al., 2014; Sinclair et al., 2017; Zhang, Liu, & Xie, 2012) and performed in laboratory settings. These studies have provided limited practical guidance for placekickers and their coaches: that kickers should aim to generate greater angular momentum in their non-kicking-side arm to oppose angular momentum of the kicking leg (Bezodis et al., 2007), position their kicking leg close to their base of support (Bezodis et al., 2007), lean their trunk towards their kicking side (Bezodis et al., 2007), 'retract' or 'open' their pelvis to a greater extent at the top of backswing and their trunk during downswing (Atack et al., 2019), use a more shallow swing plane inclination (Bezodis, Atack, Willmott, Callard, & Trewartha, 2019), and develop high peak knee extension (Sinclair et al., 2014; Sinclair et al., 2017), hip extension (Sinclair et al., 2017), and linear foot (Atack et al., 2019; Sinclair et al., 2017) velocities to enhance ball velocity. However, opposite recommendations of leaning the trunk away from the ball (i.e., towards the non-kicking side) have been made for placekicking in elite Rugby League players (Ball, Talbert, & Taylor, 2013) likely due to trunk modelling in 2D rather than 3D, and differences in placekicking conditions (set 40 m versus varied distances) and key performance indicator (distance vs accuracy).

In fact, several factors can influence placekicking outcomes and biomechanics. There are fundamental differences in lower-extremity and ball 3D biomechanics between placekicking for maximal velocity or distance compared to accuracy in laboratory settings; notably lower ball, foot, knee extension, and hip extension velocities, and greater ankle dorsiflexion and peak external rotation when kicking for accuracy (Sinclair et al., 2017). Outdoors, research suggests that lesser trunk rotation and trunk-pelvis separation angles characterise accurate placekicking attempts (Green et al., 2016).

Coaches perceive that ball placement, approach, body position, support-leg mechanics, path of the kicking foot, foot orientation at contact, follow through mechanics, and proper coordination are key areas to address on-field with players (Bezodis & Winter, 2014). Support-leg foot position appears to have little effect on ball velocity in Rugby Union placekicking (Baktash et al., 2009), with final foot position showing large variations between players in Rugby Union (Cockcroft & Van Den Heever, 2016).

There are clear gaps in our knowledge on Rugby Union placekicking mechanics at a professional level that hinder coaching and athlete development. As highlighted, the few 3D biomechanical studies on Rugby Union placekicking are from a mix of playing standards and performed in laboratory settings. These studies tend to focus on the average performance of players, with limited consideration of individual idiosyncrasies in placekicking performance. Identifying the biomechanical determinants of placekicking success not only at a group level, but also at an individual level, appears vital to implement best practice in Rugby Union.

The limited opportunities to conduct detailed investigations in high performance sports is one of the main reasons for the lack of published data on professional-level Rugby Union placekickers. Indeed, there is a need for researchers to understand the needs and address questions relevant to coaches and athletes (Sandbakk, 2018). Although group-based analyses can provide insights regarding the 'on average' performance of athletes, individual-based analyses can highlight different combinations of meaningful parameters unidentified through group-based approaches.

The use of standardised effect sizes (ES) (Hopkins & Batterham, 2016) and deep learning approaches (Cust, Sweeting, Ball, & Robertson, 2019) to analyse human movement and performance is steadily increasing in sport science. A self-organising map (SOM) is an unsupervised neural network that is useful for clustering high-dimensional data and visualising those clusters on a low-dimensional output map according to overall relatedness of data. This type of analysis has the potential to enhance our understanding of human movement and function (Croft, Willcox, & Lamb, 2017). Alongside analysing team performances and large datasets, it becomes possible to analyse a number of trials, represented by high-dimensional biomechanical data, from a small sample of individuals.

The purpose of this exploratory work was two-fold. First, we aimed to identify which biomechanical variables relate to successful placekicking in professional Rugby Union players in an ecologically valid environment using standardised effect sizes. Second, we aimed to use SOM analysis to determine whether meaningful sub-groups existed within the data. We hypothesised that we would identify a subset of variables that differentiated the *best* from the *worst* placekicking attempts, and that sub-groups would be detected within the data using SOM analysis.

Methods

Participants

Three competitive male placekickers (mean body mass: 89 kg and height: 1.81 m) in good self-reported general health voluntarily participated. The three players were right-legged placekickers, part of the New Zealand Rugby Union, and professional players in the Mitre10 and Super Rugby competitions. The University of Waikato Human Research Ethics Committee approved the study protocol [UoW HREC(Health)#2017-54], which was conducted in accordance with international ethical standards (Harriss, Macsween, & Atkinson, 2017) and adhered to the Declaration of Helsinki.

Study design

Participants completed one experimental session on the same day outdoors on a rugby field 10 m above sea level. Environmental conditions during testing were 15 °C with 48 to 64% relative humidity. Light to fresh breeze wind gusts from a primarily headwind direction were less than 21 knots. The environmental conditions were recorded to ensure comparable conditions between placekickers given that these can affect the motion of objects in fluid environments (Hall, 2015). After providing written informed consent, participants completed a coach-led standardised warm-up. Retro-reflective markers were subsequently positioned on participants and the ball in preparation for experimentation. More specifically, sixty-one 19-mm retro-reflective markers were affixed over anatomical landmarks of placekickers using double-sided tape (3M™), adhesive non-woven fabric (Hypafix®), and liquid adhesive (Mastisol®) based on the Calibrated Anatomical System Technique (Cappello, Cappozzo, La Palombara, Lucchetti, & Leardini, 1997) and established guidelines (Grood & Suntay, 1983). Five 19-mm markers were placed on the ball. All 66 markers were used for static calibration, whereas 15 markers were removed for the placekicking efforts (Figure 1).

*****FIGURE 1*****

Placekickers were asked to perform 10 kicks, 35 m from the goalposts (i.e., 0° angle). The 35-m distance was chosen based on discussions with the placekicking skills coach to provide a moderate degree of difficulty. Indeed, the expected success rates of a placekick positioned at 32 m in front of the goalposts is 88% (Pocock et al., 2018). Furthermore, longer placekickers have been defined by their ability to successfully kick from a distance greater than 32 m (Atack et al., 2019). Marker positions were recorded at 300 Hz during placekicking attempts using eight infrared cameras (Oqus700+ with sun filters, Qualisys AB, Gothenburg, Sweden) alongside two video cameras (Oqus210c, Qualisys AB, Gothenburg, Sweden) recording at 50 Hz. These two video cameras were positioned to the right-hand side and behind placekickers to confirm placekicking outcomes. All data were collected and time-synchronised using the Qualisys Track Manager Software (version 2.11, build 2902).

The outcome of the placekick was recorded as successful (points scored) or unsuccessful (no points scored). Immediately after each kick, qualitative feedback from the coach and player regarding kicking performance was also recorded. An example of positive and negative feedback from the coach include 'Perfect sound, contact' and 'Contact point on ball not right'. The feedback was used as primary tool to define the three '*best*' and the three '*worst*' kicks for each player, with all the best kicks being successful. The remaining kicks were deemed to represent '*typical*' attempts. Note that one player performed two additional kicks, with some placekicking trials missed due to the unfamiliarity of the researcher with the pre-kick routine of individuals (i.e., user error). Hence, the total number of kicking trials captured and analysed varied between placekickers (kicker 1, n = 12; kicker 2, n = 9; kicker 3, n = 7). The corresponding placekicking trials were successful in 9 (75%), 9 (100%), and 5 (71%) of cases.

Kinematic data collection

A 13-segment biomechanical model of placekickers with 6 degrees of freedom at each joint and a one-segment ball model with 6 degrees of freedom relative to the virtual laboratory were constructed in Visual3D Professional™ Software version 6.00.15 (C-Motion Inc., Germantown, MD, USA; Figure 1). The local coordinates of the head, upper arms, lower arms, trunk, pelvis, thighs, shanks, feet, and ball were derived from the static calibration, and a CODA pelvis was used to define the hip-joint centres. The centre of mass (CoM) of participants was derived following mechanical principles and Dempster (1955) regression equations. Prior to each session, the measurement volume was calibrated using a 601.5-mm wand and L-frame that defined the Cartesian origin of the field. The X-axis of the virtual laboratory was aligned with the target direction (forward–backward), Y-axis perpendicular to the target direction (medial/right–lateral/left), and Z-axis aligned with vertical (superior–inferior).

Data processing

Marker data were exported to the C3D format and processed in Visual3D Professional™. Marker data from the placekicking trials were interpolated using a least-squares fit 3rd order polynomial allowing a maximum of 10 frames for gap filling (3.33 ms), and filtered using a 4^{th} order Butterworth bidirectional filter with a 20 Hz cut-off. This cut-off frequency was selected as suitable for outdoor motion capture of sports movements (Hébert-Losier, Mourot, & Holmberg, 2015) and to minimise attenuation of the kinematic waveforms upon inspection of the data (Sinclair, Taylor, & Hobbs, 2013). The following key events were identified for each placekicking trial (see Figure 1): penultimate left foot plant (left foot CoM acceleration reaching 0 m/s^2 in the X-direction before right foot plant), right foot plant (right foot CoM acceleration reaching 0 m/s^2 in the X-direction before left foot plant), left foot plant (left foot CoM acceleration reaching 0 m/s^2 in the X-direction before ball contact), ball contact start (ball CoM velocity exceeding 0.5 m/s in the X-direction), ball contact end (ball CoM velocity reaching maximal velocity in the X-direction), top of swing (right foot CoM reaching maximal position in the Z-direction after ball contact), and end of swing (right foot CoM reaching minimal position in the Z-direction after top of swing). These events were used to define the right step, left step, start of swing, ball contact, top of swing, and end of the swing in sequential order.

Kinematic parameters were calculated using rigid-body analysis, Euler angles obtained from the static calibration, and right-hand rule sign convention. Body angles in the sagittal, coronal, and transverse planes were calculated using an x-y-z Cardan sequence equivalent to the Joint Coordinate System (Grood & Suntay, 1983). Pelvis, trunk, and X-factor angles were defined relative to the virtual laboratory using an z-y-x Cardan sequence based on work from Baker (2001). X-factor angles defined the separation of the trunk in relation to the pelvis around the Z-axis, wherein positive values indicate the trunk leading the pelvis.

A number of biomechanical variables were extracted from the dataset based on previous literature and discussions with the New Zealand Rugby Union placekicking skills coach. In total, 116 discrete variables were identified a priori to data extraction. These variables related to ball, left (plant) foot, temporal, stride, right (kicking) foot, CoM, X-factor, angular and linear speed, opposite arm, impact kinematic, and swing kinematic parameters.

More specifically, parameters included ball position on the tee and ball launch angle, speed, and spin (n = 11); left (plant) foot position in relation to the ball CoM (n = 2); temporal execution of the placekick (n = 7); right step, left step, and left stride lengths (n = 3); right foot speed at the start, during, and end of ball contact (n = 12); right foot path at the top of swing vs ball path (planar angle, n = 1); CoM speed at left foot plant, ball contact start, ball contact end, and change during ball contact (n = 16); CoM vertical oscillation (n = 3); X-factor maximum, minimum, range, at impact, peak speed, time from peak to ball contact start, and time from zero-crossing to ball contact start (n = 7); peak angular speed of the pelvis (x and z), hip (x), knee (x), and foot (linear speed) of the kicking leg during swing and time from peak to ball contact start (n = 10); opposite arm speed axially and vertically at ball contact start, ball contact end, change during ball contact, and at top of swing (n = 8); kicking side ankle, knee, hip, shoulder, pelvis, and trunk sagittal plane (x) angles at ball contact start (n = 6); non-kicking side ankle, knee, hip, and shoulder sagittal plane (x) angles at ball contact start

(n = 4); pelvis and trunk frontal (y) and sagittal (x) plane angles at ball contact start (n = 4); shoulder, hip, knee, and ankle coronal (z) plane angles at ball contact start (n = 8); kicking side peak and range of motion of ankle, knee, hip, pelvis, and trunk in the sagittal (x) plane during swing (n = 10); and peak and range of pelvis and trunk rotation (z) during swing (n = 4). A more detailed description of these variables is available as supplementary material.

Cohen's standardised effect size analysis

Cohen's standardised effect sizes (ES) comparing the three *best* to the three *worst* placekicking attempts for each player were computed for the 116 parameters to establish the meaningfulness of variables on performance. ES were calculated according to the change in mean, and standardised using the pooled standard deviation as:

$$ES = \frac{\mu_{best} - \mu_{worst}}{\sqrt{\frac{{\sigma_{best}}^2 + {\sigma_{worst}}^2}{2}}} \quad (1)$$

ES that went in the same direction for all three players (i.e., all positive or all negative ES) were termed as '*consistent*' at a group level. From these, absolute ES that exceeded 0.50 (i.e., moderate effect) (Sawilowsky, 2009) for all three players were termed as '*meaningful*' at a group level. Absolute ES that exceeded 1.20 (i.e., very large effect) (Sawilowsky, 2009) for a single player were deemed as '*key*' at an individual level. The ES analyses were performed in Microsoft Excel 2016 (Microsoft Inc., Redmond, WA, USA).

Self-organising map analysis

The *consistent* and *meaningful* biomechanical variables relating to placekicking success derived from the ES analysis were extracted from all placekicking attempts for SOM analyses. The SOM analysis therefore included the three *best*, three *worst*, and remaining *typical* trials. There were 6, 3, and 1 *typical* trials from kickers 1, 2, and 3, respectively.

SOM analysis provides maps consisting of a lattice of nodes, each of which has an associated prototype vector with values attained through an iterative process. The dimensionality of the prototype vector matches that of the input data – that is, the number of *consistent* and *meaningful* biomechanical variables. The competitive learning algorithm and the neighbourhood function dictate that similar input data are located in similar map regions, thus preserving the input topology. The *k*-means clustering algorithm was run to partition the SOM nodes into $k = 2, \ldots, 11$ clusters. A 3-cluster solution minimised the Davies–Bouldin index (the ratio of the intra-cluster to the inter-cluster separation, Figure 2A) and was chosen to represent sub-groups. All SOM procedures were performed in MATLAB (R2016a, The MathWorks, Inc., Natick, MA) and incorporated functions in the SOM Toolbox (Vatanen et al., 2015).

FIGURE 2A and B

Results

Cohen's standardised effect size analysis

Forty-four (38%) of the 116 variables were consistently associated with better kicking performances across players (i.e., all positive or all negative ES comparing best vs worst), with only seven (6%) reaching the moderate threshold of 0.50 for all three players (Table 1). Inspection of these seven variables discriminating the *best* from the *worst* placekicks at a group level indicated the *best* kicks exhibited the following characteristics: CoM forward and resultant speed was slower at ball contact start, but resultant speed was better maintained throughout ball contact; the kicking leg reached greater knee flexion during swing and was more flexed at the hip and knee at ball contact start; and placekickers were better aligned with the kicking direction (i.e., trunk was less rotated outwards) during the swing phase (Table 1). At an individual level, the number of key variables that discriminated the *best* from *worst* placekicks and reached the very large ES threshold of 1.20 varied (kicker 1, n = 17; kicker 2, n = 34; and kicker 3, n = 42).

TABLE 1

Self-organising map analysis

The input data for SOM analysis were the seven *consistent* and *meaningful* biomechanical variables from all placekicking trials of the three players (i.e., *best*, *worst*, and *typical*). The prototype vectors and SOM nodes therefore had seven dimensions. In Figure 3, the best-matching node for each trial is shown with colour indicating the respective kickers. Inspection of the three clusters identified on the SOM grid (Figure 2B) indicated that each cluster corresponded to a specific kicker (Figure 3).

FIGURE 3 A to C

Within-clusters, however, the *best* kicks tended to be represented by nodes located to one side of the cluster, whereas the *worst* kicks were represented by nodes on the opposite side (Figure 3). The inter- and intra-individual differences can be observed by considering the separate biomechanical variables across the three clusters (Figure 4). For example, kicks with the greatest resultant CoM speeds are represented by nodes in the top right corner of the SOM; lowest resultant CoM speeds are represented by the bottom left corner (Figure 4A).

FIGURE 4A to G

Discussion and Implications

The Cohen's standardised effect size (ES) approach identified a subset of variables that consistently and meaningfully discriminated the *best* from the *worst* placekicking performances in three professional Rugby Union placekickers. These variables may be general indicators of performance that can guide coaching of placekicking skills at a group level in absence of individual data, but needs confirmation from a larger study. Controlling centre of mass (CoM) speed at ball contact (i.e., appropriate rhythm and control – not rushing the placekick), maintaining CoM speed during contact (i.e., kicking 'through' the ball), greater knee and hip flexion at ball contact (i.e., biomechanically advantageous position – being 'on top' of the ball), enhancing knee flexion during swing (i.e., pre-tensioning knee extensors – 'heel to bum'), and lesser trunk rotation away from the target during swing (i.e., more aligned with the target – 'heart' to target) appear important in promoting overall placekicking success at 35 m in front of the goalposts.

The seven variables linked with performance based on our 3D data and ES analysis are in general agreement with coaches' perspectives (Bezodis & Winter, 2014) and previous literature. A recent study highlighted that placekickers who are able to kick long (i.e., over 32 m) perform more positive work on their kicking side at the knee and hip (Atack et al., 2019), which agrees with our findings of greater maximum knee flexion angle during swing in the *best* versus *worst* attempts. The greater knee and hip flexion angles at ball contact in our players' *best* kicks also appeared to place these joints at a greater mechanical advantage based on reported force–length (Kulig, Andrews, & Hay, 1984) and joint torque–angle (Anderson, Madigan, & Nussbaum,

2007) curves. On the other hand, these longer-distance placekickers also exhibited less 'front-on' thorax and pelvis orientations than shorter-distance placekickers (Atack et al., 2019), which contrasts with our findings of better performance when the thorax was more front on. This between-study disagreement might be due to the inter-individual (rather than intra-individual) analyses performed, the laboratory (rather than field-based) nature of the experiment, amateur to senior international playing level (rather than exclusively professional level) of participants, modelling approaches, and placekicking from a maximum range (rather than from 35 m). Indeed, data from Green et al. (2016) suggest that greater trunk rotations may enhance kicking distance, but impede kicking accuracy.

The self-organising map (SOM) analysis on the subset of seven *consistent* and *meaningful* variables identified using an ES approach clustered the individual placekickers rather than the *best*, *typical*, and *worst* attempts. This finding suggests that for the seven variables extracted, the majority of the variability in placekicking biomechanics resulted from inter-individual variation in technique rather than from placekicking performance. Indeed, there was no overlap between kickers in the SOM, which suggests that the identified biomechanical variables from the ES analysis were driven by specific placekickers rather than from the cohort of placekickers. However, within-clusters, there was a tendency for the *best* kicks to congregate to one region of the cluster, suggesting similar relative biomechanical traits characterising kicking performance at its best; but dissimilar biomechanical metrics between players in absolute terms. These findings from our sample of professional Rugby Union placekickers mirror those from Peacock and Ball (2019) wherein individual Australian punt-kickers exhibited idiosyncrasies in foot impact location at ball impact relative to punt-kicking outcomes.

SOM clearly identified intra-individual and inter-individual variability, indicating that players presented a spectrum of kinematic abilities to perform kicks. The execution of placekicking may not be the result of a single kinematic variable, but rather a complex interaction of several variables. There may exist no unique movement pattern that optimises sports performance, as shown for running gait (Lussiana, Patoz, Gindre, Mourot, & Hébert-Losier, 2019). Hatze (1973) defined optimal human motion as one yielding a maximal performance under given constraining conditions and for a given individual. It becomes important to consider individual optimisation processes in sports given that athletes might already be adopting a self-optimised biomechanical approach (Glazier & Mehdizadeh, 2019), especially at an elite level. The SOM approach provides a tool potentially able to identify an athlete-specific optimum technique.

Several factors can influence placekicking outcomes and biomechanics. For instance, there are fundamental differences in lower-extremity and ball 3D biomechanics between placekicking for maximal velocity compared to accuracy in laboratory settings; notably lower ball, foot, knee extension, and hip extension velocities, and greater ankle dorsiflexion and peak external rotation when kicking for accuracy (Sinclair et al., 2017). That the CoM forward and resultant speeds of our placekickers were slower at ball contact in their *best* compared to *worst* attempts might appear as counterintuitive and unexpected findings. However, we believe that these findings reflect a better control of the placekicking attempt (as suggests the better maintenance of the resultant CoM speed during contact), which ultimately resulted in a superior accuracy of the placekicking attempt.

It is recognised that the success rate of Rugby Union placekicks at international competitions decreases with an increase in distance, and depends on the left-to-right side position of the placekick attempt on the field (Flemmer & Flemmer, 2015; Pocock et al., 2018). In Rugby Union game situations, placekicking distance and angle are significant predictors of success (Pocock et al., 2018). Specifically, the expected success of a placekick positioned at 32 m in front of the goalposts (0° angle) is 88% (Pocock et al., 2018). This rate drops to 75% when the distance is increased to 42 m (with a 0° angle) or angle is increased to 39° (at a 32 m distance) (Pocock et al., 2018). Our study findings derive from 35 m placekicks in front of the goalposts. A change in kick distance and angle will likely lead to different subsets of biomechanical factors related to performance and SOM outputs. Likewise, studies on sub-elite Australian football players punt-kicking for maximal distance indicate the manifestation of biomechanical adaptations to maintain foot velocity whilst kicking following a game-specific fatigue-inducing protocol (Coventry, Ball, Parrington, Aughey, & McKenna, 2015). These findings of compensatory strategies and biomechanical changes with fatigue align with the lower placekicking success rates observed in the 10 minutes prior to half-time at the 2015 Rugby Union World Cup (Pocock et al., 2018). Combined, these studies reinforce that fatigue and position relative to the goalposts are additional factors that can influence placekicking biomechanics and outcomes: Factors which were not assessed as part of this exploratory investigation.

The relationship between placekicking outcome and biomechanics in our group of professional Rugby Union players was non-linear, which implies that placekicking technique development or training should be implemented at an individual rather than group level. The current SOM results go against dictating an optimal movement template approach in placekicking skill acquisition and coaching. Rather, the results imply that different kickers use idiosyncratic movement patterns to optimise kicking performance, although the SOM findings might simply reflect the small sample size and input data selection based on effect sizes. Indeed, the current study is limited by its small sample size, and more data are needed to substantiate our results and practical recommendations. Replicating the current study with more trials and participants would help corroborate the extent to which kicking technique is individual specific, and which aspects are generalisable. It is possible that numerous effective movement templates exist that players can rely on to enhance placekicking outcomes. Another limitation of this study was the varied success rates of placekickers during their attempts. The *best* kicks were all successfully converted, whereas 10% of *typical* and 44% of *worst* kicks were unsuccessful. Although analysing successful versus unsuccessful kicking performances may lead to different results and interpretation, we believe the current separation of *best*, *typical*, and *worst* coach and player perceived performance is more ecologically valid. This approach is readily understandable from a coach and player perspective, and provides individualised information to improve placekicking technique.

Conclusion

Not rushing the placekick, 'heel to bum' (during swing), 'point your heart towards the target' (when approaching the ball), being 'on top' of the ball (at contact), and kicking 'through the ball' are coaching cues that might assist in promoting placekicking success in general in absence of resources or expertise to coach or analyse placekicking at an individual level. Both ES and SOM analyses indicate idiosyncrasies in movement patterns of placekickers linked with performance, highlighting the value of individualised-based approaches in high-performance sports. This exploratory work on top-level placekickers is a first step, but needs to be repeated with a larger sample size.

Self-organising map analyses have been used in biomechanics to cluster movement patterns; however, the decision of which input variables to use remains difficult. In this paper, we used standardised effect sizes to determine a subset of *consistent* and *meaningful* variables from professional Rugby Union placekickers to train the neural network. Future work may use a similar approach to develop coaching cues from group data, with the effectiveness of using individualised SOM in coaching needing further research.

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Declaration of interest statement

The authors report no conflict of interest.

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Table 1. Biomechanical variables that *consistently* and *meaningfully* discriminated the three *best* from the three *worst* placekicking attempts in three professional Rugby Union players based on Cohen's standardised effect size analysis.

Variable	Attempt	Kicker 1	Kicker 2	Kicker 3
CoM resultant speed at ball contact start (m/s)	*Best*	2.11 ± 0.02	1.91 ± 0.15	2.40 ± 0.00
	Worst	2.15 ± 0.06	1.98 ± 0.11	2.55 ± 0.06
	ES	-1.01	-0.53	-3.20
CoM forward speed at ball contact start (m/s)	*Best*	2.02 ± 0.02	1.83 ± 0.15	2.30 ± 0.03
	Worst	2.05 ± 0.06	1.91 ± 0.10	2.43 ± 0.07
	ES	-0.62	-0.59	-2.34
CoM resultant speed drop during ball contact (m/s)	*Best*	-0.15 ± 0.02	-0.09 ± 0.01	-0.17 ± 0.00
	Worst	-0.18 ± 0.01	-0.11 ± 0.02	-0.22 ± 0.04
	ES	1.78	1.69	1.90
Knee angle of kicking leg at ball contact (°)	*Best*	41.9 ± 4.1	30.5 ± 2.7	41.8 ± 2.9
	Worst	37.6 ± 4.8	25.9 ± 1.8	36.9 ± 3.2
	ES	0.98	1.94	1.60
Hip angle of kicking leg at ball contact (°)	*Best*	15.8 ± 1.8	-3.4 ± 0.8	40.3 ± 1.3
	Worst	12.8 ± 0.6	-5.0 ± 0.7	35.3 ± 3.9
	ES	2.28	2.02	1.72
Maximum knee angle of kicking leg during swing (°)	*Best*	111.9 ± 3.0	120.4 ± 0.9	110.0 ± 2.7
	Worst	110.6 ± 1.9	116.6 ± 1.2	107.7 ± 4.1
	ES	0.52	3.55	0.66
Trunk rotation vs kick direction (°)	*Best*	-26.2 ± 0.4	-16.3 ± 1.6	-20.9 ± 1.1
	Worst	-28.0 ± 0.7	-17.5 ± 2.2	-21.9 ± 2.5
	ES	3.20	0.62	0.53

Notes. Values are mean ± standard deviation. ES deemed *consistent* and *meaningful* when going in the same direction and reaching 0.50 (moderate effect) for all three placekickers. The associated biomechanical variables were selected for the self-organising map analysis. Abbreviations: CoM, centre of mass; ES, standardised effect size.

Figure 1. Marker placement for 3D motion capture of the placekicker (anterior view) and rugby ball (anterior-lateral view). Anatomical reference markers on the placekicker were placed bilaterally on the: lateral aspects of the head; acromial processes; medial and lateral humeral epicondyles; ulnar and radial styloid processes; anterior and posterior superior iliac spines; medial and lateral femoral epicondyles; medial and lateral malleoli; and heel, 1st, 2nd, and 5th metatarsal heads. Tracking markers on the placekicker were placed bilaterally on the: lateral aspects of the mid-foot, upper arm, and forearm; iliac crest tubercles; and lateral aspects of the thigh and shank using 4-marker rigid clusters. Reference markers were placed on the proximal, distal, and lateral aspects of the ball, with two additional markers used for tracking. The red circles indicate markers that were removed for the placekicking trials. Key events identified for each placekicking trial are shown.

Figure 2. A) Davies-Bouldin index for clusters $k = 2, \ldots, 11$; (B) SOM output grid visualisation. The respective clusters are identified by numbers.

Figure 3. Self-organising map (SOM) grids showing best-matching nodes (coloured hexagons) for the three kickers (K1 – blue, K2 – red, K3 – green) in the (A) *best*, (B) *worst*, and (C) all (*best*, *worst*, and *typical*) placekicking trials. **Note**. Coloured node size indicates the number of trials represented by each node. The maximum number of trials is relative to each kicker on each grid visualisation; e.g., there are three trials per kicker shown in (A), the larger green node represents two trials for K3; there are twelve, nine, and seven trials corresponding to K1, K2, and K3 shown in (C), the larger nodes represent two trials for K1 and K3, and one trial for K2.

Figure 4. Self-organising map components corresponding to the seven *consistent* and *meaningful* biomechanical variables linked with performance in three professional Rugby Union placekickers. Variables shown are: (A) centre of mass (CoM) resultant speed at ball contact start; (B) CoM forward speed at ball contact start; (C) CoM resultant speed drop during ball contact; (D) knee flexion angle of the kicking leg at ball contact start; (E) hip flexion angle of the kicking leg at ball contact start; (F) maximal knee angle of the kicking leg during swing; and (G) trunk rotation vs kick direction during swing. The three main clusters locate the three kickers (K1 – middle, K2 – bottom, K3 – top). Nodes representing their best (**B**) and worst (**W**) attempts are indicated.