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**The Application of Regression Based Normative Profiling
for International Male Taekwondo Performance.**

by

Matthew Milligan

A Research Project submitted in partial fulfilment of the requirements of the
University of Chester for the degree of M.Sc. Sports Sciences (Performance
Analysis)

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5477 Words

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Abstract

The purpose of this study was to compare the predictive accuracy of two regression based normative profiling methodologies (O'Donoghue & Cullinane, 2011; 2- Non-parametric regression) for the assessment of elite male Taekwondo performance. Following 'inter-operator' reliability analysis, retrospective performance data (319 performance indicators; 167 matches) was used for forty-eight elite senior male Taekwondo athletes (<58kg - <80kg) during participation across 22 major competitions between 2010 and 2013. The world rankings of all athletes were converted into relative quality ratings (*RQ*), with an *RQ* differential calculated for all respective matches. A Chi-Square χ^2 test of independence was employed to identify the existence of a significance association between relative quality and match outcome. All data was then subjected to either Pearson's *r* (O'Donoghue & Cullinane, 2011) or Kendall's Tau (τ) (Non-Parametric regression) correlation analysis, where the performance indicators ($n=34$) deemed to bear the most meaningful relationships with relative quality were then included within the both profiling methodologies. The 'standard error of estimate' (SEE) and SEE% values were computed for all performance indicators and subjected to both Mann Whitney-U and binomial testing comparisons, from which the most accurate method was recruited to analyse a selected athlete. A Chi-square test of independence identified the validity of including relative quality within regression based performance profiling (χ^2 ; $P < .01$). Non-parametric regression was found to exhibit moderately superior mean SEE and SEE% values, in addition to superior SEE and SEE% values for a greater proportion of the performance indicators of interest. It was concluded that non-parametric regression offered an advance upon previous profiling methodologies for the assessment of elite male Taekwondo performance.

Declaration

I hereby declare that no portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

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Date

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1.0 Introduction

Over the past 30 years, several studies seeking to compare the observational efficacy of elite sports coaches to that of quantified performance statistics have consistently found that approximately 40 - 70% of 'key' occurrences typically remain un-recalled (Franks & Miller, 1986, 1991; Laird & Waters, 2008). Possible explanations have extended to the complicated processes of simultaneously viewing and assimilating all such incidents, in addition to the inhibiting influence of human memory limitations and personal bias upon clarity of interpretation (Franks & Miller, 1986; Carling, Williams & Reilly, 2007; Hughes & Franks, 2008). Additionally, previous research has also proven that expert coaches and athletes across Soccer, Tennis and collegiate Basketball are no better at forecasting future match outcomes (win/lose) or basic performance related statistics than either chance or novice sport enthusiasts respectively (Boulier & Stekler, 1999; Andersson, Memmert & Popowicz, 2009). Indeed, owing to such recollection and forecasting limitations, an obvious consequence is that practical interventions such as training schedules and tactical strategies are likely to be based upon subjective interpretation, thus possessing significant inaccuracies (Plessner & Harr, 2006; Heasman, Dawson, Berry & Stewart, 2008; Hughes & Bartlett, 2008; Arseneau, Mekary & Ledger, 2011).

Subsequently, 'normative profiling', a performance analysis methodology for analysing potential patterns of performance indicators derived from a team or individual, ostensibly offering some prediction of future performance would appear to tender a more suitable basis for practical evaluation purposes (Hughes, 2004; James, Mellalieu & Jones, 2005; Waldron & Worsfold, 2010). Principally, three key methods have been proposed within previous research, one of which has sought to

systematically determine that of 'typical' sporting performance (Hughes, Evans & Wells, 2001), whilst alternative methodologies have demonstrated the virtue of considering both the typical performance (median or mean values) and any degree of variability therein (James et al., 2005; O'Donoghue, 2005). However, given the reported existence of a multitude of 'confounding' influences upon that of a 'typical' sporting performance, such as venue (Tucker, Mellalieu, James & Taylor, 2005), score line (Taylor, Mellalieu, James & Shearer, 2008), match importance (Hale, 2004) and oppositional quality (McGarry & Franks, 1994; James et al., 2005; O'Donoghue, Mayes, Edwards & Garland, 2008; O'Donoghue, 2009), the assumed contextual consistency in which comparisons of multiple performances are made would seem erroneous (Waldron & Worsfold, 2010).

On this premise, research by Cullinane (2011) and O'Donoghue and Cullinane (2011) sought to propose a more comprehensive methodology for interpreting sporting performance with due regard for the direct influence of oppositional quality. Specifically, O'Donoghue and Cullinane (2011) used both correlation coefficients and linear regression analysis to firstly ascertain any performance indicators of critical importance, before formulating predictive values concerning that of forthcoming sporting performance thereafter. Therein, a noteworthy strength of this particular profiling method pertains to the manner in which oppositional quality is objectively accounted for, based on an expectancy of progression within a given competition (i.e. expected finalist vs semi-finalist), as opposed to simply considering how the performance of a particular athlete or team fares against opponents categorized within differing ranking related thresholds (i.e. world top 20 vs 21-75 vs ≥ 76) (O'Donoghue et al., 2008; O'Donoghue, 2009).

However, Butterworth, O'Donoghue and Cropley (2013) postulated that such a methodology cannot be considered as a profiling technique per se, given that it fails to offer any notion of how to represent a collection of different performance variables within the contour of a singular graphical format. Although, such a criticism was not stringently justified. Perhaps, more plausibly, O'Donoghue and Cullinane's (2011) research can be criticised for demonstrating the application of this profiling methodology without acknowledging the potentially detrimental influence associated with observing weak relationships between sport performance variables and relative oppositional quality. Therefore, the moderate correlation and coefficient of determination values (i.e. % 1st service points won; $r = 0.485$, $R^2 = 0.24$) presented by O'Donoghue and Cullinane (2011) may have inferred that a highly invalid predictive model was demonstrated rather than a depiction of the variable nature of elite sporting performance, as originally posited. Indeed, such a predictive limitation would have been evident from the standard error of estimation (SEE) values usually generated within regression based analysis (Palmer & O'Connell, 2009). However, such statistics were ultimately omitted from the research, as was any efforts made to pre-determine the validity of utilising relative quality as an independent predictor variable within regression analysis.

Moreover, O'Donoghue and Cullinane (2011) stressed the requirement for all performance indicator values to yield normal distributions ($P > 0.05$) within the proposed model, alternatively tendering the application of log transformations as a possible circumvention. However, given that the majority of statistics derived within performance analysis research tend to be non-parametric in nature (Hughes, Cooper & Nevill, 2002), coupled with the practical complexity of interpreting log transformed statistics (Severini, 2014), alternative approaches such as non-parametric regression

would seem warranted. Although, to date, the accuracy in using both parametric and non-parametric regression for profiling purposes within performance analysis research has yet to be established. Though, such a process would seem prudent. Notwithstanding, regression based performance profiling has been proven useful in documenting both Rugby League and International male Tennis performance respectively (Cullinane, 2011; O'Donoghue & Cullinane, 2011). However, the extension of this methodology towards additional sports has remained entirely unexplored. In particular, given the apparent paucity in performance analysis related inquiry towards that of combat sports, such as competitive Taekwondo (Bridge, Jones & Drust, 2011), a suitably established profiling methodology of this nature would appear to lend itself well for facilitating a more comprehensive understanding of both the technical and tactical parameters that underpin the sport.

Taekwondo is a high-intensity martial art, with the aim of knocking out or scoring more points than an opponent through the use of the hands and feet to attack and defend (Estevan, Falco, Alvarez & Molina-Garcia, 2012). Of note, since 2000, several fundamental rule changes have been enforced on the premise of making all standards of competition more challenging. Firstly, the round duration and fighting area have been reduced from four, two minute rounds and 10 x 10m, to three, two minute rounds and 8 x 8 metres respectively. Moreover, whilst a clean blow with 'sufficient' displacement causing force ($\geq 119\text{N}$) is required to score to the body (Ramazanoglu, 2013), points (≥ 3) are now awarded for contact made with the head of an opponent, regardless of the level of force applied (WTF; World Taekwondo Federation, 2012). Additionally, the complexity of a successful attack can also determine the resultant scoring value (WTF, 2012).

With regard to previous performance analysis research, negligible differences have been identified in both offensive and counter-offensive male Taekwondo performance between medallists and non-medallists at the Olympic Games in 2000, 2004 and 2008 respectively (Kazemi, Waalen, Morgan & White, 2006; Kazemi, Cassella & Perri, 2009; Kazemi, Perri & Soave, 2010), thus denoting the seemingly infinitesimal margins that determine success within the sport. Furthermore, the tactical tendencies within Taekwondo competition have also been documented, in that, 75% of all kicks performed are typically roundhouse in nature, mostly performed from the back foot with an attack to defending ratio of 6:4 respectively (Luk, Hong & Chu, 2001; Chou & Chiu, 2009; Capranica, Chiodo, Cortis, Corrado, Ammendolia & Tessitore, 2010).

However, a number of criticisms can be levelled at previous performance analysis research surrounding competitive Taekwondo (Bridge et al., 2011; Bridge, McNaughton, Close & Drust, 2012). In that, such investigations have often included small sample sizes of sub-elite athletes (Luk, et al., 2001; Cular, Krstulovic & Janovic, 2011; Falco, Landeo, Menescardi, Bermejo & Estevan, 2012; Kwok, 2012), from singular nationalities (Luk et al., 2001; Chou & Chiu, 2009; Falco et al., 2012), within non-WTF-competitive match scenarios (Matsushigue, Hartmann & Franchini, 2009). Moreover, the aforementioned rule changes may have also inhibited the generalizability of the findings within previous research (Cular et al., 2011). Consequently, the tactical parameters that underpin elite male Taekwondo performance would still appear to remain largely unexplored (Capranica et al., 2010; Kwok, 2012), thereby necessitating the use of an appropriate profiling methodology, once such accuracy has been established, for the purpose of comprehensively analysing the sport.

1.1 Aim of Study

Thus, the aim of the present paper was to compare the accuracy of two regression based normative profiling methodologies (O'Donoghue & Cullinane, 2011; 2- Non-parametric regression) before demonstrating the application of such an approach for the assessment of elite male Taekwondo performance (Table 1).

Table 1. Sequential objectives of the research investigation.

Objective	Definition
1	Assess the validity of using 'relative quality' as an independent predictor variable within regression analysis.
2	Use correlation analysis to identify "key" performance indicators within elite male Taekwondo competition that bare meaningful relationships with relative quality.
3	Establish the accuracy of both regression based predictive models bespoke to each "key" performance indicator.
4	Adopt the most accurate model to evaluate both the actual and expected performances of a select male competitor, subject to the different quality of opposition encountered.

2.0 Methodology

2.1 Participants

Approval for this study was granted from the University of Chester faculty of life sciences ethical committee. To ensure this study yielded a statistical power (δ) of 0.9 (Mayr, Erdfelder, Buchner & Faul, 2007), 48 elite senior male Taekwondo performers, ranging from Flyweight (<58kg) to Welterweight (<80kg) were analysed during participation across 22 major competitions between 2010 and 2013. The study required no active involvement from the participants and thus the provision of any study explanations, consent forms or pre-test health screening questionnaires prior to data collection were not deemed as necessary. However, written consent was obtained from the English Institute of Sport (EIS) and Great British Taekwondo for use of the retrospectively notated data.

2.2 Design

The study adopted an 'observational' 'case-series' design involving one stage of retrospective data utilisation (Hopkins, 2008; Field, 2009) for a single purposefully selected athlete, based on the differing quality of opposition encountered. The independent variable within this investigation was 'relative quality' (*RQ*) and all dependant variables were those which concerned offensive and counter-offensive Taekwondo performance.

2.3 Procedure

All matches took place within a standardized contest area of 8m² (WTF, 2012). Any matches in which one of the involved participants was either stopped (e.g. retirement) or disqualified was ultimately excluded from the eventual sample, apart from those in which a particular athlete reached the required point difference maximum (≥ 12 points) (WTF, 2012). Thus, all completed matches were performed across 3 x 2 minute rounds, with 1 minute rest intervals scheduled between each respective round (WTF, 2012). Data collection was conducted retrospectively, for 167 performances (134 matches) by the head performance analyst at Great British Taekwondo, using pre-recorded video footage that was obtained from the publicly available internet domain known as Dartfish Tv (<http://www.dartfish.tv/WTF>).

2.3.1 Data collection

Using a previously devised computerized 'coding' template (Dartfish; Version 6.0, Switzerland), all offensive and counter-offensive incidents within each respective Taekwondo contest were analysed by the lead data collector (head analyst) in a sequential manner, by firstly identifying a summary of each strategic 'movement' performed (i.e. Pressing), subject to any subsequent offensive or reactive 'actions' also performed (i.e. Attack). Thereafter, each respective 'action' was further notated subject to the underpinning 'kick' or 'punch' types performed (i.e. Turning) and their intended 'target area' (head, body) and 'outcome' (typically 1 - 4 points) (Figure 1).

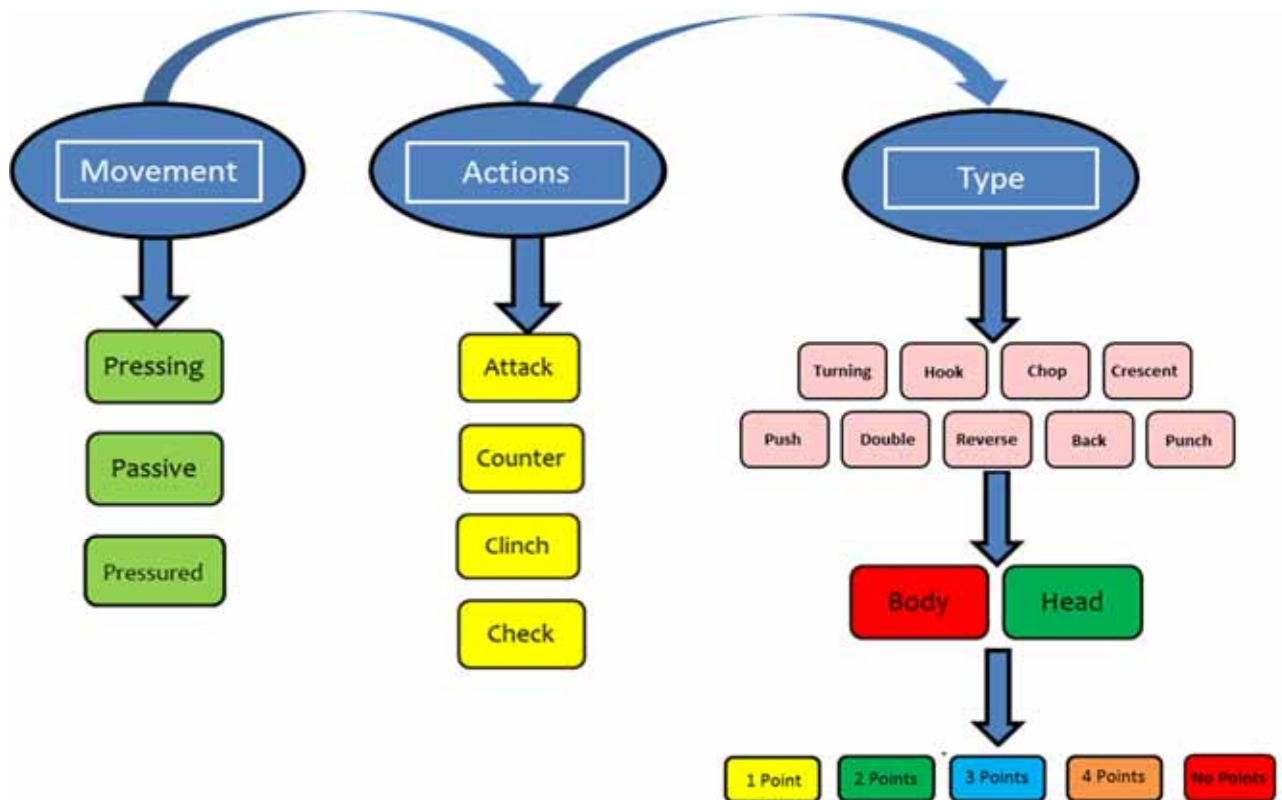


Figure 1. A schematic representation of how offensive and counter-offensive elite Taekwondo performance was analysed.

Furthermore, several descriptive and miscellaneous events were also notated, including the round, score-line and details of any penalty warnings issued by the referee.

2.3.2 Performance Indicators & Operational Definitions

All performance indicators and their supplementary operational definitions were used in accordance with both previous literature (Luk et al., 2001; Bridge et al., 2011) and those pre-defined within conventional applied use at the EIS (Table 2). Further, to facilitate more effective analytical comparisons, each performance indicator was subsequently normalized to a 'percentage' (%) (i.e. successful kicks / total kicks *

100) and 'per-minute' value (i.e. total counters performed / minutes of contest) respectively.

Table 2. Summarised list of offensive and counter-offensive performance indicators and the corresponding operational definitions used during the analysis procedure.

Performance Indicator	Operational Definition
Pressing	A phase of forward movement towards an opponent that often results with an attacking manoeuvre being performed.
Attack	Any kick, punch or combination performed that is deemed to be initiated by the performer under analysis.
Turning Kick	A kick made with either the lead or rear leg that moves along the transverse axis in a semi-circular motion, deemed as intentional in making contact with the opponent's head or body with the top of the foot.
Body	An offensive or counter-offensive manoeuvre that is deemed to have either 1) visibly landed and scored, 2) visibly made contact, but failed to score, or 3) visibly failed to make any contact but moved towards any part of the front or sides of the trunk of the opponent, below the neckline.
Points	Labelled as the number of points awarded to a player for a valid kick made with the foot, below the ankle bone or a punch, with the knuckle part of a closed fist upon the legal target area of an opponent.

2.3.3 Reliability Analysis

Following this, an inter-observer reliability assessment was performed using two key methods, requiring two analysts (lead data collector and the author; experience; > 4 years) to notate a total of 8 randomly selected contests (~5% of all matches analysed) (O'Donoghue, 2007). Firstly, for all 8 match performances analysed, percentage agreement calculations were computed, in which a threshold of acceptable agreement, deemed as $\geq 90\%$ was established for all 37 relevant performance indicators (Hughes et al., 2002). Thereafter, 1 match performance was also compared using the method formally proposed by Cooper, Hughes, O'Donoghue and Nevill (2007). With due regard for the frequent occurrences of all relevant actions performed within competitive Taekwondo, all events from the respective contest were divided into discrete 20-second time cells (~6 per round, ~18 per contest) to ensure a more comprehensive test-retest comparison that would likely leave few, if any, empty time cells (Cooper et al., 2007; Thomson, Lamb & Nicholas, 2013). Thereafter, following the computation of both median sign testing and approximate confidence intervals for every proportion of agreement (upper 97.5% CI = $p_o + (1.96 \times SE(p_o))$; lower 2.5% CI = $p_o - (1.96 \times SE(p_o))$), an observed concordance of $\geq 95\%$ was ascertained for all but one (passive incidents) of the performance indicators within a permitted reference value of ± 1 errors per time cell (Table 3). Following the removal of this single unreliable performance indicator, the remaining data was deemed as sufficiently accurate for research purposes (Cooper et al., 2007; Thomson et al., 2013).

Table 3. Summarised ‘inter-observer’ reliability results in accordance with the method formally proposed by Cooper et al. (2007).

Performance Indicator	Median Sign Test ($P > 0.05$)	PA \pm 1 (%)	PA \pm 1 95% CI
Attacks	$P = 1.00$	100	100 to 100
Counters	$P = 1.00$	100	100 to 100
Successful Attacks	$P = 1.00$	100	100 to 100
Successful Counters	$P = 1.00$	100	100 to 100
Total Kicks	$P = 1.00$	100	100 to 100
Total Head Kicks	$P = 1.00$	100	100 to 100
Total Body Kicks	$P = 1.00$	100	100 to 100
Total Successful Kicks	$P = 1.00$	100	100 to 100
Total Front Leg Kicks	$P = 1.00$	100	100 to 100
Total Back Leg Kicks	$P = 1.00$	100	100 to 100
Turning Kicks	$P = 1.00$	100	100 to 100
Passive Incidents	$P = 0.45$	79%	66 to 99
Pressing Incidents	$P = 0.15$	97%	91 to 100
Pressured Incidents	$P = 0.29$	97%	91 to 100

PA \pm 1 = proportion of perfect agreement within the permitted reference value of \pm 1 errors per 20 second time cell; CI = Confidence intervals of the observed agreement within 95% of the data.

2.4 Relative Quality (RQ) Validity Analysis

Thereafter, the world ranking (*Rank X*) of each respective athlete (*X*) was obtained and transformed into a quality rating (*RX*), thus denoting an expected tournament progression value (stages) in accordance with the calculation method previously proposed by Klassen and Magnus (2001). Then, the relative quality (*RQ*) differential between each respective athlete, per match, was subsequently determined (Table 4).

Table 4. Relative quality rating (*RQ*) calculation procedure.

Determinant	Calculation
Quality Rating (<i>RX</i>)	$RX = 7 - \log_2 * (\text{Rank}X)$.
Relative Quality Differential (<i>RQ</i>)	$RQ = RX (\text{Player 1}) - RX (\text{Player 2})$.

The relative quality differentials of all athletes under analysis were then categorized as being 'negative' (inferiorly ranked), 'neutral' (similarly ranked) or 'positive' (superiorly ranked) in relation to that of their direct opponent. Subsequently, the percentage of wins and losses within each respective relative quality category were then compared using a Chi-Squared χ^2 test of independence, whereby a significant association was set at $P < 0.05$ (O'Donoghue, 2012).

2.5 Regression Based Profiling Methodologies

2.5.1 Correlation Analysis

In creating both profiling methods, Kolmogorov-Smirnoff testing procedures were performed, which identified the non-normal nature of the data distribution for over 90% of all (n=319) performance indicators ($P > 0.05$), thus confirming the data as sufficient for use within non-parametric regression (Field, 2005; 2009). Conversely, for the O'Donoghue and Cullinane (2011) profiling methodology, a 'natural' log data transformation was applied to all values within the respective data set, in addition to the removal of all 0 based outliers to ensure that 95% of all values resided within 1.96 standard deviations of the mean for each performance indicator (Reid, McMurtrie & Crespo, 2010; O'Donoghue & Cullinane, 2011). Thereafter, for the O'Donoghue and Cullinane (2011) methodology, Pearson's (r) correlation coefficients were performed on all respective log-transformed performance indicators, whereby the alpha level of significance was set to $P < 0.05$ and a relationship with relative quality (RQ) was considered as meaningful at $r \geq (+/-) .06$ (Cohen & Holliday, 1996). Alternatively, for non-parametric regression, Kendall's tau (τ) correlations were performed, in which a relationship was considered as meaningful at $\tau \geq (+/-) 0.03$ ($P < 0.05$) (Hopkins, 2010). The author also consulted the head performance analyst with Great British Taekwondo to ascertain the 34 most critical, 'meaningfully' related performance indicators for inclusion within both profiling methodologies.

2.5.2 O'Donoghue and Cullinane (2011) Profiling Methodology

A bivariate linear regression analysis was subsequently performed on each meaningfully related performance indicator (n=34) to assess predictive strength with that of relative quality (*RQ*) (Field, 2009). All regression equations were determined using the 'Slope' and 'Intercept' functions within Microsoft Excel, denoting the log transformed gradient of the line of best fit (i.e. -0.072590621) and the value of the dependant variable (*Y*) when the relative quality differential (*X*) is at 0 (i.e. 2.569871362).

An example prediction calculation is as follows:

$$Y = 2.569871362 + -0.072590621 * RQ.$$

Thereafter, for each back-transformed residual value, a Z-score was calculated, whereby the residual of interest was divided by the standard deviation of all residual values for a given performance indicator before being entered as a parameter of the 'NORMDIST' function within Microsoft Excel and multiplied by 100(%). The resultant value thus determines a percentage score that considers all match performances under the same relative quality differential (*RQ*) in which a corresponding performance indicator value would be lower (Cullinane, 2011; O'Donoghue & Cullinane, 2011).

2.5.3 Non-Parametric Regression ('Kendall') Profiling Methodology

For each meaningfully related performance indicator, all values were ranked (lowest to largest) according to the *RQ* values (*X*-axis).

A slope was then computed for every possible pair of x and y-values, using the following calculation:

$$\text{Slope } 2-1 = \frac{Y_2 - Y_1}{X_2 - X_1}$$

Thus, there were 13861 ($167 \cdot (167-1)/2$) slope estimates per performance indicator. Thereafter, the actual slope (β) was calculated as the median value of all consecutive slope gradients. The y-intercept (α) was determined as the median value computed via the calculation of the actual performance indicator value (Y_1) – (median slope * RQ) for each respective ($n=167$) performance within the model.

Therefore, the non-parametric prediction of Y was:

$$Y = (\text{median } a) + (\text{median } \beta * RQ).$$

2.5.4 Regression Based Profiling Accuracy Comparison

For each corresponding performance indicator within both profiling methodologies, the overall standard error of estimation (SEE) was computed and calculated as a percentage of the mean value to denote the SEE%, with an applied threshold of acceptable error being defined as $\leq \pm 10\%$ (Field, 2013) (Table 5). Of note, within the O'Donoghue and Cullinane (2011) profiling methodology, the equivalent back-transformation procedure is alternatively represented as a percentage (%) of the geometric mean for each respective performance indicator (Olivier, Johnson & Marshall, 2008) (Table 5).

Table 5. Standard error of estimation (SEE) and SEE% calculation procedures for both profiling methodologies.

Determinant	Calculation
<u>Non-Parametric Regression</u>	
SEE	= SQRT(Sum Squared Error / (167-2))
SEE%	= (SEE) / (Performance Indicator Mean * 100)
<u>O'Donghue & Cullinane (2011)</u>	
Log SEE	= 'Log Sum Squared Error' / (167 -2)
Log SEE SQRT	= SQRT(Log SEE)
Exponential SEE	= (EXP(Log SEE SQRT)-1) * 100
Back-Transformed SEE	= (GEOMEAN / 100) * Exponential SEE
Back-Transformed SEE%	= (EXP(Log SEE SQRT-1) * 100

To compare the predictive accuracy of both regression based profiling methodologies across 18 select performance indicators of interest, 'Shapiro-Wilks' testing procedures identified the non-normal distributions of the SEE and SEE% values ($P < 0.05$), with an alternatively normal distribution for Correlation scores ($P > 0.05$). Thus, correlation data was subjected to a 'paired-samples' t-test, with Mann-Whitney-U testing applied to compare SEE and SEE% values, in which the alpha level of significance was uniformly set at ($P < 0.05$) (Field, 2005). Furthermore, binomial testing was also performed to compare the superiority of a given profiling method with regards to the Correlations, SEE and SEE% scores attained across all performance indicators, in which the alpha level of significance was again set at $P < 0.05$.

2.6 Regression Based Performance Profiling Case Study

Thereafter, using the profiling methodology identified to yield the greatest predictive accuracy, a case study analysis was performed upon a select elite male Taekwondo athlete, thus demonstrating how both the actual performances and performance predictions respond subject to the differing quality of opposition encountered within the sport. All statistics were calculated using Microsoft Excel and SPSS software (Version 21.0.0).

3.0 Results

3.1 Relative Quality (RQ) Validity Analysis

A Chi-squared test (χ^2) of independence identified the existence of a significant association between 'Relative Quality' (RQ) and 'match outcome' within elite male Taekwondo competition, ($\chi^2_2 = 29.44, P < 0.001, V = 0.313$). Specifically, elite male Taekwondo athletes with superior RQ ratings to that of their opponents won a greater percentage of matches than was expected, whilst athletes with inferior RQ ratings lost a greater than expected percentage of matches respectively.

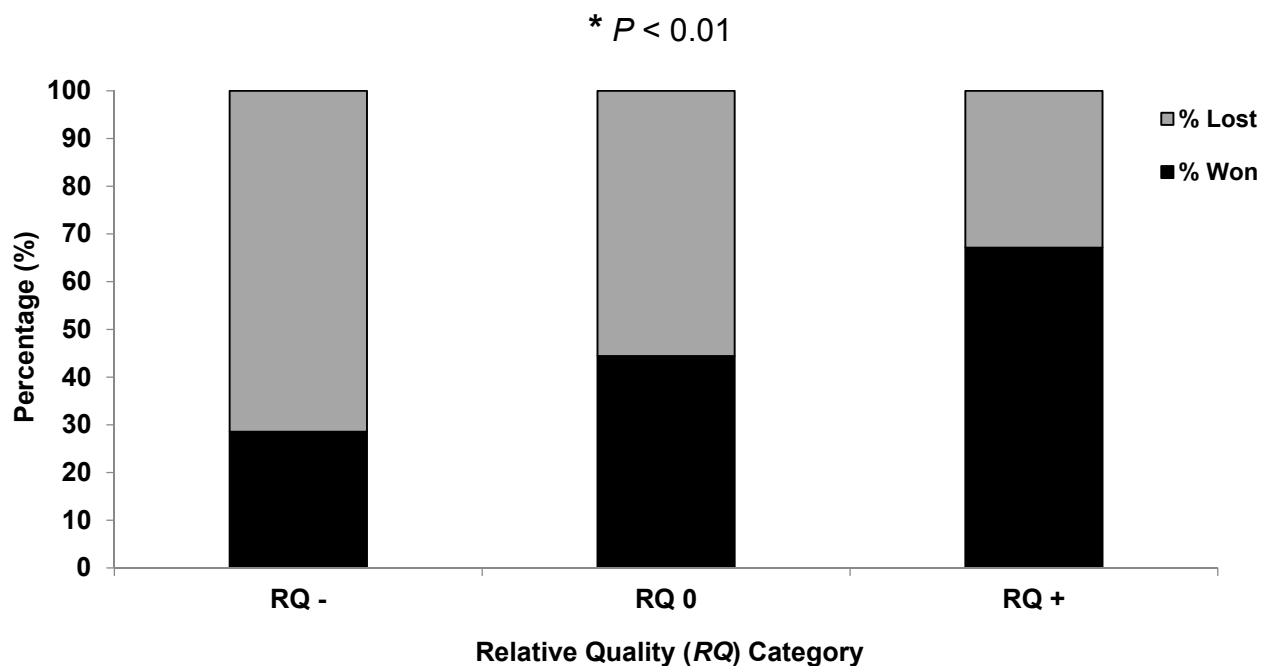


Figure 2. Chi-Squared (χ^2) test of independence comparison for the percentage (%) occurrence of successful and unsuccessful match outcomes across varying thresholds of 'Relative Quality' (RQ).

3.2 Regression Based Profiling Accuracy Comparison

For the performance indicators of interest (n=18), a paired t-test analysis indicated that the O'Donoghue and Cullinane (2011) regression based profiling methodology displayed a significantly greater mean correlation strength than that of non-parametric regression (0.22 ± 0.07 vs 0.14 ± 0.05 ; $t(17) = 4.85$, $P < 0.05$). Furthermore, Binomial test analysis also identified that superior correlation values were determined for a significantly greater proportion of the specified performance indicators (n=16 / 18) within the O'Donoghue and Cullinane (2011) profiling methodology ($P < 0.05$). However, a Mann-Whitney-U test analysis revealed that no significant differences were apparent between both regression based performance profiling methodologies for the mean 'standard error of estimation' (SEE) values established ($U = 139.5$, $Z = -.71$; $P > 0.05$). Although, Binomial test analysis further indicated that 'non-parametric' regression displayed lower SEE values for a significantly greater proportion of the specified performance indicators (n=14/18) than the O'Donoghue and Cullinane (2011) profiling methodology ($P < 0.05$).

In addition, whilst not significant ($U = 135.0$, $Z = -.85$, $P > 0.05$), the O'Donoghue and Cullinane (2011) profiling methodology was found to display a marginally greater mean 'Standard Error of Estimation Percentage' than 'non-parametric' regression (79.86 ± 28.14 vs 72.60 ± 30.02). Likewise, Binomial test analysis also indicated that a greater proportion of lower 'SEE%' values were evident for the performance indicators of interest (n=12/18) within 'non-parametric' regression ($P > 0.05$). However, for all of the specified performance indicators, it was of note that both regression based profiling methodologies displayed SEE% values that were greater than the optimal mean derived threshold of $\leq \pm 10\%$ in accordance

with Field (2013). Notwithstanding, owing to the marginally greater accuracy afforded within 'non-parametric' regression, the following procedure will seek to demonstrate the application of this particular profiling methodology for the assessment of elite male Taekwondo performance.

Table 6. Predictive accuracy comparison of two regression based profiling methodologies (1- O'Donoghue & Cullinane, 2011; 2- Non-Parametric 'Kendall' Regression) for assessing offensive performance indicators in elite male Taekwondo competition.

Performance Indicator	Correlation		Standard Error of Estimate (SEE)		SEE %	
	O'Donoghue & Cullinane (2011)	Non-Parametric Regression	O'Donoghue & Cullinane (2011)	Non-Parametric Regression	O'Donoghue & Cullinane (2011)	Non-Parametric Regression
Successful Attack %	0.251	0.165	14.02	13.58	102.72	97.95
Successful Body Attack %	0.248	0.158	14.06	14.22	105.19	107.10
Successful Front Leg Attack %	0.219	0.148	18.23	16.22	114.24	116.98
Successful Counter %	0.218	0.179	10.15	10.04	77.33	76.23
Counters Head Occurrence %	0.261	0.029	13.14	13.37	100.1	109.87
Counters Body Occurrence %	-0.187	-0.029	16.93	14.86	19.56	16.92
Total Successful Kick %	0.306	0.233	10.04	8.43	90.49	63.11
Total Head Kick Occurrence %	0.215	0.096	11.28	9.70	89.16	66.47
Total Body Kick Occurrence %	-0.092	-0.096	11.18	9.70	13.18	11.35
Total Successful Kick to Body %	0.299	0.188	10.47	8.98	98.09	70.21
Successful Front Leg Kicks to Body %	0.252	0.115	12.80	11.81	112.00	112.81
Successful Back Leg Kicks to Body %	0.194	0.136	14.29	13.51	93.36	93.91
Turning Kick Success %	0.235	0.174	11.12	10.44	91.03	75.85
Successful Attacks Performed	0.063	0.153	1.78	1.86	72.67	82.70
Counters Launched Per Min	-0.311	-0.201	1.69	1.49	71.86	54.66
Total Kicks Attempted	-0.229	-0.160	17.40	17.57	52.24	47.90
Total Successful Kicks Performed	0.152	0.150	2.96	2.27	79.97	53.82
Total Body Kicks Performed	-0.274	-0.174	15.04	15.03	54.25	48.90
Mean ± SD	0.22±0.07^{*#}	0.14±0.05	11.48±4.81	10.73±4.69[#]	79.86±28.14	72.60±30.02

* Denotes a significant difference established from opposing regression condition for corresponding variable ($P < 0.05$). # Denotes a significant departure from binomial (50-50%) equality for the corresponding variable ($P < 0.05$). Note: Correlational values were obtained using Pearson's (r) for O'Donoghue and Cullinane (2011) regression and Kendall's Tau (τ) for non-parametric regression.

3.3 Non-Parametric Regression Based 'Relative Quality' Modelling

Kendall's (tau) rank correlational analysis identified both a meaningful and highly significant relationship with 'RQ' for 26 performance indicators within elite male Taekwondo competition. For example, a meaningful relationship was established with 'RQ' for both 'Successful Kick %' ($\tau = 0.233$) and 'Turning Kick %' ($\tau = 0.174$) respectively ($P < 0.001$) (Figure 3 & 4). Alternatively, certain variables, such as 'Counters Performed Per Minute' (Figure 5), displayed a significant negative ($\tau = -0.201$; $P < .001$) relationship with 'RQ', thereby indicating a progressive decline of the performance indicator values with advancing ranking related superiority of an athlete under assessment. All performance indicators included within the following profile displayed relationships ranging between $\tau \geq (+/-) 0.096$ to $\tau = (+/-) 0.233$ with that of 'RQ'.

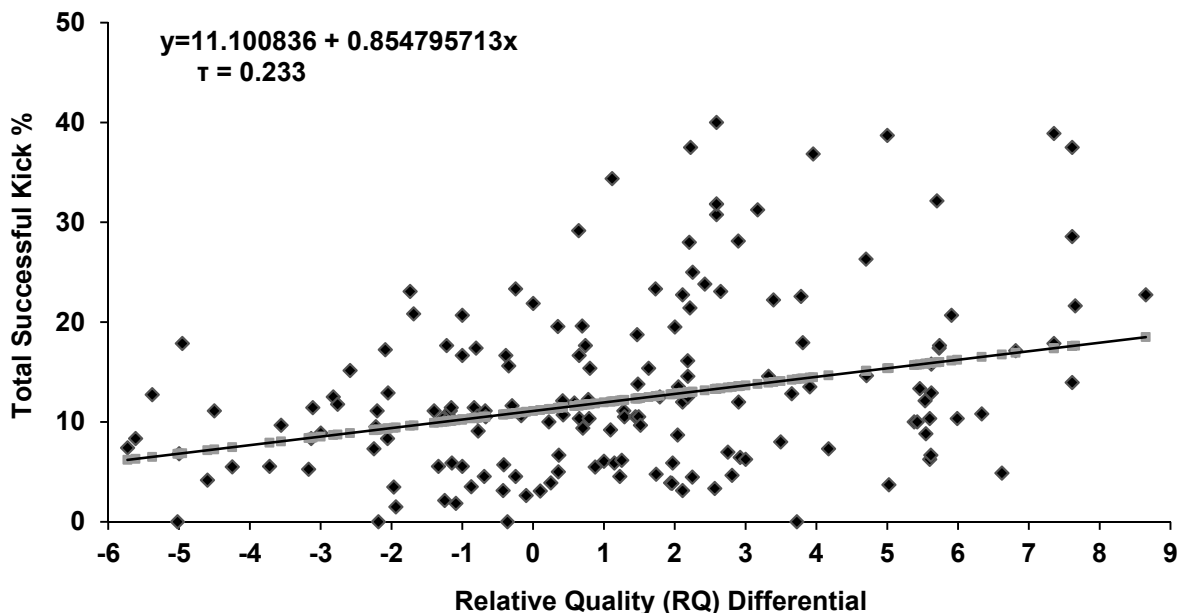


Figure 3. Relationship between 'total successful kick percentage (%)' and the 'relative quality (RQ) differential' for elite male Taekwondo performers.

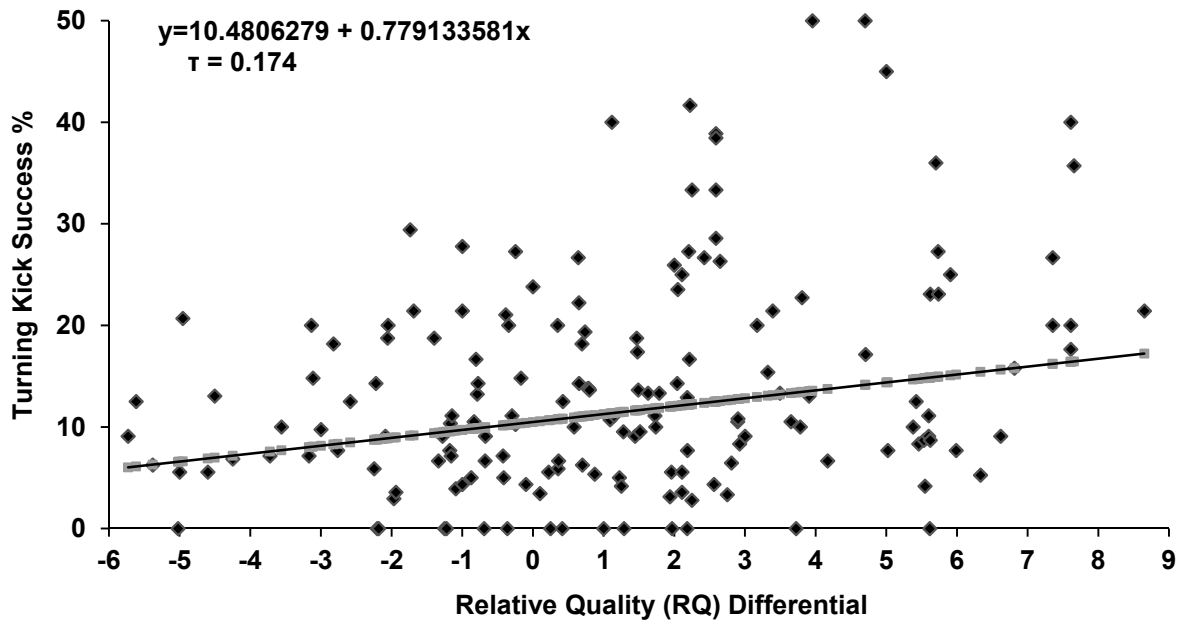


Figure 4. Relationship between ‘turning kick success percentage (%)’ and the ‘relative quality (RQ) differential’ for elite male Taekwondo performers.

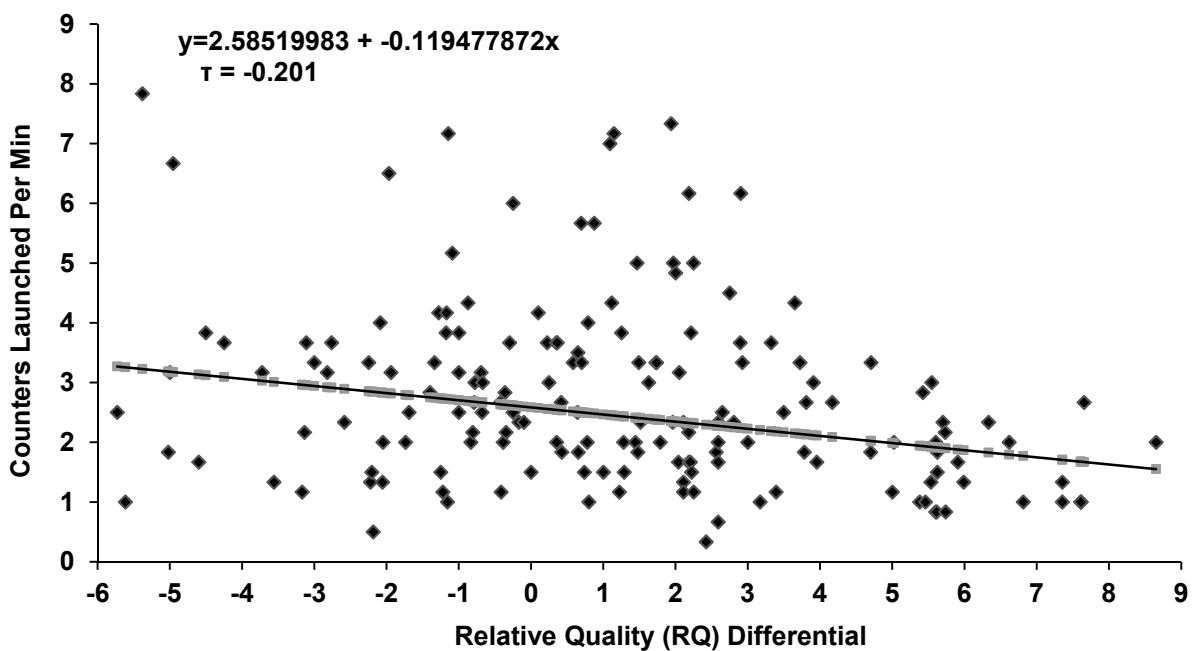


Figure 5. Relationship between the frequency of ‘counters launched per minute’ and the ‘relative quality (RQ) differential’ for elite male Taekwondo performers.

3.4 Non-Parametric Regression Based Profiling Case Study

Within the following profile example, the performance of the male-68kg competitor, Diogo Silva was analysed across competition within the WTF Olympic Qualification Tournament in 2011. This athlete competed within five matches, winning four and losing one. Concerning the four successful matches, the athlete of interest (World Rank = 18) competed against athletes inferiorly ranked at 88, 39, 49 and 44 (mean = 55) respectively. Thus, the mean 'RQ' differential for this 6 stage competition was $(6-\log_2 18) - (6-\log_2 55) = +1.518$. Interestingly, when winning, Silva achieved better than 'expected' performances for 5 of 6 indicators, displaying superior attack, counter and overall kicking efficiency values of 28%, 21% and 23% respectively. However, given the quality of opposition therein, Silva would have only been 'expected' to have scored between 11 - 12% for these performance indicators. Additionally, Silva also displayed a greater than expected body kicking tendency (89.58% vs 86.18%), whilst also proving to be approximately 2x more efficient than initially expected for successful turning kick performance (Residual = 11.03%).

However, when Silva competed against the number 2 seed, thereby altering the 'RQ' differential to $-3.170 ((6-\log_2 18) - (6-\log_2 2))$, lower than expected values were noted for 4 out of 6 performance indicators. Specifically, inferior kick, attack and turning kick accuracy were evident (Residual = -3.13, -7.19 & -0.87), in addition to a moderately inferior propensity to kick to the head of the opponent (Observed = ~ 11%; Expected = ~ 12%). Despite the notable reduction in 'expected' performance indicator values subject to the specific quality of opponent (i.e. successful attack % = 11.14% vs 7.19%), such considerable underperforming ultimately resulted in a defeat within this contest.

Table 7. Example non-parametric (Kendall) regression based performance profile for a select elite male Taekwondo athlete subject to both positive (+) and negative (-) relative quality (*RQ*) differentials.

Performance Indicator	Observed Value	Expected value	Residual
<u>+RQ Wins</u> Mean <i>RQ</i> = +1.518			
Successful Attack %	28.21	11.14	17.07
Successful Counter %	20.89	12.25	8.63
Successful Kick %	23.23	12.40	10.83
Total Head Kick Occurrence %	10.42	13.82	-3.40
Total Body Kick Occurrence %	89.58	86.18	3.40
Turning Kick Success %	22.69	11.66	11.03
<u>-RQ Loss</u> <i>RQ</i> = -3.170			
Successful Attack %	0.00	7.19	-7.19
Successful Counter %	14.29	8.73	5.56
Successful Kick %	5.26	8.39	-3.13
Total Head Kick Occurrence %	11.11	11.86	-0.75
Total Body Kick Occurrence %	88.89	88.14	0.75
Turning Kick Success %	7.14	8.01	-0.87

4.0 Discussion

The current paper has sought to advance upon the present body of performance profiling research by attempting to validate the predictive accuracy of two regression based profiling methodologies for analytical use within elite male Taekwondo competition.

4.1. Relative Quality Validity Analysis

However, firstly, to establish the validity of utilising relative quality (*RQ*) as the independent 'predictor' variable within both regression based analysis procedures, a Chi-square (χ^2) test of independence was employed which subsequently identified the existence of a significant association between match outcome and relative quality (Figure 2). Specifically, the findings from figure 2 indicated that elite male Taekwondo athletes with superior *RQ* ratings to that of their opponents won a considerably greater percentage of matches than was expected (67% vs 50%), whilst inferiorly ranked athletes lost a greater percentage of matches than was expected (71% vs 50%). As such, the difference in quality between elite male Taekwondo competitors would appear to bare a significant impact upon the likelihood of experiencing favourable or unfavourable contest outcomes. In this regard, the current findings correspond with a strong body of previous research from which the potential for rankings to accurately reflect both the likely match outcomes and final league standings across grand slam Tennis, American Football and collegiate Basketball have been established (Boulier & Stekler, 1999; 2003; Caudill & Godwin, 2002). Furthermore, the potential existence of relationships between ranking and underlying sports performance have also been demonstrated (Ibáñez et

al., 2008; Marcelino, Mesquita & Afonso, 2008; Ziv et al., 2010), thereby justifying the inclusion of ranking derived relative quality as a function of performance prediction within the present paper (Pedhauzr, 1997). Of note, the validity of using relative quality within regression based sports analysis had not been previously established.

4.2. Profiling Method Accuracy Comparison

Following this, the findings of the regression based accuracy comparison indicated that non-parametric 'kendall' regression offered moderately superior predictive accuracy than that of bivariate 'linear' regression (O'Donoghue & Cullinane, 2011) by virtue of the lower mean SEE and SEE% values evidenced. Furthermore, owing to the lower error values posited (SEE & SEE %) for the majority of the specified performance indicators of interest (Results 3.2), non-parametric regression would appear to be the preferable profiling methodology for the assessment of elite male Taekwondo performance. One such reason for the superior accuracy of non-parametric regression might extend to the more appropriate inclusion of median values for the slope and intercept computations, given their reduced sensitivity to extreme observations when included as a measure of central tendency for non-normally distributed data, such as that typical of sports performance (Hughes et al., 2002; McCluskey & Lalkhen, 2007). Moreover, non-parametric ('kendall') regression would also appear to provide a more comprehensive slope and intercept calculation procedure through the pairwise comparisons of all possible x and y gradients within a given model. Indeed, in the present case, the slope and intercept values were derived from the medians of

13861 and 167 separate calculations respectively, as oppose to the two mean and standard deviation values (x & y) utilised within the 'least squares' approach of bivariate linear regression (Conover, 1999). However, whilst the influence of extreme data observations may be somewhat negated following appropriate log transformation procedures (Osborne, 2010), the absence of any such preceding data treatments within non-parametric regression further outlines this methodology as a more efficient and user friendly process for inclusion within applied performance analysis. Indeed, this supposition is reinforced by the complexity of relating any subsequent back-transformed values as an alternative percentage of the geometric mean within the O'Donoghue and Cullinane (2011) methodology (Olivier et al., 2008). On this basis, given the typically lower central tendency of the geometric mean in comparison to the arithmetic mean, the SEE% values denoted within the O'Donoghue and Cullinane (2011) methodology may have also been exacerbated somewhat in comparison to those derived within non-parametric regression.

However, it is of note that both regression based profiling methodologies displayed 'standard error of estimation percentage' values that exceeded the optimal mean derived thresholds ($\leq \pm 10\%$) for all selected performance indicators (i.e. 'Successful Attack %' = 98%; Table 6) (Field, 2013). As such, the practical implications of using regression based performance profiling in the presence of high degrees of potential error extend to the case study example provided (Results 3.4). In that, for the athlete of interest (Diogo Silva), the 'percentage standard error of estimation' values for attack, counter and total kicking accuracy whilst using 'non-parametric' regression were 98%, 76% and 63% respectively. Therefore, despite estimated values of 11 – 12% for all of the aforementioned performance indicators (Results 3.4), a notable performance improvement, above which can be explained by

predictive error would have to exceed ~25% (i.e. mean = $14/100 * 98 + 11$), ~22% (mean = $13/100 * 76 + 12$) and ~21% (mean = $13/100 * 63 + 12$) respectively. Ultimately, the detection of noteworthy performance changes or intervention efficacies appear somewhat obstructed in the presence of profound measurement errors as reported (Hopkins, Hawley & Burke, 1999; Trewin, Hopkins & Pyne, 2004; Gregson, Drust, Atkinson & Salvo, 2010).

Indeed, a possible explanation for the apparent predictive inaccuracy of both regression based profiling methodologies may be attributed to the existence of a multitude of additional 'confounding' influences upon sporting performance that were omitted from the present paper, such as venue (Brown et al., 2002; Carron, Loughhead & Bray, 2005; Tucker et al., 2005), match importance (Hale, 2004), score line (O'Donoghue & Tenga, 2001; Redwood-Brown, 2008; Taylor et al., 2008) and tactical strategy (O'Donoghue, 2009; Gregson et al., 2010). However, given that oppositional quality has been identified as a major confounding influence within sports performance research (McGarry & Franks, 1994; James et al., 2005; Taylor et al., 2008), the present paper would appear somewhat justified in this manner.

On another note, correlation values for the performance indicators of interest were found to be significantly stronger within the O'Donoghue and Cullinane (2011) profiling methodology (Results 3.2), despite the moderately greater inaccuracy demonstrated. However, such findings can be related to the different correlation procedures adopted within both profiling methods. In that, the 'monotonic' rank related correlations derived via non-parametric Kendall's Tau (τ) reportedly possess inferior statistical power to that of the value specific relationships classified within 'pearsons r ' correlation coefficients (Gauthier, 2001). As such, the present paper

ultimately considered non-parametric regression as the superior profiling methodology for the assessment of elite male Taekwondo performance.

4.3. Non-Parametric Regression Based Profiling Case Study

Indeed, whilst using this methodology, attack, counter and turning kick efficiency; in addition to head shot tendencies were found to possess positive, yet moderate relationships with relative quality ($\tau \leq 0.233$). However, whilst such small correlations would initially appear to demonstrate the negligible disparity between elite male Taekwondo competitors, in accordance with earlier research (Kazemi et al., 2010), the important distinction between practical and statistical significance has been documented previously (Hopkins, 2001; Stoove & Andersen, 2003). As such, the findings of the regression based analysis procedure intimated that a heightened kicking accuracy, mostly performed in an offensive manner, alongside an enhanced head shot propensity are all 'key' aspects associated with superior elite male Taekwondo performance to which coaches would be prudent to attend (Luk et al., 2001; Chou & Chiu, 2009; Capranica et al., 2010; Reid et al., 2010).

In similar regard, Lames and McGarry (2007) specified the purpose of practical performance analysis as being to optimize both the tactics employed and training provided within an applied setting. On this premise, the predictive element of non-parametric regression, notwithstanding the potentially high error associated (i.e. SEE % = 98%), could still hold particular virtue in objectively establishing where an athlete severely over and underperformed (+/- residuals) in comparison to that of reasonable expectation. For example, concerning the case study example provided for Diogo Silva (Results 3.4), negative (-) residual values were noted for four of six

performance indicators when losing. However, given that two of these indicator values were seemingly negligible (Total head kick occurrence % = -0.75%; Turning kick success % = -0.87%), applied focus may ultimately centre upon the inferior kick accuracy (-3.13%) displayed, before attributing this to the stark inefficiency of the attacks performed (-7.19%). In this regard, from the benchmark values provided by non-parametric regression, bespoke training can be duly implemented, in addition to more appropriate tactical strategies to negate such performance flaws against forthcoming opponents.

5.0 Conclusion

Overall, the current paper has sought to advance upon the present body of performance profiling research by demonstrating the accuracy of regression based normative profiling with due regard for the direct ranking related quality differentials between elite sports performers. Notwithstanding the established validity of including relative quality within sports performance modelling, high predictive errors were evident across both regression based profiling methodologies (1; O'Donoghue & Cullinane, 2011, 2; Non-parametric regression). However, owing to the moderately greater accuracy afforded, non-parametric regression would appear to offer an advance upon previous profiling methodologies given it's feasibility for interpreting both individual and multiple match performances whilst also accounting for the exact quality differential between competing athletes. Indeed, practical uses of non-parametric regression can extend to utilising the predicted values posited for benchmarking purposes in order to objectively identify where an athlete severely over and under-performed.

Although, future research should adhere to enhancing the predictive accuracy associated with the proposed model via the implementation of multiple-regression analysis, thus accounting for an additional number of confounding influences upon sporting performance. Alternatively, in considering that classical performance analysis may be unable to truly identify the systematic interactions between competing athletes, future research might also extend to using dynamical systems analysis to more comprehensively understand the latent features of the sport (McGarry, 2009).

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