INSTEP SOCCER KICK TECHNIQUE AND PERFORMANCE THROUGH AN ANALYSIS OF MOVEMENT VARIABILITY

Tim Bennett[1] Chris Low[1] and Carlton Cooke[2]

Carnegie Faculty of Sport and Education, Leeds Beckett University, Leeds, UK[1]
Department for Sport, Health and Nutrition, Leeds Trinity University, Leeds, UK[2]

The purpose of this study was to investigate the structure of movement variability (MV) for hit and missed instep kicks using the uncontrolled manifold (UCM) analysis. University soccer players (n=11) performed a maximal instep kick at a target 11metres (m) away. Hit and missed kicks were analysed using the UCM method. Dependent measures for UCM analysis were UCM variability measures and strength of synergy across six performance variables. Clear differences were noted between hit and missed kicks based on the UCM analysis. The UCM analysis provided a powerful tool for showing clear differences between hit and missed kicks and suggest that accurate kicking performance could be dependent on the structure of MV within the human motor system.

KEYWORDS: soccer, instep kick, variability, synergy, motor equivalence

INTRODUCTION: The instep kick is an important technique in soccer for generating maximum ball speed, which combined with accuracy, can help successfully score a goal. Instep kick research has shown that skilled soccer players display natural variations in their technique from trial-to-trial (Egan, Verheul, & Savelsbergh, 2007; Lees & Rahnama, 2013). This inherent movement variability (MV) has been described as a demonstration of 'motor equivalence', which has been defined as the ability to achieve an invariant end using variable means (Abbs & Cole, 1987). This movement strategy would benefit a soccer player by facilitating a consistent (stable), accurate performance outcome whilst utilising a flexible range of solutions to adapt to different constraints. However, few studies have investigated the inherent MV within instep soccer kicking technique and performance (Lees & Rahnama, 2013).
'Motor equivalence' is closely associated with the concept of synergies, which indicate that elemental variables (e.g. joint angles) can work in functional units to stabilise task relevant performance variables through sharing and error compensation. The uncontrolled manifold (UCM) method has been widely used in motor control research to provide a quantitative measure of synergies in a range of tasks such as sit-to-standing (Scholz & Schoner, 1999) and pistol shooting (Scholtz, Schoner, & Latash, 2000). However, the application of the UCM to a complex and dynamic skill such as the instep soccer kick has not been investigated.
A study from a recent PhD thesis (Bennett, 2016) has also shown that a traditional biomechanical analysis of maximal instep kicking displayed no significant differences between kicks that hit and missed a target across a range of technique and performance variables that represent the instep kick (Lees & Rahnama, 2013). Therefore, the purpose of this study was to investigate MV structure and 'motor equivalence' within the a maximal instep soccer kick at a target and to determine whether the UCM method could provide a better understanding of the relationship between technique and performance (i.e. kicking accuracy) through an analysis of MV. Six task relevant performance variables were identified as potential variables to be stabilized within the kick technique. It was hypothesised that the inter-trial variations in joint configurations of the kicking leg for successful kicks would be structured in such a way as to stabilise one or more of these six variables.

METHODS: Eleven male university soccer players (age 20.8 ± 2.7 years, height 1.80 ± 0.03 m and mass 79.6 ± 6.2 kg) participated in this project. Each participant completed an informed consent and the research project was conducted according to the ethics policy and procedure of Leeds Beckett University.

DATA COLLECTION: Participants were instructed to perform a maximal instep kick at a $1m^2$ target at a distance of 11m directly in front of the ball (i.e. the distance for a penalty kick) in the centre of a full size indoor soccer goal (2 x 3 m). Participants were instructed to kick the ball at the target as fast as possible. 20 successful kicks that hit the target were recorded for further analysis in addition to a variable number of unsuccessful kicks that missed the target. All kicks were recorded at 50 Hz using a high-speed digital camera (Panasonic AVCCAM AG-HMC81E) to provide evidence of both successful and unsuccessful kicks.
Three-dimensional kinematic data for hit and missed kicks was captured at 250 Hz using six infrared cameras (Oqus 300) and Qualysis Track Manager (Qualysis, Gothenburg, Sweden). A 15-segment whole-body model was created using Visual3D software (version 4 Professional, C-Motion, USA) from 69 reflective markers (all static and 51 dynamic), with an additional 3 tracking markers attached to the ball using pieces of $2cm^2$ reflective tape to calculate the speed of the ball for each trial.

DATA ANALYSIS: The whole movement cycle of the instep kick was measured from toe-off to ball contact (BC) in line with other previous kicking studies (Egan, Verheul, & Savelsbergh, 2007). A cubic spline interpolation was used to normalise all movement trajectories to 100% (100 samples) for each participant using Visual3D software.

UNCONTROLLED MANIFOLD: Trial-to-trial variations of seven joint angles hip, knee and ankle) of the kicking leg were analysed across the normalised whole movement trajectory to investigate the MV structure for hit and missed kicks for six hypothesised performance variables:

1. Position of the centre of mass (COM) of the kicking foot relative to the kick-side hip (KFPH).
2. Linear velocity of the COM of the kicking foot relative to the kick-side hip (KFVH).
3. Angular momentum of the COM of the kicking foot relative to the kick-side hip (KFMH).
4. Angular momentum of the COM of the kicking foot relative to the whole-body COM (KFMCOM).
5. Angular momentum of the kicking leg relative to the kick-side hip (KLMH).
6. Angular momentum of the kicking leg relative to the whole-body COM (KLMCOM).

The UCM method partitions the total variance (V_{TOT}) in joint coordination patterns into variance that does (V_{UCM}) and does not affect (V_{ORT}) the value of the performance variable. V_{UCM} provides a measure of the error compensation and range of solutions in joint configuration space that keeps the performance variable stable. V_{ORT} provides a measure of the stability of the performance variable. The Z-transformed synergy index (ΔVz) was used to indicate whether trial-to-trial joint configuration variance was structured into a synergy (Krishnan, Rosenblatt, Latash, and Grabiner, 2013). $V_{UCM} > V_{ORT}$ ($\Delta Vz > 0$) supports the existence of a synergy, which shows that MV is structured to stabilise the performance variable. A higher ΔVz suggests a stronger synergy, depending on the magnitude of V_{ORT} (because V_{ORT} directly affects the performance variable) (Black, Riley & McCord, 2007). See Krishnan, Rosenblatt, Latash and Grabiner (2013) for more details on the mathematical procedures used to calculate V_{UCM}, V_{ORT} V_{TOT} and ΔVz.

STATISTICAL ANALYSIS: The dependent variables for this study were V_{UCM}, V_{ORT} V_{TOT} and ΔVz. The independent variables were *condition* (hit and missed), *phases* (BS, LC, and LA), and *variable* (6 UCM performance variables). Three-way repeated measures ANOVAs were used to test effect of *condition*, *phase* (BS, LC, and LA phases) and *variable*. All dependent variables were averaged across each phase. Pairwise comparisons with Bonferroni corrections were used to explore significant effects across all dependent variables. Paired sampled t-tests were used to test for significant differences between hit and missed kicks across all phases, and at BC for all dependent variables. Effect sizes were calculated using Cohen's d, with effect sizes defined as .2 = small, .5 = medium, and .8 = large (Cohen, 1988) across all independent variables.

RESULTS:
A synergy ($V_{UCM} > V_{ORT}$ ($\Delta Vz > 0$)) was present across all performance variables at BC for hit and missed kicks, where hit kicks displayed stronger synergies across all performance variables (Table 1).

Table 1. Strength of synergy (ΔVz) for hit and missed kicks across all kicking leg performance variables. $V_{UCM} > V_{ORT}$ ($\Delta Vz > 0$) supports the existence of a synergy

	KFPH	KFVH	KFMH	KFMCOM	KLMH	KLMCOM
Hit	0.16	0.47	0.39	0.44	0.36	0.43
Miss	0.08	0.22	0.31	0.34	0.35	0.42

The partitioned variance showed hit kicks displayed less range of solutions and less stability across all performance variables (Figure 1). Paired sampled t-tests showed missed kicks displayed a large decrease in stability for KFVH in comparison to hit kicks (approaching significance) ($t(10) = -2.2$, $p = 0.052$, $d = 0.66$), producing a moderate effect size. Greater total variability was observed for hit kicks in comparison to missed kicks across all performance variables at BC. A similar trend was observed across all phases of the instep kick, across all performance variables.

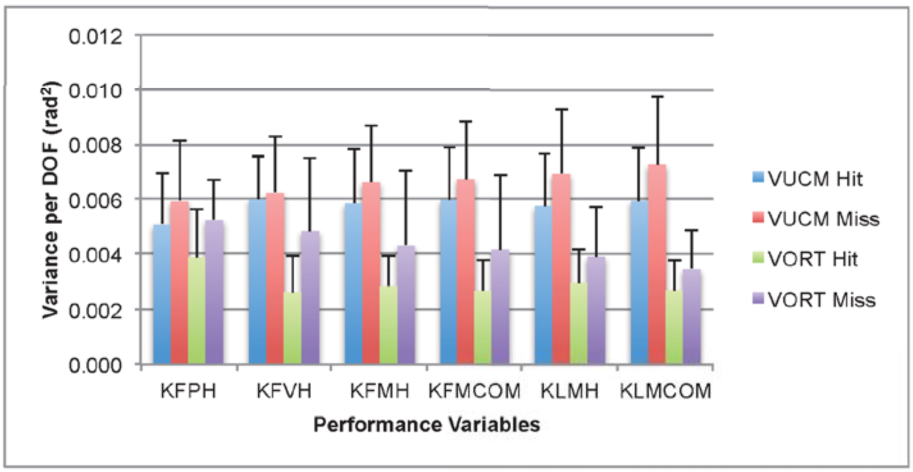

Figure 1. Range of solutions (V_{UCM}) and stability of the performance variable (V_{ORT}) for hit and missed kicks at BC for all kicking leg performance variables.

DISCUSSSION: Both hit and missed kicks showed that MV was structured into synergies at BC ($V_{UCM} > V_{ORT}$ ($\Delta Vz > 0$)), for all UCM performance variables. These findings indicate that the trial-trial variations displayed between joint angles are structured into synergies, which utilised error compensation strategies to stabilise a range of task relevant performance variables. Therefore, the joints of the kicking leg were not working in isolation, but as functional units that work together in a task specific way. Similar findings have also been noted in several UCM studies that have noted the presence of synergies for task relevant performance variables (Scholtz, Schoner & Latash, 2000; Morrison, McGrath & Wallace, 2016).

As a complex and dynamic whole-body movement, these findings indicate that a wide range of synergies are utilised for instep kicking, to control multiple task relevant performance variables. The presence of synergies across all six hypothesised variables also provides empirical evidence to show that 'motor equivalence' is a characteristic aspect of instep soccer kicking technique. These findings confirm what has been previously speculated in instep soccer kicking research, that soccer players can produce a consistent endpoint using a range of different solutions (Egan, Verheul, & Savelsbergh, 2007; Lees & Rahnama, 2013). In terms of practical implications, the range of solutions aspect of synergies confirms that MV can be very useful allowing players to adapt to different task constraints to produce an accurate kick at goal.

Comparisons between hit and missed kicks showed clear differences in MV structure between both conditions using the UCM analysis. Although both hit and missed kicks displayed synergies across all variables, hit kicks displayed stronger synergies at BC in comparison to missed kicks as a result of the joints producing more stability and less error compensation. Scholz, Schoner & Latash (2000) have also noted similar findings to this study, where unsuccessful trials have displayed less stability of task relevant performance variables. A decrease in error compensation for hit kicks also suggests that amore refined MV structure was utilised for successful kicks in contrast to missed kicks. In addition, the clear differences in MV structure between hit and missed kicks for KFVH suggest that this performance variable may be critical variable to be stabilised at BC. This would make sense based on the speed/accuracy trade-off noted in previous instep kicking literature (Lees & Nolan, 2002).

By applying the UCM method to the instep soccer kick, this study has provided a better understanding of technique and performance through an analysis of MV structure, whereas a study from a recent PhD thesis (Bennett, 2016) showed no significant differences between hit and missed kicks using a traditional biomechanics approach.

CONCLUSION: The UCM method provided a novel insight into instep soccer technique showing that the inherent MV displayed between trials was structured into synergies across all six performance variables of the kicking leg. This finding provided empirical evidence to support the demonstration of 'motor equivalence', which would enable the player to produce a consistent, successful outcome from an abundant range of variable solutions. The UCM method was also sensitive enough to identify clear differences in MV structure between hit and missed kicks. Therefore, this suggests that a consistent, accurate performance could be dependent on MV structure within the human motor system.

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