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Inertial Sensors-Determined Match Characteristics That Serve As Predictors of Elite Male Badminton Players' Performance Levels

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Abstract

The study purpose was to establish the inertial sensors-containing device (ISCD)-determined match characteristics that serve as predictors of elite, male badminton players' performance levels. Twenty-two (22) male single players (aged: 23.39 ± 3.92 years), who represented 10 African countries participated in the study. Players were categorised as successful and less-successful players according to the results of five championships during two seasons. ISCD units (Catapult MinimaxV4), Polar Heart Rate Transmitter Belts and digital video cameras were used to collect match data. ISCD-determined variables were corrected for match duration and independent t-tests, a cluster analysis and a binary forward stepwise logistic regression were used for statistical analyses. A Receiver Operating Characteristic Curve (ROCC) indicated the validity of the group classification model. High-intensity accelerations per second was identified as the only ISCD-determined variable that showed a significant difference ($p = 0.05$) between groups. Furthermore, only high-intensity accelerations per second ($p = 0.03$) and low-intensity efforts per second ($p = 0.04$) were identified as significant predictors of group classification with 76.88% of players that could be classified back into their original groups by making use of the ISCD-based logistic regression formula. The ROCC showed a value of 0.87. The identification of the last-mentioned ISCD-determined variables for the attainment of badminton performances emphasizes the importance of using badminton drills and conditioning techniques not only to improve the physical fitness levels of players, but also their ability to accelerate at high-intensities.

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INTRODUCTION

The popularity and competitiveness of badminton have highlighted the need for accurate and up-to-date match performance analysis that will enable coaches and other sport-related professionals to accurately determine the match characteristics of players (Faude et al., 2007; Gomez et al., 2019). The value of match analysis results in evaluating and improving match performance have in recent years led to an increase in match analysis-related studies of racket sports (Fernandez-Echeverria et al., 2017; Hughes, 2003; Hughes & Franks, 2004; Kovacs, 2006). However, while badminton is generally acknowledged as the fastest moving racket sport, distinguished for its high paced and vigorous rallies (Book et al., 2018; Ooi et al., 2009), researchers have not given this sport a lot of attention with regard to match analysis characteristics and the possible link between these characteristics and the match performances of players. Furthermore, there is paucity of information on the possible link between inertial sensors-containing device (ISCD)-determined match characteristics of badminton players and match performance.

Up until now the preferred method for determining the match analysis characteristics of badminton players is through video, notational analyses (Liddle et al., 1996; Pearce, 2002; Pérez-Turpin et al., 2020; Tong & Hong, 2000). Despite the value of video analyses-determined match analysis characteristics in providing important information to sport-related professionals in the badminton fraternity, the need to identify match analysis characteristics that discriminate between different levels of badminton players, is even more important. The identification of last-mentioned match analysis characteristics will assist coaches and sport scientists to recognise and develop these characteristics to enable players to perform successfully. In this regard, successful badminton players play a more effective and aggressive game and make less forced or unforced errors while playing compared to less-successful players (Abián et al., 2014; Chen et al., 2011; Gomez et al., 2019; Jeon et al., 2019; Primo et al., 2019).

The introduction of ISCDs in the 1990s offered an alternative method for the measurement of average duration, frequency and speed of movements, with the potential to minimise some and circumvent other shortcomings of notational analyses (Townshend et al., 2008). These shortcomings include: the time-consuming nature of notational analyses (Hughes & Franks, 2009), the inaccuracy of notational analyses to analyse total time spent on individual movements and the frequency of individual movements (Duthie et al., 2003), and the inability to assess the specific demands of certain activities (O'Donoghue, 2008). However, to date no research made use of ISCDs to perform this type of analyses on badminton players. The use of a tri-axial accelerometer, magnetometer and gyroscope in an ISCD for analysing badminton matches, is still a new phenomenon. Accelerometers, gyroscopes and magnetometers are inertial sensors used to monitor and describe movements as well as the intensity and frequency of these movements in various clinical and sports settings without support from GPS-signals (Cust et al., 2019; Gastin et al., 2013; Li et al., 2016; Luteberget et al., 2017; Luteberget & Spencer, 2017; Worsey et al., 2019).

ISCDs were found to be valid for estimating physical activity intensity during indoor basketball practice sessions (Montgomery et al., 2010), and for quantifying accelerations and decelerations in three orthogonal axes during team sport movement simulations in an indoor laboratory (Roell et al., 2018). Good within- and between-device reliability was also reported for the physical activity levels of semi-professional, Australian football players during an indoor, volleyball exercise session (Boyd et al., 2011). Similarly, good reliability values were presented for inertial movement analysis counts, player load and associated variables, measured during laboratory-based handball tasks, handball training sessions and ice hockey task-simulating game conditions (Luteberget et al., 2017; Van Iterson et al., 2017). A study also confirmed the potential of ISCDs to determine the demands of indoor sports such as ice hockey (Douglas & Kennedy, 2020). These findings would suggest that available wearable tracking device technology such as the Catapult MinimaxV4 that integrate multiple sensors into a single unit, may provide researchers with an alternative, more time efficient and accurate method of determining the match characteristics of badminton players.

Despite the potential benefits of the ISCD-match analysis method, no researchers have made any attempt to utilise this method to predict the ISCD-determined match characteristics that determine the match outcomes of badminton players. Practitioners in the field of sport and conditioning need clarity concerning the use and applicability of ISCD-determined match characteristics to serve as predictors of "real life" match performances. The identification of ISCD-determined match characteristics will enable practitioners to focus on the most relevant components for training and performance monitoring in badminton. Hence, the purpose of this study was to establish the ISCD-determined match characteristics that serve as predictors of elite, male badminton players' performance levels.

METHODS

Participants

The study consisted of male, single players who participated in the following championships during two playing seasons: All Africa Badminton Senior Championships, South African International Championships, Free-State National Championships, U/19 South African National Championships and the University Sport South Africa (USSA) Badminton Championships. All together 22 players (age: 23.39 ± 3.92 years; body stature: 177.11 ± 3.06 cm; body mass: 83.46 ± 14.59 kg) were analysed during 46 matches. Therefore, each player was measured not less than two times, with several players being measured three times. All championships took place over a period of two to three days, with an exception of the Free-State National Championships, which took place over a day, implying that players were monitored and measured sequentially in a day.

Players represented 10 African countries, namely: Botswana, Cameroon, Congo, Egypt, Namibia, Nigeria, South Africa, Uganda, Zambia and Zimbabwe. Only players who were actively involved and competing as members of their respective teams and national badminton federations in the above-mentioned tournaments as well as those who were injury free at the time of testing were eligible to participate in the study. The competitive playing experience of players ranged between 4 and 12 years (8.96 ± 2.8 years). The following information with regard to their training regimen was obtained: players trained for 3.88 ± 1.21 days a week, which consisted of on-court training for 3.54 ± 1.08 days a week, and weight training for 2.08 ± 0.78 days a week. Players could be classified into three categories, namely: (1) competitive-elite players who regularly compete at the highest level but did not have any success at that level; (2) successful-elite players who have experienced some (infrequent) success at the highest level and (3) world-class elite players who sustained success at the highest level, with repeated wins over a prolonged period (Swann et al., 2015).

Players were grouped according to tournament results. Players, who reached the quarter finals, semi-finals or finals of each tournament were categorised as successful players, whereas the rest were categorised as less-successful players.

Sampling Procedure

An observational, descriptive and ex post facto design was used for this study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council of South Africa. Approval for the study was obtained from the Health Research Ethics Committee of the institution where the research was conducted (NWU-00199-14-A1). Written permission to conduct the study was also obtained from the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), the Botswana Badminton Association (BBA), and Badminton South Africa (BSA). Before each tournament, a brief meeting was summoned in which the researchers explained in detail the study design, purpose and possible risks to players, managers and coaches. Thereafter, written informed consent was obtained from all players. Next, the Demographic and General Information questionnaire was filled in. This was followed by the measurement of body mass and stature. Prior to each match warm-up, players were fitted with a Fix Polar HR Transmitter Belt and a harness with an ISCD that players warmed-up with in order to become accustomed to the equipment and so that the heart rate monitor belt and harness could be adjusted according to the preference of each player. Before the start of each match, a video camera was stationed on a tripod stand behind the baseline of the court and adjusted in such a way that the whole court was in view. The warm-up period was also used to check the signals of both the ISCD and HR monitor before each match began. Data from the ISCD and HR monitors as well as the video footage were downloaded to a laptop computer for off-line analyses.

Materials and Apparatus

Demographic and general information questionnaire

The demographic and personal information of players was collected by means of the above-mentioned questionnaire. Ages, exercising habits, injury incidences, competing levels and best performances of players were also obtained by means of a questionnaire.

Anthropometric measurements

Body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam Equipment Co. Ltd., Milton Keynes, UK) and body stature to the nearest 0.1 cm, using a Harpenden portable stadiometer (Holtain Ltd., Crosswell, UK) in order to describe the specific cohort of badminton players.

ISCD match analyses

An ISCD (Catapult MinimaxV4, Catapult Innovations, Melbourne, Victoria, Australia) was fitted to the upper back of participants by using a harness supplied by the manufacturer just before the match warm-up period. ISCD recorded data every 100 m s-1 (10 Hz) during each match. The ISCD allowed researchers to obtain data with regard to the following match related variables (Catapult-Sports, 2012a, 2012b): Inertial Movement Analysis (IMA), which included: Efforts performed at different intensities; number of accelerations performed at different intensities; number of decelerations performed at different intensities; changes in direction; free-running events, and jump height and frequency. The Individual Match Analysis, which included the following parameters: Total duration of a match; player load; equivalent distance run during the entire match; peak player load; player load per min; the minimum, mean and maximum heart rates (HR) achieved during the match; the number of efforts in each of the top 3 player load zones; rest time; work:rest ratio and HR exertion index (the amount of time that a player spent in a heart rate zone).

Other parameters measured were: the amount of time within the play period that a player kept active and did not take long breaks; the total accumulated player load that was obtained for a specific player load zone; the absolute and relative distance covered and time spent during the match within a specific player load zone; the number of efforts that was performed under each of the player load zones; the average, minimum and maximum length of time spent in each effort that was performed under each of the player load zones and recovery times. The following additional parameters were taken: the absolute and relative amounts of time that a player spent within a specific heart rate band; the average heart rate reached within a specific heart rate band; the different player load variations for the match; the total accumulated player load when measured over all movement planes as well as with the vertical accelerometer information omitted, only using the forward/ backward movement planes and only using the upward or vertical movement plane. Recordings from the ISCD were downloaded to a PC and analysed using the Catapult Sprint 5.0.9.2 software (Catapult Sports, Melbourne, Victoria, Australia). MinimaxV4 GPS Doppler data was used to analyse the ISCD-related variables.

Heart rate monitoring

In addition to the ISCD-derived values, the HR of each player was recorded through a Fix Polar HR Transmitter Belt (Polar Electro, Kempele, Finland) at 5-second intervals during the course of different matches.

Video match analysis

A digital video camera (Sony HDR-PJ790VE handycam, Sony Corporation, Tokyo, Japan) with a high frame rate, good resolution, wide angle lens and an ability to deal with lower light levels of indoor sport facilities was stationed behind the court on a tripod stand to cover the entire court. Video footage was used to determine the time periods of each match so that researchers were able to set the correct duration for ISCD match analyses.

Data Analysis

Data analysis was conducted using the Statistical Data Processing package (Version 13.3, TIBCO Software Inc., Tulsa, USA). Firstly, all ISCD-related variables were corrected for match duration by dividing the specific ISCD-related variable by the match duration in seconds. Secondly, descriptive statistics (averages, standard deviations, minimum and maximum values) for each of the variables were calculated. Subsequently, an independent t-test was performed to determine significant differences in ISCD-related variables between successful and less-successful groups of players. The level of significance was set at $p \leq 0.05$. This was followed by a tree clustering, single-linkage, 1-Pearson Correlation Coefficient cluster analysis of the ISCD-related variables, which was performed to detect clusters of measures that appeared to tap similar abilities. Linkage distance for detection of different clusters was set at 0.2. In the next step, a binary, forward stepwise logistic regression was used to screen for the predictive value of different ISCD-related (independent) variables in predicting the group classification of players (successful and less-successful players) (dependant variables). A binary (or binomial) logistic regression is a form of regression used when the dependent variable is a dichotomy (successful and less-successful players) and the independent variables are of any type (Allison, 2012; Garson, 2010). The significance of the individual logistic regression coefficients for each independent variable was determined by using the Wald statistic. The level of significance was set at $p \leq 0.05$. The validity of the group classification model was then determined by making use of the Receiver Operating Characteristic Curve (ROCC).

RESULT

Demographic and general information questionnaire

The descriptive statistics as well as the statistical significance of differences in the demographic and IMA components between the successful and less-successful groups of players are presented in Table 1. From the tabulated results, it is clear that many differences exist with regard to the demographic and IMA results between the successful and less-successful player groups. Despite these differences only the number of high-intensity accelerations performed during the matches corrected for match duration revealed a significant difference with successful players, who obtained significantly higher ($p = 0.05$) values than less-successful players.

Individual match analysis results: Player load and effort-related components

Descriptive statistics as well as statistical significance of differences for the ISCD-determined player load and effort-related components between successful

Table 1. Descriptive statistics as well as statistical significance of differences in demographic and ISCD IMA results between successful and less-successful badminton players

Variable	Successful players (n = 10)	Less-successful players (n = 12)	Total group (n = 22)
Age (years)	23.41 ± 4.43	23.37 ± 3.65	23.38 ± 3.92
Height (cm)	177.62 ± 3.94	176.88 ± 2.83	177.11 ± 3.06
Weight (kg)	86.42 ± 12.62	82.14 ± 15.91	83.46 ± 14.59
Years playing badminton	9.70 ± 2.98	9.42 ± 2.57	9.54 ± 2.70
Training days	3.50 ± 1.18	4.17 ± 1.75	3.86 ± 1.52
Weight training days	1.30 ± 0.82	2.50 ± 2.07	1.95 ± 1.70
On-court training days	3.10 ± 1.10	3.92 ± 1.38	3.54 ± 1.29
Field training days	1.80 ± 1.03	1.67 ± 1.15	1.73 ± 1.08
Training hours (per day)	2.50 ± 1.35	3.08 ± 1.16	2.82 ± 1.26
Weight training hours (per day)	1.20 ± 0.63	1.17 ± 0.58	1.18 ± 0.59
On-court training hours (per day)	2.20 ± 1.13	2.58 ± 1.24	2.41 ± 1.18
Field training hours (per day)	1.00 ± 0.47	1.08 ± 0.51	1.04 ± 0.48
Low-intensity accelerations (reps)	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
Medium-intensity acceleration (reps)	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00
High-intensity acceleration (reps)	0.01 ± 0.00	0.00 ± 0.00*	0.00 ± 0.00
Low-intensity deceleration (reps)	0.11 ± 0.18	0.05 ± 0.06	0.08 ± 0.13
Medium-intensity deceleration (reps)	0.02 ± 0.03	0.01 ± 0.01	0.02 ± 0.03
High-intensity deceleration (reps)	0.04 ± 0.0.07	0.02 ± 0.03	0.03 ± 0.05
Low-intensity left COD (reps)	0.94 ± 0.05	0.08 ± 0.02	0.09 ± 0.03
Medium-intensity left COD (reps)	0.04 ± 0.02	0.02 ± 0.01	0.03 ± 0.02
High-intensity left COD (reps)	0.05 ± 0.03	0.03 ± 0.01	0.04 ± 0.02
Low-intensity right COD (reps)	0.10 ± 0.09	0.08 ± 0.06	0.09 ± 0.07
Medium-intensity right COD (reps)	0.03 ± 0.06	0.03 ± 0.05	0.03 ± 0.05
High-intensity right COD (reps)	0.05 ± 0.10	0.04 ± 0.10	0.05 ± 0.09
Low jumps (reps)	0.08 ± 0.13	0.03 ± 0.04	0.05 ± 0.09
Medium jumps (reps)	0.03 ± 0.03	0.01 ± 0.01	0.02 ± 0.03
High jumps (reps)	0.03 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

* $p \leq 0.05$; Mean values ± standard deviation; Low-intensity = A movement that occurs between 1.5-3 m·s-2; Medium-intensity = A movement that occurs between 3-4 m·s-2; High-intensity = A movement that occurs above 4 m·s-2; COD = Change of direction; Low jumps = classified as jumps performed over heights of between 0 and 20 cm; Medium jumps = classified as jumps performed over heights of between 20 and 40 cm; High jumps = classified as jumps performed over heights of above 40 cm

and the less-successful players are presented in Table 2.

Despite the relative differences with regard to the above-mentioned variables between successful and less

Table 2. Descriptive statistics as well as statistical significance of differences in ISCD-determined individual match analysis, player load and effort-related variables between successful and less-successful badminton players

Variables	Successful players (n = 10)	Less-successful players (n = 12)	Total group (n = 22)
Match duration (min)	29.75 ± 10.20	31.20 ± 9.89	30.54 ± 9.82
Player load per seconds	5.83 ± 0.92	5.81 ± 0.62	5.82 ± 0.75
Distance covered per seconds ($m \cdot s^{-1}$)	0.92 ± 0.14	0.91 ± 0.09	0.91 ± 0.12
Peak player load per seconds	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Player load per minutes	5.84 ± 0.96	5.78 ± 0.62	5.81 ± 0.77
Work-rest ratio	0.75 ± 0.10	0.73 ± 0.07	0.74 ± 0.08
0 - 1 Total load per seconds	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
0 - 1 Distance per seconds ($m \cdot s^{-1}$)	0.49 ± 0.09	0.48 ± 0.07	0.48 ± 0.08
0 - 1 % Distance per seconds	53.88 ± 8.62	54.42 ± 8.62	54.17 ± 8.41
0 - 1 % Time per seconds	88.40 ± 3.17	88.26 ± 3.33	88.32 ± 3.18
0 - 1 Time per seconds	26.11 ± 9.59	27.24 ± 8.23	26.73 ± 8.68
0 - 1 Efforts per seconds	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1 - 2 Total load per seconds	0.03 ± 0.01	0.04 ± 0.01	0.03 ± 0.01
1 - 2 Distance per seconds ($m \cdot s^{-1}$)	0.32 ± 0.09	0.34 ± 0.10	0.33 ± 0.09
1 - 2 % Distance per seconds	34.70 ± 6.65	36.08 ± 7.12	35.45 ± 6.78
1 - 2 Time per seconds	2.73 ± 1.03	3.17 ± 1.73	2.97 ± 1.44
1 - 2 % Time per seconds	10.10 ± 2.60	10.53 ± 2.96	10.34 ± 2.75
1 - 2 Efforts per seconds	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01
2 - 3 Total load per seconds	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00
2 - 3 Distance per seconds ($m \cdot s^{-1}$)	0.08 ± 0.03	0.07 ± 0.03	0.07 ± 0.03
2 - 3 % Distance per seconds	8.74 ± 2.92	7.26 ± 2.36	7.93 ± 2.67
2 - 3 Time per seconds	0.22 ± 0.13	0.23 ± 0.21	0.22 ± 0.17
2 - 3 % Time per seconds	1.25 ± 0.63	1.03 ±0.46	1.13 ± 0.55
2 - 3 Efforts per seconds	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3 - 4 Total load per seconds	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3 - 4 Distance per seconds ($m \cdot s^{-1}$)	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01
3 - 4 % Distance per seconds	2.42 ± 1.59	2.07 ± 1.49	2.23 ± 1.51
3 - 4 Time per seconds	0.03 ± 0.02	0.03 ± 0.03	0.03 ± 0.03
3 - 4 % Time per seconds	0.00 ± 0.00	0.02 ± 0.07	0.01 ± 0.05
3 - 4 Efforts per seconds	0.00 ± 0.00	0.00 ± 0.00)	0.00 ± 0.00
4 - 6 % Distance per seconds	0.30 ± 0.41	0.38 ± 0.56)	0.34 ± 0.49
4 - 6 % Time per seconds	0.00 ± 0.00	0.00 ± 0.00)	0.00 ± 0.00
4 - 6 Total load per seconds	0.00 ± 0.00	0.00 ± 0.00)	0.00 ± 0.00
4 - 6 Distance per seconds ($m \cdot s^{-1}$)	0.00 ± 0.00	0.00 ± 0.01)	0.00 ± 0.00
4 - 6 Time per seconds	0.00 ± 0.00	0.00 ± 0.01)	0.00 ± 0.00
4 - 6 Efforts per seconds	0.00 ± 0.00	0.00 ± 0.00)	0.00 ± 0.00
4 - 6 Efforts per seconds	0.00 ± 0.00	0.00 ± 0.00)	0.00 ± 0.00
Low-intensity efforts per seconds	0.33 ± 0.30	0.25 ± 0.11	0.29 ± 0.22
Medium-intensity efforts per seconds	0.11 ± 0.11	0.08 ± 0.07	0.09 ± 0.09
High-intensity efforts per seconds	0.15 ± 0.19	0.10 ± 0.14	0.12 ± 0.16
All efforts per seconds	0.58 ± 0.61	0.43 ± 0.31	0.49 ± 0.46

0-1 = Low work load during a match; 1-2 = Medium work load during a match; 2-3 = High work load during a match; 3-4 = Very high work load during a match; 4-6 = Very, very high work load during a match

-successful players, differences in values between groups were non-significant.

Individual match analysis results: Heart rate and player load variant-related components

Descriptive statistics as well as statistical significance of differences for the above-mentioned variables between successful and less-successful players are presented in Table 3.

bles for the stepwise logistic regression, a cluster analysis was executed. ISCD variables were reduced from 91 to 12 variables by means of the cluster analysis. ISCD variables that remained were: work-rest ratio, peak player load per second, 0 – 1 total load per second, 0 – 1 distance percentage, 1 – 2 time, 3 – 4 distance per second, 2 dimensional and low-intensity efforts per second, as well as low-, medium- and high-intensity accelerations per second.

Table 3. Descriptive statistics as well as statistical significance of differences in individual match analysis, heart rate and player load variant-related components between the successful and less-successful players

Variables	Successful players (n = 10)	Less-successful players (n = 12)	Total group (n = 22)
HR minimum (beats·min^{-1})	115.15 ± 24.31	115.58 ± 19.78	115.39 ± 21.41
HR mean (beats·min^{-1})	168.00 ± 13.47	165.73 ± 14.65	166.76 ± 13.84
HR maximum (beats·min^{-1})	195.35 ± 10.58	190.64 ± 11.91	192.78 ± 11.31
HR exertion index	93.90 ± 56.11	85.67 ± 37.87	89.41 ± 46.02
120-160 beats·min^{-1} Time (s)	6.47 ± 5.32	8.72 ± 9.21	7.69 ± 7.61
120-160 beats·min^{-1} %	23.25 ± 18.19	29.36 ± 26.25	26.58 ± 22.64
120-160 beats·min^{-1} Average	146.45 ± 5.11	145.27 ± 7.02	145.81 ± 6.12
160-170 beats·min^{-1} Time (s)	4 .62 ± 2.34	5.25 ± 4.59	4.97 ± 3.67
160-170 beats·min^{-1} %	17.55 ± 11.09	17.17 ± 10.52	17.35 ± 10.52
160-170 beats·min^{-1} Average	163.15 ± 0.88	162.07 ± 3.39	162.56 ± 2.58
170-180 beats·min^{-1} Time (s)	6.06 ± 3.97	5.50 ± 3.67	5.76 ± 3.73
170-180 beats·min^{-1} %	20.25 ± 10.49	18.21 ± 11.66	19.14 ± 10.93
170-180 Average	172.85 ± 1.41	172.50 ± 1.59	172.66 ± 1.49
180-185 Time (s)	3.32 ± 2.94	3.17 ± 2.78	3.24 ± 2.78
180-185 beats·min^{-1} %	10.75 ± 7.49	11.04 ± 9.41	10.91 ± 8.39
180-185 beats·min^{-1} Average	162.10 ± 56.96	164.92 ± 51.94	163.64 ± 52.97
185-220 beats·min^{-1} Time (s)	7.51 ± 6.46	8.35 ± 9.55	7.97 ± 8.11
185-220 beats·min^{-1} %	25.15 ± 22.77	23.01 ± 23.72	23.98 ± 22.76
3 D per seconds	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01
2 D per seconds	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01
1 D Forward per seconds	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01
1 D Side per seconds	0.04 ± 0.01	0.04 ± 0.00	0.04 ± 0.01
1 D Up per seconds	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01

3 D = Three dimensional (a geometric 3-parameter model); 2 D = Two dimensional (motion along 2 axes which can be plotted by its coordinate); 1 D = One dimensional (motion along a straight line; either forward or backward); 1 D Forward = Player load accumulated using only sagittal plane movements calculated at 100Hz; 1 D Side = Player load accumulated using only coronal plane movements calculated at 100 Hz; 1 D Up = Player load accumulated using only vertical plane movements calculated at 100Hz

Despite differences with regard to the above-mentioned variables between successful and less-successful players, no significant differences between groups were found.

In an attempt to first identify the variables that relate to each other and only retain the relevant varia-

Binary forward stepwise logistic regression results

Table 4 presents the forward stepwise logistic regression results of the cluster analysis' reduced ISCD variables that acted as predictors between the two groups (successful and less-successful) of players.

Table 4 indicates that high-intensity accelerations and low-intensity efforts per second were the only variables identified as significant predictors of group allocation.

Badminton is portrayed by its sporadic moderate to high-intensity efforts, instigated by short and repetitive actions that occur during series of high-intensity,

Table 4. Summary of the forward stepwise logistic regression analysis with successful and less-successful players as dependant variables and GPS variables as independent variables

Variables	Wald statistics (95% CI)	P-level
High-intensity accelerations per second	4.76 (70.51-1312.87)	0.03*
Low-intensity efforts per second	4.34 (0.41-13.71)	0.04*

Table 5. Classification table of predicted probabilities of being in the successful or less-successful group

Groups	Value of the predicted probability		
	Successful players group	Less-successful players group	Percentage correct
Successful players	7	3	70.00
Less-successful players	2	10	83.33
Total	9	13	76.88

Table 5 shows the probabilities of being in the successful or less-successful player groups, when the logistic regression formula is applied to predict group allocation. The classification table indicates that 76.88% of players could be classified into their original groups by making use of the ISCD-based logistic regression formula. The ROCC showed a value of 0.87.

DISCUSSION

To the knowledge of the researchers, this is the first attempt to investigate the predictive value of ISCD-determined match characteristics to classify badminton players into successful and less-successful groups according to tournament results. However, only high-intensity accelerations and low-intensity efforts per second were identified as significant predictors of group allocation, with 76.88% of players, who could be classified into their original groups by making use of the ISCD-based logistic regression formula. Furthermore, the ROCC (0.87) revealed that the classification model is a valid model to classify players into successful and less-successful player groups. An additional analysis by means of the independent t-test showed that high-intensity accelerations per second was the only ISCD-determined variable that obtained significant higher values for the successful compared to the less-successful group. Although not significant, the successful group also obtained higher values for low-intensity efforts per second than the less-successful player group.

brief and lengthier, moderate- or high-intensity rallies (Abián-Vicén et al., 2012; Cabello-Manrique & Gonzalez-Badillo, 2003; Jeyaraman et al., 2012; Majumdar et al., 1997). Consequently, badminton involves various sprinting movements, in the form of continual short sprints with changes in direction, which accentuate the importance of high-intensity accelerations (Sheppard & Young, 2006). The swift pace of badminton, the precision and complexity of player movements and the incessant unpredictability of the on-court situation make speed and all its basic components (reaction time, speed and frequency of movements) the decisive factor of this sport (Bańkosz et al., 2013). Previous time and motion analysis-related studies also showed that the ability of players to sprint repetitively and change direction while sprinting is the basis of sport performance (Keogh et al., 2003; Reilly et al., 2000).

A study on a dynamical system perspective to understanding badminton singles match play, revealed that relative speed during match play and distance at racket-shuttle contact point served as important factors to win points (Chow et al., 2014). Furthermore, research revealed a significant relationship ($r = 0.83$, $p < 0.05$) between agility and the qualities of sub-elite and elite players (Tiwari et al., 2011). Moreover, research suggests that successful players respond more rapidly than less-successful players due to a better reaction time and efficacy of effort (Bańkosz et al., 2013). Researchers have not just highlighted the importance of movement speed and high levels of agility for badminton players but also the speed of nervous system conductivity (Bańkosz et al., 2013). Therefore, badminton requires that players react quickly and precisely on different cues during match play and are able to accelerate effectively at a high-intensity to reach the shuttle at various locations on the court (Dube et al., 2015). In view of last-mentioned findings, it is not surprising that high-intensity accelerations per second was identified as a significant predictor of group allocation.

Successful players did not only perform more high-intensity accelerations per second during matches but also more low-intensity efforts per second when compared to less-successful players. Even more surprisingly, results show that successful players performed more overall efforts and efforts in each of the three intensity zones than their less-successful colleagues. The level and quality of play increased as players progressed to the quarter-finals, semi-finals as well as finals. this contention is verified by the fact that more successful players covered a higher distance per second than less-successful players. Therefore, more successful players had to exert themselves more as tournaments progressed (Cabello-Manrique et al., 2004).

The fact that low-intensity efforts per second were also highlighted as a group predictor would suggest that more successful players had a better ability to anticipate the tactics of opponents and the trajectory of the shuttle than less-successful players, which may benefit them in terms of the intensity of efforts that they need to perform. Last-mentioned assertion confirms the findings of others that visual search strategies allow successful players to perceive and anticipate the movements of their opponents more accurately (Alder et al., 2014).

The identification of high-intensity accelerations and low-intensity efforts per second for the attainment of badminton performances, emphasizes the importance of using badminton drills and conditioning techniques, not only to improve the physical fitness level of players, but also their abilities to accelerate at high intensities. Although athletic coaches do spend a lot of time on speed training, which is focused on developing acceleration and top speed sprinting (Sheppard, 2004; Young et al., 2001), this type of training is not common among badminton coaches. it is evident that badminton coaches need to spend more time on speed and acceleration training to improve the abilities of players to accelerate at high intensities so that they can achieve more success in badminton.

Findings of this study provide insight into an area of research where uncertainty still remains as it brings clarity with regard to the usefulness of ISCD match characteristics to predict male singles badminton players' performance levels. Although only two variables served as predictors of group classification, a high percentage of players (76.88%) could be classified back into their original groups by making use of the ISCD-based logistic regression formula. The ROCC value also showed that the classification model is a valid model to classify players into successful and less-successful player groups. Therefore, coaches and sport scientists should not only focus on the development of high-intensity accelerations during match play, but also on the physical conditioning and anticipation of players, which will allow them to perform more efforts at a low-intensity during a match. Therefore, it is imperative that coaches, sport scientists and other sport related professionals set up and apply training and conditioning drills that will mimic the specific demands of badminton match play. The study outcome also suggests that badminton talent identification and development programs should not only focus on technical and tactical aspects of match play, but also on the physical and motor performance components of players.

CONCLUSION

Despite the value of study findings, outcomes of the present study must be construed with caution, since the prediction model was developed specifically for male, single African badminton players. This connotes that the outcome cannot be generalized to all badminton players. It may also be of paramount importance to test logistic models of the classified ISCD individual match analysis results, player loads and effort-related variables through longitudinal studies in order to appraise the precision, significance, usefulness and its suitability for badminton players globally. Finally, it should be noted that technical and tactical components, which have also been recognized as important determinants for badminton performance (Chin et al., 1995), were not measured in this study. As such, it can be recommended that further studies should focus on a more elaborate range of variables, which also include the last-named components as part of the testing protocol.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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