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WHEN BOTH SPEED AND ACCURACY ARE IMPORTANT: USING CANONICAL CORRELATION TO EVALUATE SKILLS

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Many sports skills such as the tennis serve, goal shot in soccer and golf drive, require both speed and accuracy. However, evaluation of these skills has been limited to assessing these factors separately. The use of analyses that allow for the inclusion of both features is an important direction for sports biomechanics. This study highlights the use of canonical correlation to achieve this. Canonical correlation analysis allows the assessment of relationships between two sets of variables, providing the opportunity for more than one dependent variable. Using Australian football handballing, in which both speed and accuracy are necessary, canonical correlation analysis found a strong relationship between covariate and criterion groups. Moreover, the results differed from the evaluation of speed and accuracy when these had been analysed separately.

KEY WORDS: Australian football, accuracy, speed, multivariate

INTRODUCTION: Many ball sports require the ball to be propelled with a combination of speed and accuracy for a successful outcome. Skills such as kicking (Ball, 2008), the tennis serve (Blackwell & Knudson, 2002) and cricket fast-bowling (Phillips, Portus, Davids & Renshaw, 2012) require ball speed to achieve the necessary distance or to make interception more difficult for the opponent. These skills also require accuracy to pass to another player or to land the ball in a specified area. Speed and accuracy are integrally linked; both dependent variables share a relationship, as suggested by theories such as the speed-accuracy trade-off (putting, Beilock, Hoerger, Bertenthal & Carr, 2008; throwing, van den Tillaar & Ettema, 2006) and the impulse-momentum theory (Urbin, Stodden, Boros, & Shannon, 2012). This trade-off is apparent, for example, in the tennis serve, where a fast but inaccurate serve may result in a fault; whereas a slow serve, with a focus on accuracy may be more easily returned by an opponent.

Many studies have found important technical information by examining performance using maximum speed tasks. Similarly, technical components of accuracy based tasks have been assessed. Some researchers have analysed both variables, but they have done so without linking the two together. Assessing skills based on only one of these performance indicators may discount technical parameters that contribute significantly to the outcome of the movement. Australian football handballing is another example of a skill requiring both ball-speed, for distance or to avoid interception from the opposition, as well as accuracy to hit the intended target player in an easily receptive manner (Parrington, Ball & MacMahon, 2012). It has been suggested that players may sacrifice the speed at which they contact the ball to provide greater accuracy. Therefore, assessment of the factors leading to performance where both hand-speed and accuracy are considered is an appropriate step in analysis.

Canonical correlation analysis (CCA) is a statistical method that can provide the means to assess speed and accuracy together. The aim of CCA is to analyse the linear relationship between two sets of variables and allows for the inclusion of more than one dependent variable (DV). It is a multivariate statistical method that falls within the general linear model and is used to assess the complex relationships between and within independent and dependent variables. It is a correlational technique and researchers should note that while they may like to nominate independent (IV) and DV sets, relationships found do not infer causality (Tabachnick & Fidell, 2007). Canonical correlation analysis provides information without the need to examine IVs separately (i.e. separate analysis for speed and accuracy), divide the sample, or run multiple statistical tests between groups, which can inflate type 1 error (Sherry & Henson, 2005). Despite the potential contribution of CCA, little scientific attention has been paid to this technique due to a lack of understanding of how to perform and interpret this type of analysis (Tabachnick & Fidell, 2007). The aim of this paper is to demonstrate the use of CCA in sports biomechanics in throwing or striking activities where performance outcome considers both speed and accuracy.

METHOD: Data Collection: Eighteen male elite Australian football players (19 ± 1 years, 1.9 ± 0.1 m, 87.5 ± 8.4 kg) performed five handballs with the preferred hand. Participants were required to catch the ball at chest height and then attempt to hit the centre of a bullseye target positioned 5 m away at a height of 1.5m. Players were instructed to perform at game intensity. Accuracy scores were manually recorded based on a 3-2-1 rating, per 0.2 m deviation from the centre and reviewed using video footage. The total score for the five handballs was used for analysis. Participants wore standard training apparel and had rigid marker clusters attached to the upper limbs and trunk. Anatomical landmarks were virtually stored to determine joint centres at the shoulder, elbow, wrist and the centre of the hand and to define anatomical segment frames. One marker was placed on the base of the fifth metatarsal of each foot to assess step characteristics. Optotrak Certus [Northern Digital Inc. (NDI), Ontario, Canada] was used to collect 3D data (100 Hz). Trials were imported into Visual3D (C-Motion, Inc., Maryland, USA) for analysis. Raw data were smoothed using a low-pass filter (4^{th} order Butterworth, 7Hz cut-off, chosen based on residual analysis, Parrington et al., 2012). Maxima and minima data between leading foot toe-off until ball contact were collected and used in the calculation of elbow range of motion (ROM) and elbow angular velocity. Hand-speed and hand-path were collected at the instant prior to ball contact. Mean and standard deviation per parameter for the five handballs were calculated in Microsoft Excel and imported into SPSS 20.0 for statistical processing.

Statistical Analysis: There is no strict guide on case-to-IV ratio. Tabachnick and Fidell (2007) indicate that a ratio of 10 cases per variable is appropriate when reliability is 0.8, but that a lower ratio is acceptable if reliability of data is high. Two DVs (speed and accuracy) and three IVs (hand-direction, elbow angular velocity and elbow ROM) were chosen based upon previous performance assessment (Parrington, Ball, & MacMahon, under review) and entered into the CCA. Tabachnick and Fidell (2007) provide an example of running a CCA statistical output from three separate software packages.

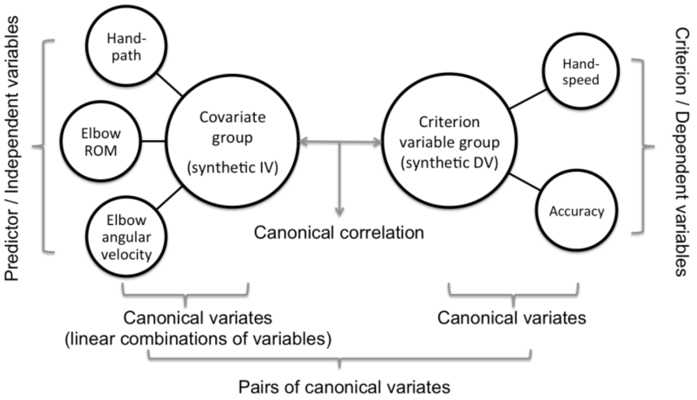

Figure 1: Diagram of canonical correlation

Interpretation of CCA requires interpretation of both the full canonical model and the canonical functions of the model. The full model evaluates the shared variance between the two sets of variables (covariate/IVs and criterion/DVs) across all of the canonical functions (Sherry & Henson, 2005). There will be as many canonical functions as criterion variables entered (typically DVs) into the CCA. A canonical function maximises the correlation between the variable sets. The first function uses all pairs of canonical variates. The second function is orthogonal and explains the remaining variance using all pairs of canonical variates after the first and most important pair of canonical variates has been removed (Hair et al., 1998; Tabachnick & Fidell, 2007). This process continues in this fashion for the number of criterion variables entered in the CCA. As subsequent functions are responsible for explaining the residual variance not accounted for by the preceding function(s), the canonical correlation value is smaller (Hair et al., 1998). Assessment of whether the model warrants further interpretation is driven by evaluation of both statistical significance and the magnitude of the relationship (effect size). While significance level is at the discretion of the researcher, acknowledging how sample size may inflate or deflate *P*-values is an important consideration (Sherry & Henson, 2005). Effect size of the full model can be calculated by $R_c^2 = 1 -$ wilks lambda (λ). This gives the amount of variance shared between the variable sets and can be interpreted in the same manner as R^2 for a multiple regression (Sherry & Henson, 2005). If further interpretation of the model is warranted, the *P*-values and variance explained for each of the canonical functions should be assessed. Variance explained is given by the canonical correlation, where $R_c > 0.3$ (or $R_c^2 > 10\%$) is a common rule of thumb for cut-off (Tabachnick & Fidell, 2007). Of note, it is possible that the sum of the squared canonical correlations explains more than the full canonical model (Hair et al., 1998). Finally, interpretation of the canonical functions (or groups of canonical variates) requires assessment of structure coefficients. Structure coefficients reflect the direct contribution of one predictor covariate to the criterion variable regardless of the other predictors and therefore provide information on the contribution and direction of their relationship within the function (Sherry & Henson, 2005). Cut-offs for meaningful correlations are at the discretion of the researcher, but can be guided by suggested values for factor analysis (excellent > 0.71; very good > 0.63; good > 0.55; fair > 0.45; poor > 0.32, Tabachnick & Fidell, 2007).

RESULTS AND DISCUSSION: The canonical model is significant ($P = 0.009$) and explained 73% of variance shared between the variable sets (Table 1). This effect was calculated by $R_c^2 = 1 - \lambda$ (i.e. 1 - 0.267 = 0.733). The strength of this relationship coinciding with the statistical significance found warranted further interpretation of the canonical functions.

Table 1. Full canonical model

Test name	Value	*F*	Hypoth. DF	Error DF	*P*	Effect
Wilks	0.267	3.739	6	24	0.009	0.733

Table 2 and 3 provide information on the canonical functions. Function one explained 60% of the variance between the variable sets ($R_C^2 = 0.60$, $P = 0.009$). Function two was not significant after the leading pair of canonical variates was extracted. However, function two explained 33% ($R_C^2 = 0.33$, $P = 0.074$) of the variance, with an $R_C = 0.57$. This is a reasonable effect considering the suggested cut-off of $R_C > 0.3$, and is thus deemed worthy of interpretation. In order to assess the direction and contribution of the IVs, the structure coefficients were assessed. These are provided in Table 4.

Table 2. Eigenvalues and canonical correlations

Root No.	Eigenvalue	%	Cumulative %	Canonical Correlation	Squared Correlation
1	1.51	75.46	75.46	0.78	0.60
2	0.49	24.54	100.00	0.57	0.33

Table 3. Dimension reduction analysis

Roots	Wilks L.	F	Hypoth. DF	Error DF	*P*
1 TO 2	0.267	3.739	6.000	24.000	0.009
2 TO 2	0.671	3.193	2.000	13.000	0.074

Table 4. Canonical solution for Functions 1 and 2

	Function 1			Function 2			
Variable	Coef	r_s	r_s^2 (%)	Coef	r_s	r_s^2 (%)	h^2 (%)
Accuracy	-0.560	-0.706	49.87	0.853	0.708	50.12	99.9997
Hand-speed	0.723	0.836	69.87	0.721	0.549	30.13	99.9998
Hand-path	0.303	0.397	15.73	-0.877	-0.837	69.99	85.72
Elbow ROM	-0.040	-0.767	58.85	0.656	0.017	0.03	58.88
Maximum elbow angular velocity	0.891	0.953	90.86	0.893	0.285	8.14	99.01

Note. Structure coefficients (r_s) > 0.45 are underlined. Communality coefficients (h^2) greater than 45% are underlined. Coef = standardized canonical function coefficient; r_s = structure coefficient; r_s^2 = squared structure coefficient; h^2 = communality coefficient.

Function one identified an inverse relationship between hand-speed and accuracy, indicating faster hand-speeds were associated with lower accuracy and vice-versa. This reflects the previously described speed-accuracy trade-off, where a decrease in release (or ball contact) velocity is linked to an emphasis on accuracy (van den Tillaar & Ettema, 2006). Structure coefficients of IVs demonstrate a large contribution from maximum elbow angular velocity and elbow ROM and a smaller contribution from hand-path. This indicated that increased elbow angular velocity and increased flexion (denoted by negative sign) are related to increased hand-speed but decreased accuracy. The relationship between hand-path and accuracy suggests that accuracy decreases as hand-path is more angled (less direct path). Smaller elbow angular velocity and elbow ROM were linked with a more direct line to the target and therefore, accuracy. Notably, elbow ROM was not significant at the 0.05 level when assessed individually against either hand-speed (r = 0.46) or accuracy (r = 0.45).

The structure coefficients for function two indicated a linear relationship between the DVs hand-speed and accuracy. Of the IVs, hand-path is the primary contributor (r_s > 0.7), while the contribution of elbow angular velocity is poor and less than 1% for elbow ROM. Hand-path was inversely related to hand-speed and accuracy, indicative that a less angled strike path is associated with greater hand-speeds and accuracy. Linked together, this suggests that accuracy would not be adversely affected through an increase in hand-speed in cases where the hand-path is directed toward the target. Further interpretation of the canonical model using theories such as the speed-accuracy trade-off (Beilock et al., 2008) and impulse-variability theory (Urbin et al., 2012), may help the understanding of the relationships between parameters. Canonical correlation analysis was useful to provide insight into the kinematics of handballing by determining the multivariate relationship between elbow angular velocity, elbow ROM and hand-path and accuracy and hand-path. Clarification of variance unexplained is warranted with this type of analysis.

CONCLUSION: Canonical correlation analysis provided an effective method of identifying key information on the interaction both between and within variate groups. Furthermore, CCA identified a parameter, elbow ROM that was an important contributor to the canonical model, but was not significantly related to either hand-speed or accuracy when measured separately. This case helps illustrate that in biomechanics research, CCA may be useful for researchers wishing to assess skills where more than one dependent variable is important.

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