

Singles Match Analysis Characteristics and Work Loads Associated with Success in Male Badminton Players

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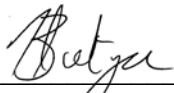
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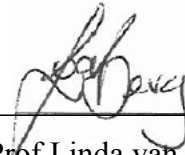
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DECLARATION

The co-authors of the three articles that form part of this thesis, Prof Ben Coetzee (Promoter) and Prof Linda van den Berg (Assistant-promoter) hereby give permission to the candidate, Mr Yahaya Abdullahi to include three articles as part of the PhD thesis. The contribution (advisory and supportive) of the co-authors was kept within reasonable limits, thereby enabling the candidate to submit this thesis for examination purposes. Hence this thesis serves as fulfilment of the requirements for the degree Doctor of Philosophy within PhASRec (Physical Activity, Sport and Recreation Focus Area) in the Faculty of Health Sciences at North-West University (Potchefstroom Campus).



Prof Ben Coetzee



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SUMMARY

To date, researchers have made no attempt to investigate the notational singles match analyses results nor the relationships between last-mentioned results of African badminton players. Furthermore, up until now, no researchers have investigated the possible link between global positioning system (GPS) determined match characteristics of badminton players and match performance, nor the possible relationships between match-analysis results of external and internal match-load-determining methods in badminton players. It is in the light of this background that the objectives of this study were as follows: firstly, to determine the notational singles match-analysis results of male badminton players who participated in the African Badminton Championships; secondly, to determine the relationships between notational singles match-analysis determined strokes and foot movements in male badminton players that participated in the African Badminton Championships; thirdly, to establish the GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification; and lastly, to determine relationships between results of an internal and external match-load-determining method in male singles badminton players.

To achieve the first two objectives of the study, twenty matches of twelve male singles players (age: 24.4 ± 4.6 years) that participated in the team and individual events of the All Africa Senior Badminton Championships of 2014 were recorded live via video cameras, and analysed using the Dartfish Video Analysis Software Package. For the third objective of the study, 46 matches of twenty-two players (age: 23.39 ± 3.92 years; body stature: 177.11 ± 3.06 cm; body mass: 83.46 ± 14.59 kg) were analysed via GPS units (MinimaxX V4.0, Catapult Innovations, Victoria, Australia), Fixed Polar HR Transmitter Belts (Polar Electro, Kempele, Finland) and digital video cameras. Players that reached the quarter finals, semi-finals or finals of the five tournaments during the 2014/2015 season were categorised as successful players whereas the rest of the players were categorised as less successful players. For the last objective of the study, 45 matches of twenty-one male singles badminton players (age: 23.2 ± 3.6 years; body stature: 176.1 ± 3.4 cm; body mass: 79.6 ± 12.3 kg) were analysed via GPS units, Fixed Polar HR Transmitter Belts and digital video cameras.

For the first objective of the study, computerised-notational analysis revealed that male badminton players that participated in the African Badminton Championships were active for

29.8% of the total match time, which relates to 1470.4 s and spent 17.3 s on average on rest in-between rallies; they performed 68.4 rallies per match at an average duration of 5.6 s, during which a stroke was performed every 1.03 sec; the real time played was 432.9 s, which relates to a work density of 0.43; they executed the drive (122.1) and clear strokes (118.0) the most times during a match and performed the shuffle (161.7) and chasse-step (174.6) foot movements the most frequently during match-play. For the second objective of the study, Spearman Rank Correlation Coefficients revealed that the net (4) and smash (4) followed by the clear shots (3) showed the highest number of significant relationships with foot movements. On the other hand, split steps (3), chasse steps (2), backward lunges (2) and lunges to the right (2) displayed the highest number of significant relationships with strokes.

For the third objective of the study, an independent *t*-test revealed that high-intensity accelerations per second was identified as the only GPS-determined variable that showed a significant difference between groups. Furthermore, the forward stepwise logistic regression analysis results of the cluster analysis' reduced GPS variables showed that only high-intensity accelerations per second and low-intensity efforts per second were identified as significant predictors ($p < 0.05$) of group allocation with 76.88% of players that could be classified into their original groups by applying the GPS-based logistic regression formula. Lastly, the Receiver Operating Characteristic Curve (ROC) revealed that the classification model valid (0.87) for classifying players into successful and less successful player groups.

For the fourth objective of the study, Spearman's Rank Correlation indicated that only the following GPS-derived measures of external match-load obtained significant relationships ($p < 0.05$) with heart rate- (HR) related measures: absolute distance covered ($r = 0.42$), time spent ($r = 0.44$) and player load (PL) in the high-intensity (HI) zone ($r = 0.44$) as well as absolute ($r = 0.43$) and relative match duration in the low-intensity (LI) zone ($r = 0.38$). Furthermore, the duration of activities, which can be used as an external match-load measure, was more related to measures of internal match-loads than any of the other external match-load-related parameters (distance covered or PL).

On the whole, the study showed that computerised-notational analysis is a reliable method for determining the singles match characteristics of male badminton players. However, shortcomings with regard to applying only one method for determining the match profiles of players accentuated the need to quantify both internal and external match-load measures and assess relationships between them. Consequently, findings of this study indicated that results of

an internal and external badminton match-load-determining method are more related to each other in the HI zone than in other zones and that the strength of relationships depended on the duration of activities performed in especially LI and HI zones. Nevertheless, results of an external badminton match-load-determining method suggested that a typical conditioning programme for badminton players should develop drills and activities that take place for durations of 5.57 s at a time at a work:rest ratio of 1:3 for a total duration of 3-5 minutes after which a break of 2 minutes must be allowed before continuing with another set for 3-5 minutes. The intensity of activities must be quite high (maintained at a work density of more or less 0.4) and incorporate especially chasse-steps, shuffle-steps, split-steps, half- and forward lunges as well as the drive, clear, serve, smash and net strokes as these strokes are performed most during match-play. The identification of high-intensity accelerations per sec and low-intensity efforts per sec for the attainment of badminton performances also emphasized the importance of using badminton specific drills and conditioning techniques to not only improve players' physical fitness levels but also their abilities to accelerate at high intensities.

Key words: badminton, foot movements, notational analysis, strokes, global positioning system, match-analysis, heart rate

OPSOMMING

Tot dusver het navorsers geen poging aangewend om die resultate van 'n notasie-, enkelwedstryd-analise te ondersoek nie, en ook nie verhoudings tussen laasgenoemde resultate van Afrika-pluimbalspelers nie. Voorts het geen navorsers tot nou toe ondersoek ingestel na die moontlike verband tussen die globale posisioneringsstelsel- (GPS) bepaalde wedstrydkarakteristieke van pluimbalspelers en wedstrydprestasie nie, en ook nie na die moontlike verbande tussen die wedstrydanalise-resultate van eksterne en interne wedstrydlading-bepalingsmetodes by pluimbalspelers nie. Dit is in die lig van hierdie agtergrond dat die doelwitte van hierdie studie was om eerstens die notasie-, enkelwedstryd-analiseresultate van manlike pluimbalspelers wat aan die Afrika Pluimbalkampioenskappe deelgeneem het, te bepaal; tweedens, om verbande tussen notasie, enkelwedstryd-analisebepaalde houes en voetbewegings by manlike pluimbalspelers wat aan die Afrika Pluimbalkampioenskappe deelgeneem het, vas te stel; derdens, om die GPS-bepaalde enkelwedstryd-karakteristieke wat dien as voorspellers van suksesvolle en minder suksesvolle manlike enkelspel-pluimbalspelers se groepsklassifisering te bepaal en ten slotte, om verbande tussen die resultate van 'n interne en eksterne wedstrydlading-bepalingsmetode manlike enkelspel-pluimbalspelers te bepaal.

Ten einde die eerste twee doelwitte van die studie te behaal is twintig wedstryde van twaalf manlike enkelspelers (ouderdom: 24.4 ± 4.6 jare) wat aan die span en individuele nommers van die Alle Afrika Senior Pluimbalkampioenskappe van 2014 deelgeneem het, lewendig opgeneem deur middel van videokameras, en met behulp van die Dartfish Video Analysis Software Package ontleed. Vir die derde doel van die studie is 46 wedstryde van twee-en-twintig spelers (ouderdom: 23.39 ± 3.92 jaar, liggaamslengte: 177.11 ± 3.06 cm, liggaamsmassa: 83.46 ± 14.59 kg) geanaliseer deur gebruik te maak van GPS-eenhede (MinimaxX V4.0, Catapult Innovations, Victoria, Australië), Fixed Polar HR Transmitter Belts (Polar Electro, Kempele, Finland) en digitale videokameras. Spelers wat die kwartfinale, halfeindronde of eindstryde van vyf toernooie wat gedurende die 2014/2015-seisoen plaasgevind het, gehaal het, is gekategoriseer as suksesvolle spelers, terwyl die res van die spelers as minder suksesvolle spelers gekategoriseer is. Vir die laaste doel van die studie is 45 wedstryde van een-en-twintig manlike enkelspel-pluimbalspelers (ouderdom: 23.2 ± 3.6 jare, liggaamslengte: 176.1 ± 3.4 cm, liggaamsmassa: 79.6 ± 12.3 kg) geanaliseer aan die hand van GPS-eenhede, Fixed Polar HR Transmitter Belts en digitale videokameras.

Vir die eerste doelwit van die studie, het 'n rekenaarnotasie-analise aan die lig gebring dat manlike pluimbalspelers wat aan die Afrika Pluimbal-kampioenskappe deelgeneem het, vir 29.8% van die hele duur van die wedstryd aktief was, wat uitwerk op 1470.4 sek, en gemiddeld 17.3 sek aan rus afgestaan het tussen houe-reekse; hulle het 68.4 houe-reekse per wedstryd vir 'n gemiddelde duur van 5.6 sek uitgevoer waartydens 'n hou elke 1.03 sek uitgevoer is; die werklike speelyd was 432.9 sek, wat ooreenstem met 'n werksdigtheid van 0.43; hulle het die dryf- (122.1) en die opklaarhou (118.0) die meeste tydens 'n wedstryd uitgevoer en die skuifel- (161.7) en die “chasse”-treë (174.6) voetbewegings die meeste tydens die wedstryd uitgevoer. Vir die tweede doelwit van die studie het Spearman Rank Korrelasiekoëffisiënte getoon dat die net- (4) en mokerhou (4) gevolg deur die opklaarhou (3) die hoogste aantal betekenisvolle verbande met voetbewegings getoon het. Aan die ander kant, het die split-treë (3), “chasse”-treë (2), terugwaartse “lunges” (2) en “lunges” na regs (2) die grootste aantal betekenisvolle verbande met houe getoon.

Vir die derde doelwit van die studie het 'n onafhanklike *t*-toets aan die lig gebring dat hoë-intensiteit-versnellings per sekonde geïdentifiseer is as die enigste GPS-bepaalde veranderlike wat 'n betekenisvolle verskil tussen groepe getoon het. Verder het resultate van die vorentoe, stapsgewyse, logistiese regressie-analise van die trosontledingsverminderde GPS-veranderlikes getoon dat slegs hoë-intensiteit-versnellings per sekonde en lae-intensiteit-pogings per sekonde geïdentifiseer is as belangrike voorspellers ($p < 0.05$) van groeptoewysing met 76.88% van spelers wat in hul oorspronklike groepe geklassifiseer kon word deur van die GPS-gebaseerde logistiese regressieformule gebruik te maak. Laastens het die Receiver Operating Characteristic Curve (ROC) onthul dat die klassifikasie-model geldig (0.87) is om spelers in suksesvolle en minder suksesvolle speler-groepe te klassifiseer.

Vir die vierde doelwit van die studie het Spearman se rangkorrelasie aangedui dat slegs die volgende GPS-afgeleide metings van eksterne wedstrydlading betekenisvolle verbande ($p < 0.05$) met harttempo- (HR) verwante metings getoon het: absolute afstand afgelê ($r = 0.42$), tyd bestee ($r = 0.44$) en spelerlading (SL) in die hoë-intensiteit-(HI) sone ($r = 0.44$) asook absolute ($r = 0.43$) en relatiewe duur van die wedstryd in die lae-intensiteit- (LI) sone ($r = 0.38$). Verder staan die duur van aktiwiteite, wat as 'n eksterne wedstrydlading-verbandhoudende parameter gebruik kan word, meer in verband met metings van interne wedstrydlading as enige van die ander eksterne wedstrydlading-verbandhoudende parameters (afstand of SL).

In die geheel het die studie getoon dat 'n gerekenariseerde notasie-analise 'n betroubare metode is vir die bepaling van die enkelspel-wedstrydkarakteristieke van manlike pluimbalspelers te bepaal. Nietemin, tekortkominge met die gebruik van slegs een metode om die wedstrydprofiel van spelers te bepaal beklemtoon die behoefte om metings van beide interne en eksterne wedstrydladings te kwantifiseer en verbande daartussen te evalueer. Gevolglik het bevindinge van hierdie studie getoon dat die resultate van 'n interne en eksterne pluimbal-wedstrydlading-bepalingsmetode meer in die HI-sone met mekaar verband hou as in ander sones, en dat die sterkte van verbande afhang van die duur van aktiwiteite wat in veral die LI- en HI-sones uitgevoer word. Desondanks dui die resultate van 'n eksterne pluimbalwedstrydladingbepalingsmetode dat 'n tipiese kondisioneringsprogram vir pluimbalspelers oefeninge en aktiwiteite moet ontwikkel wat plaasvind oor 'n tydsduur van 5.57 sek by 'n werk-tot-rus-verhouding van 1:3, vir 'n totale duur van 3-5 minute, waarna 'n breek van 2 minute toegelaat moet word voordat daar voortgegaan word met nog 'n stel wat 3-5 minute lank duur. Die intensiteit van aktiwiteite moet redelik hoog wees (gehandhaaf teen 'n werksdigtheid van min of meer 0.4) en moet ook veral "chasse"-treë, skuifeltreë, split-treë, half- en voorwaartse "lunes", asook die dryf-, opklaar-, dien-, moker- en net-houe insluit aangesien hierdie houes die meeste tydens wedstryde uitgevoer word. Die identifisering van hoë-intensiteitversnellings per sekonde en lae-intensiteitspogings per sekonde vir die behaling van pluimbal-prestasies beklemtoon ook die belangrikheid van die gebruik van pluimbal-spesifieke oefeninge en kondisioneringstegnieke wat nie uitsluitlik daarop gemik is om spelers se fisieke fiksheidvlakke te verbeter nie maar ook hul vermoëns om teen hoë intensiteit te versnel.

Sluteltermes: pluimbal, voetbewegings, notasie-analise, houes, globale posisioneringstelsel wedstrydanalise, harttempo

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
2D	Two dimension
3D	Three dimension
bpm	Beats per minute
BWF	Badminton World Federation
CI	Confidence Interval
cm	Centimetres
COD	Change of direction
CW	Conditional winner
E	Effective
FF	Forced failure
GPS	Global positioning system
HI	High intensity
HR	Heart rate
HR _{max}	Maximal heart rate
I	International players
IBF	International Badminton Federation
IE	Ineffective
IMA	Inertial movement analysis
Kg	Kilogram
L	Large
LI	Low intensity
LSA	Low-speed activity
M	Moderate
m.s ⁻¹	Meter per second
MD	Men's doubles
MI	Medium intensity
MS	Men's singles
NI	Not indicated
NP	Nearly perfect

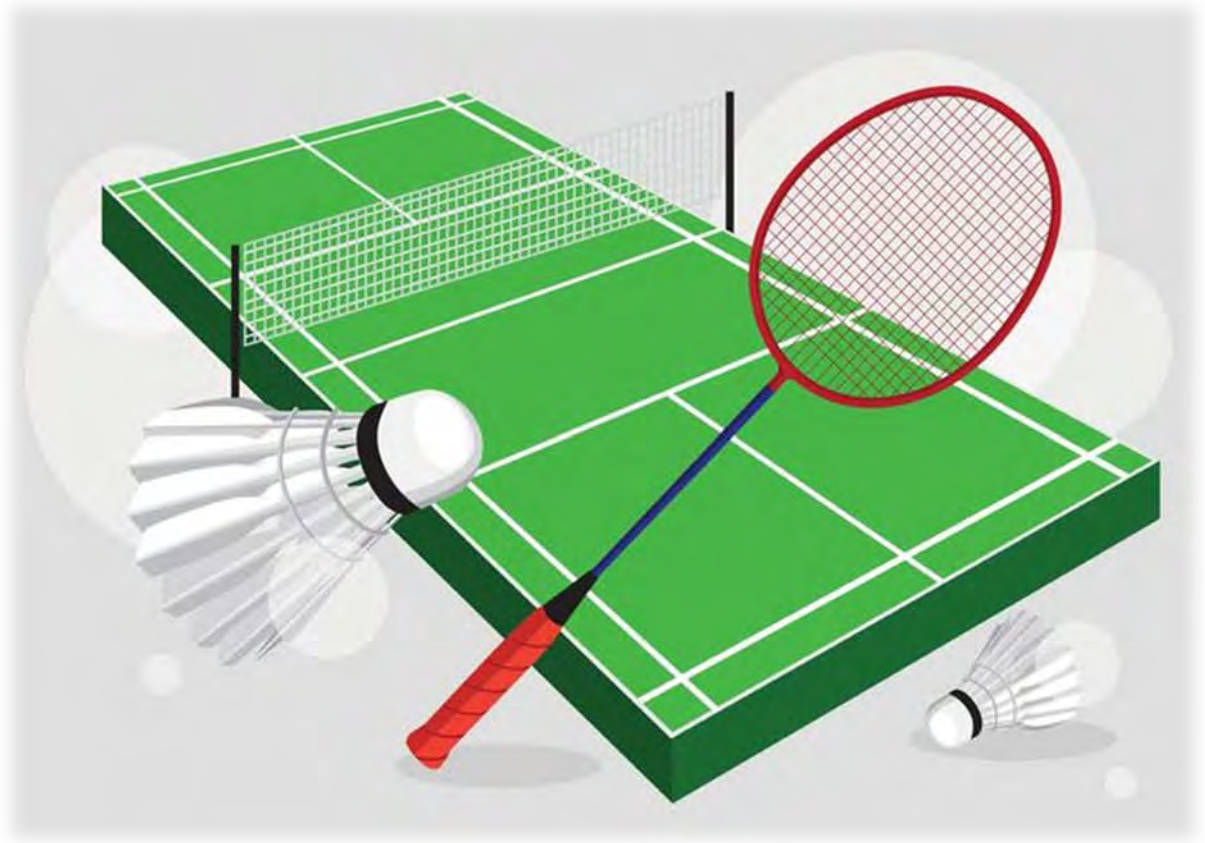
OG	Olympic Games
PL	Player load
R	Spearman's rank correlation coefficient
Reps	Repetitions
RM	Real match
S	Small
s/s ⁻¹	Second
SD	Standard deviation
SHRZ	Summated heart rate zone
SM	Simulated match
sRPE	Session rating of perceived exertion
T	Trivial
TD	Total distance
TN	Top National players
TRIMP	Training impulse
UF	Unforced failure
UW	Unconditional winner
VL	Very large
VO ₂	Oxygen consumption
VO _{2max}	Maximal oxygen consumption
Vs.	Versus
WD	Women's doubles
WS	Women's singles
XD	Mixed doubles
YN	Young National players
Yrs	Years

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CHAPTER 1

Introduction



1. INTRODUCTION

Badminton has been an Olympic sport since the Barcelona Olympic Games in 1992 and since then, has received increasingly more attention from researchers due to its popularity in countries such as Korea, China and Malaysia, amongst others (Wan & Rambely, 2008:22; Singh *et al.*, 2011:6). Despite the popularity of the sport and the need for accurate match-analysis data that will enable coaches and other sport-related professionals to determine the match characteristics of badminton, very few researchers have focused their attention on this aspect of badminton (Faude *et al.*, 2007:480). The badminton scoring system change in 2006 from the traditional 3 sets, 15 points system to the new 3 sets, 21 points system (Ming *et al.*, 2008:216) has accentuated the need for more up to date research in this area. Furthermore, until now, no other researchers have investigated the characteristics of a real badminton match by making use of a global positioning system (GPS). Moreover, despite the acceptance and use of methods for determining the internal and external match-loads of different sports, researchers have to date not investigated the relationships between match-analysis results of external and internal match-load-determining methods in badminton players.

2. PROBLEM STATEMENT

Badminton is a fast-paced net-based racket sport for two or four participants at a time, with a time-based structure that is described by actions of short duration and high intensity (Phomsoupha & Laffaye, 2015:473). The inclusion of badminton in the 1992 Olympic Games significantly boosted participation with approximately 200 million enthusiasts globally (Phomsoupha & Laffaye, 2015:473). Despite the popularity of badminton, only a small number of researchers have more recently investigated the match-analysis characteristics of the sport (Laffaye *et al.*, 2015:584). The popularity and competitiveness of badminton have led to a need for precise and up-to-date match performance analysis that will enable coaches and other sport-related professionals to correctly determine the match characteristics of players (Faude *et al.*, 2007:484). Match-analysis-related studies in racket sports have therefore increased in recent years resulting from the value of match-analysis results in examining and improving match performance (Hughes, 2003:218; Hughes & Franks, 2004:57).

Only if researchers and sport practitioners precisely analyse the different match movements and movement patterns will they be able to determine the exact demands of badminton matches (Hughes, 2007:108). In this regard, computerised-notational analysis is one of the analysis methods that can be applied to determine the match characteristics of badminton (Hughes & Franks, 2004:88; Hughes *et al.*, 2007:6; Abian-Vicen *et al.*, 2013:311). In computerised-

notational analysis, researchers usually record different badminton matches *via* a digital video camera (Hughes *et al.*, 2007:6; Ming *et al.*, 2008:218). Thereafter they use a video analysis software package such as Dartfish to analyse the video footage in detail, and then display results of the match-analysis in digital format (Hughes & Franks, 2004:78; Wilson, 2008:35; O'Donoghue, 2014:155). Despite the benefits of this analysis method, very few researchers have thus far used this method with a view to analyse badminton matches (Ming *et al.*, 2008:216; Abian-Vicen *et al.*, 2013:311). Furthermore, thus far no researchers have analysed the match characteristics of African badminton players. The need for more up-to-date research in this area has also been accentuated by the change in the badminton scoring system during 2006 from the traditional 3 sets, 15-points system to the new 3 sets, 21-points system (Ming *et al.*, 2008:216).

Several studies have made use of notational analysis to investigate the characteristics of badminton match-play. For example, temporal structure analyses of 14 matches played during a 1999 Spanish International Tournament revealed the following characteristics: the average game duration was 1689.3 ± 313 s, with 6.06 ± 1.08 shots performed per rally time; the real time played was 548.7 ± 98.6 s, while the performance time was 6.4 ± 1.25 s; the work density was found to be 0.49 ± 0.06 ; the total rallies played was 83.3 ± 11.03 , with total shots averaging 510.7 ± 109.76 (Cabello-Manrique & Gonzalez-Badillo, 2003:63). In another study, Abian-Vicen *et al.* (2013:314) assessed the temporal and notational structures of matches played during the 2008 Beijing Olympic Games and found the following average results for the first and second games of men's singles matches respectively: the duration of games was 1128 ± 256.5 s and 1121.0 ± 214.0 s; the real time played was 310.5 ± 40.7 s and 303.3 ± 52.3 s. Players only spent $28.1 \pm 3.4\%$ and $27.3 \pm 2.4\%$ of the total time on match-play activities; rally time was found to be 9.0 ± 0.9 and 9.1 ± 1.4 s; shots per rally were 9.7 ± 0.8 and 9.9 ± 1.4 ; rest time was 24.1 ± 3.8 s and 25.2 ± 4.6 s; work density was 0.38 ± 0.06 and 0.36 ± 0.04 ; and shot frequencies per rally, 1.08 ± 0.04 and 1.09 ± 0.03 , respectively. Cabello *et al.* (2004:5) analysed a large sample ($n = 79$) of national, international and world-class Spanish male badminton players and revealed an average total playing time of 2090 ± 921 s, an average total work time of 707 ± 261 s, an average work time of 7.3 ± 1.3 s, an average rest time of 14.2 ± 3.4 s, an average work:rest ratio of 0.53 ± 0.12 as well as an average number of rallies' value of 98 ± 32 . In a different study, Ming *et al.* (2008:219) used notational and time-motion analyses to investigate differences in simulated badminton match characteristics, when state-level male Malaysian badminton players made use of the new (21 points) and old scoring systems (15 points) respectively. They reported 17.27 ± 2.67 vs. 24.06 ± 2.38 min for match durations; 8.64 ± 1.33 vs. 12.03 ± 1.19 min for average game duration; 4.62 ± 0.86 s vs. 4.63 ± 0.49 s for rally time;

9.71 $\pm$ 1.32 s vs. 10.29 $\pm$ 1.42 s for rest time; 0.48 $\pm$ 0.07 vs. 0.46 $\pm$ 0.07 for work density; 331.25 $\pm$ 44.74 vs. 463.5 $\pm$ 21.41 for number of shots per match; 70.25 $\pm$ 1.26 vs. 97 $\pm$ 6.68 for the number of rallies per match and 4.74 $\pm$ 0.78 vs. 4.77 $\pm$ 0.47 for the average shots per rally for last-mentioned scoring systems respectively. Although notational analysis results do provide sport practitioners in the badminton fraternity with information regarding the singles match characteristics of male players, it is unclear whether African badminton players will display the same match characteristic profile as their international counterparts. Over the last two decades, studies have only focussed on badminton players from Spain (Cabello *et al.*, 2004:2), Malaysia (Ming *et al.*, 2008:217), and the top international players that participated in the 1996 Hong Kong Badminton Open (Tong & Hong, 2000:1) and Olympic Games (Abian-Vicen *et al.*, 2013:312).

On the other hand, possible relationships between notational singles match-analysis that determined strokes and foot movements of badminton players can be qualitatively analysed in order to gather information with regard to the technical and tactical aspects of performance (Liddle *et al.*, 1996:162). Information with regard to relationships between certain variables may promote an understanding of specific-match demands and assist coaches in setting up match-specific training schedules (Liddle *et al.*, 1996:162). However, the researcher is not aware of any other previous study that made an attempt to determine the relationships between notational singles match-analysis-determined strokes and foot movements of badminton players.

The advent of GPS in the 1990s offered an optional method for the measurement of average duration, frequency, and speed of movements, with the potential of circumventing some of the shortcomings of notational analyses and of minimising others (Townshend *et al.*, 2008:124). These shortcomings include amongst others, the time-consuming nature of notational analyses (Hughes & Franks, 2004:77; Townshend *et al.*, 2008:124), the inaccuracies of notational analyses to analyse total time spent on individual movements, the frequency of individual movements (Duthie *et al.*, 2003:983), and the inability to assess the specific demands of certain activities (O'Donoghue, 2008:189). However, as mentioned before, the researcher is not aware of any other previous study that has made use of GPS devices to do this type of analyses on badminton players. The use of a triaxial accelerometer, magnetometer, and gyroscope in a GPS device for analysing badminton matches are still a new phenomenon. Accelerometers, gyroscopes and magnetometers are devices that allow researchers to monitor and describe movements as well as the intensity and frequency of these movements in various clinical and sports settings (Gastin *et al.*, 2013:590). In this regard, Coe and Pivarnik (2001:373) found that

accelerometers are valid instruments for determining physical activity levels during indoor basketball practices where intensity is changing constantly. Other researchers also revealed that MinimaxX™ accelerometers showed acceptable reliability (< 2%) for measuring Australian Football players' external work-loads and were capable of detecting differences in physical activity levels (Boyd *et al.*, 2011:319). Wundersitz *et al.* (2015:3977) used a simulated team sport circuit to demonstrate that wearable tracking devices that make use of accelerometer and gyroscope data are precise for classifying sporting activities in sport scenarios. Despite the potential benefits of the GPS match-analysis method, no researchers have made an attempt to utilise this method for determining the relationship between GPS determined match characteristics and the championship results of badminton players.

Researchers currently use various methods to investigate, amongst other things, the match-loads of indoor sport participants such as badminton players. External match-loads are determined through manual video tracking (Burgess *et al.*, 2006:335), semi-automated video tracking (Bradley *et al.*, 2011:821) and global positioning system (GPS) analyses (Varley & Aughey, 2013:34), whereas internal match-loads are determined by performing blood lactate (Cabello-Manrique & Gonzalez-Badillo, 2003:65; Cabello-Manrique *et al.*, 2004:3) and heart rate (HR) analyses (Liddle *et al.*, 1996:163; Cabello-Manrique & Gonzalez-Badillo, 2003:63; Cabello-Manrique *et al.*, 2004:3) as well as by utilising gas exchange values obtained during graded maximal tests (Andersen *et al.*, 2007:129; Ooi *et al.*, 2009:1594; Tervo *et al.*, 2010:667). The most common method for determining the internal loads of athletes is by means of HR monitoring and analyses (Halsen, 2014:142). Overall, researchers that have analysed the HR of badminton players show that average heart rates of between 166 and 188 bpm occur during match-play, while maximal heart rates of between 191 and 195 bpm have been observed during normal and simulated matches (Cabello-Manrique & Gonzalez-Badillo, 2003:64; Wonisch *et al.*, 2003:117). Although researchers support the use of HR analysis to accurately determine players' internal loads HR shows a delayed response to sudden high-intensity movements, which may lead to an underestimation of match-loads and intensities (Jeukendrup & Diemen, 1998:92). Furthermore, HR usually takes some time to return to pre-activity levels, which means that intensity or loads will be overestimated during match-play due to HR inflation (Coe & Pivarnik, 2001:374).

In view of these shortcomings, with regard to the use of HR as an internal load-determining method, and the need for more comprehensive match-load profiles, it is important to quantify both internal and external match-load measures and to assess the relationships between them

(Scott *et al.*, 2013:271). Although research findings indicate that measures of external (total distance covered, the volume of low-speed activity, high-speed running and very high-speed running as well as player load) and internal match-loads (rating of perceived exertion, training impulse and summated-heart-rate-zones) are significantly related (r-values of between 0.38 and 0.84, $p < 0.05$) in team sport participants (Scanlan *et al.*, 2014:2402), no studies have investigated the possible relationship between the external and internal match-load measures in racket sport participants such as badminton players.

In the light of this research background and identified shortcomings the following research questions are posed: Firstly, what are the notational singles match-analysis results of male badminton players who participated in the African Badminton Championships? Secondly, what are the relationships between notational singles match-analysis-determined strokes and foot movements of male badminton players that participated in the African Badminton Championships? Thirdly, what are the GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification? Lastly, what are the relationships between results of an internal and external match-load-determining method in male singles badminton players? Answers to the aforementioned research questions could possibly enable coaches, badminton players and sport scientists to compile conditioning programs specifically in accordance with the demands of badminton matches. It may also give people in the sporting fraternity an indication of the match characteristics that discriminate between successful and less successful badminton players so that more attention can be given to these characteristics. Also, a better comprehension of the specific match-loads that badminton players experience during match-play may allow sport scientists to compile more badminton-specific conditioning programs for preparing players for the requirements of competitive match-play.

3. OBJECTIVES

The objectives of this study are to determine:

1. The notational singles match-analysis results of male badminton players who participated in the African Badminton Championships.
2. Relationships between notational singles match-analysis-determined strokes and foot movements in male badminton players that participated in the African Badminton Championships.
3. The GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification.

4. Relationships between results of an internal and external match-load-determining method in male singles badminton players.

4. HYPOTHESES

The study is based on the following hypotheses:

1. The notational singles match-analysis results of male badminton players who participated in the African Badminton Championships will compare well to those of previously investigated players that also played according to the new 21-point scoring system: an average match duration of 24.06 ± 2.38 min; an average game duration of 8.64 ± 1.33 min; an average rally duration of 4.62 ± 0.86 s; an average real time played 306.9 ± 46.5 s ($27.7 \pm 2.9\%$); an average rest time of 9.71 ± 1.32 s; an average work density of 0.48 ± 0.07 ; an average number of shots per match of 331.25 ± 44.74 ; an average number of rallies per match of 70.25 ± 1.26 and 4.74 ± 0.78 for the average shots per rally.
2. Significant relationships will exist between the majority of notational singles match-analysis-determined strokes and foot movements in male badminton players.
3. GPS measurements (characteristics) such as player load, time spent in different acceleration zones and efforts performed at different intensities will serve as significant predictors of successful and less successful male singles badminton players' group classification.
4. Significant relationships will exist between the results of an internal and external match-load-determining method in male singles badminton players.

5. STRUCTURE OF DISSERTATION

This dissertation is submitted in article format as approved by the Senate of North-West University, and structured as follows:

- Chapter 1:** Problem statement, objectives, and hypotheses. A bibliography is provided at the end of the chapter in accordance with the guidelines of North-West University.
- Chapter 2:** Literature Review: The match-analysis characteristics of badminton players. A bibliography is provided at the end of the chapter in accordance with the guidelines of North-West University.
- Chapter 3:** Article 1 - Notational Singles Match-analysis of Male Badminton Players who participated in the African Badminton Championships. The article was submitted and accepted for publication in the *International Journal of Performance Analysis in Sport*. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal (see Appendix A). Although not in accordance with guidelines of the journal, tables were included in the text to make the article easier

to read and understand. Furthermore, the line spacing of the article was set at one and a half lines to conform to the layout of the rest of the thesis.

- Chapter 4:** Article 2 - Global Positioning System (GPS) Determined Match Characteristics that Predict Successful and Less Successful Male Singles Badminton Players' Group Classification. The article was submitted for publication in the *International Journal of Sports Science and Coaching*. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal (see Appendix A), tables were included within the text so as to ease the reading and understanding of the text. Furthermore, the line spacing of the article was set at 1.5 lines instead of the prescribed 2 lines.
- Chapter 5:** Article 3 - Relationships between Results of an Internal and External Match-Load-determining Method in Male Singles Badminton Players. The article was submitted and accepted for publication in the *Journal of Strength and Conditioning Research*. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal (see Appendix A). Although not according to the guidelines of the journal, tables were included within the text so as to ease the reading and understanding of the text. Furthermore, the line spacing of the article was set at 1.5 line instead of the prescribed 2 lines.
- Chapter 6:** Summary, conclusions, limitations and recommendations of the study.

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CHAPTER 2

LITERATURE REVIEW

Match Analyses of Badminton Players



1. INTRODUCTION

Badminton is one of the major racket sports and is characterised by its speed of execution, dynamism and the need for tactical, technical and psychological abilities as well as physical fitness (Lees, 2003:707; Abian *et al.*, 2012:2). However, despite the popularity and the demands of the sport as well as the need for accurate match-analysis data that will enable coaches and other sport-related professionals to determine the match characteristics of badminton, very few researchers have focused their attention on this aspect of badminton (Faude *et al.*, 2007:480). Match-analysis refers to the objective method of examining and recording behavioural actions that arise during competitions or matches (O'Donoghue, 2008:180; Carling *et al.*, 2009:2). These types of analyses focus on all the on-court activities that an individual player performs during a match, and allow researchers and sport practitioners to integrate activities and movements into a summarised report (Hughes, 2007:108). Therefore, match analyses' activities range from in-depth technical to qualitative analyses of sporting performances (O'Donoghue, 2004b:184). The systematic assessment of badminton matches enables researchers to comprehend the sport, its strategies and the physical training needed to be successful in the sport as well as players' behaviours (Lees, 2003:713; O'Donoghue, 2004b:184). Match analyses are only efficient if researchers are able to determine which data is imperative for the improvement of players' performances (Carling *et al.*, 2009:11). In this regard, different types of video and computerised match-analysis technologies are used to enhance sporting performance (Carling *et al.*, 2009:11). Knowledge of weaknesses in players' playing profiles as well as errors made during match-play may allow players to improve their techniques (Hughes & Bartlett, 2008:8). Furthermore, match-analysis results can be used to identify opponent's strengths and weaknesses and aid in selecting players (Carling *et al.*, 2005:11).

Researchers currently use various methods to investigate, amongst other things, the match-loads of indoor sport participants such as badminton players. External match-loads are determined through manual video tracking (Burgess *et al.*, 2006:335), semi-automated video tracking (Bradley *et al.*, 2011:821) and global positioning system (GPS) analyses (Varley & Aughey, 2013:34), whereas internal match-loads are determined by means of blood lactate (Cabello-Manrique & Gonzalez-Badillo, 2003:63; Cabello-Manrique *et al.*, 2004:3) and heart rate (HR) analyses (Liddle *et al.*, 1996:159; Cabello-Manrique & Gonzalez-Badillo, 2003:63; Cabello-Manrique *et al.*, 2004:3) as well as by utilising gas exchange values obtained during graded maximal tests (Andersen *et al.*, 2007:129; Ooi *et al.*, 2009:1593; Tervo *et al.*, 2010:666). However, researchers and sport scientists will only obtain an accurate match-load profile of sport participants if they use methods that will allow them to simultaneously analyse both the internal

and external match-loads of match-play (Alexandre *et al.*, 2012:2892). Furthermore, despite the acceptance and use of last-mentioned methods to determine match-loads, information with regard to the relationships between match-analysis results of external and internal match-load-determining methods provide researchers and sport scientists with clarity concerning the external loads that are most often associated with the physiological responses (internal load) to match play.

In view of the above-mentioned background and shortcomings of current literature, the objectives of this literature review were firstly to provide the history and a detailed description of badminton as a sport; secondly, to describe the various badminton match-analysis methods that resort under the broad categories of internal and external match-load-determining methods respectively as well as present results of research that have applied each of these methods to analyse badminton; thirdly, to investigate the limitations of current match analyses methods in order to make recommendations to address these limitations and fourthly, to discuss research that has investigated relationships between results of internal and external load-determining methods in sport.

Searches for relevant literature were done in accordance with the recommendations of the International Society of Performance Analysis of Sport (ISPAS, 2014). In addition, computer searches were performed using the Academic Research, PubMed, EBSCOhost, Masterfile, ScienceDirect, PsycINFO, Cairn, SportDiscus, Academic Search Premier and Medline databases. Scirus, Google Scholar and MetaCrawler search engines as well as ResearchGate were also used to search for available, relevant and related literature. Keywords exploited in the searches included, but were not limited to, the following: GPS, video analysis, match-analysis, notational analysis, motion analysis, HR, badminton, elite players and racket sports. Only English literature was considered with publication date not regarded as a criterion for selection. Other racket sports were also considered with the exception of table tennis. With regard to gender, only literature that included men as participants was considered. Furthermore, articles/publications that included a detailed description of study methods were also considered. In order to reach the objectives of this review, the author also explored literature that applied alternative match-analysis methods that are not currently being used in badminton but hold the potential of being applied for badminton match-analysis.

2. HISTORY AND DESCRIPTION OF BADMINTON

2.1 History of badminton

Badminton originated from ancient civilisations in Europe and Asia (Badminton World Federation (BWF), 2016; Shan *et al.*, 2016:175). The archaic game that was originally known as ‘battledore’ presumably began more than 2000 years ago (BWF, 2016). In the 1600s *battledore* was mainly played by the upper class (noble elites) in England and other European countries (BWF, 2016). The original aim of *battledore* was for two persons to clout a shuttlecock backwards and forwards with a bat as much as they could without letting it touch the ground (BWF, 2016).

The standard rules of the present-day game were refined and developed in England (BWF, 2016). Badminton procured its designated name from Badminton House - home of the Duke of Beaufort, located in the heart of South Gloucestershire, in the United Kingdom. In the year 1873 the Duke introduced his guests to a rendition of “Poona”, a game that he saw in India (BWF, 2016). The sport expeditiously grew in popularity and reputation, especially amongst elites, and in 1877 the first and antecedent set of drafted written rules were contrived by the then newly constituted Bath Badminton Club (BWF, 2016). The Badminton Federation of England was actualised 16 years later, and in March of 1898 the first prestigious Open Tournament, which was held at Guildford in 1899, was organised (BWF, 2016). During the 1930s, Canada, Denmark, and the USA also evolved into passionate accomplices of the game (BWF, 2016).

In 1934 the International Badminton Federation (IBF) was established, with the initiatory members that included England, Wales, Scotland, Ireland, Denmark, Canada, Holland, France and New Zealand, alongside India which was acknowledged as an affiliate in 1936 (BWF, 2016). In 1948 the first prominent IBF tournament known as the Thomas Cup (world men's team championships) was played (BWF, 2016). Ever since, the number of major world tournaments has increased with the inclusion of the Sudirman Cup for mixed teams, Uber Cup for women's teams, World Championships for all individual events, World Junior Championships and the World Grand Prix Finals (BWF, 2016).

Badminton was popularised and included in the Commonwealth Games programme in 1966 and since then it has been part of every Commonwealth Games program (BWF, 2016). The Commonwealth Games included all five game formats, namely: men's (MS) and women's singles (WS) as well as men's (MD), women's (WD) and mixed doubles (XD). Team events were later on included in the Commonwealth Games program (BWF, 2016). Badminton had its

debut inauguration as an exhibition sport at the 1972 Olympic Games, which was held in Munich. It obtained official inclusion into the Olympic Games program during the 1992 Barcelona Games, with MS, WS, MD and WD events having been included. The XD event was also included in the 1996 Atlanta Olympic Games program. Since then, the number of badminton events and medals, which are up for grabs, have remained unchanged (BWF, 2016).

Although the creation of modern badminton is attributed to England, Asian countries currently dominate the sport (BWF, 2016). Between 1992 and 2008, Asian countries won 69 of the 76 available medals in Olympic competitions. Currently, the following countries dominate badminton internationally: China, Indonesia, the Republic of Korea, followed by Great Britain and Denmark (BWF, 2016).

2.2 Description of badminton

Badminton is played on a rectangular court that is marked by easily observable white lines (BWF, 2010:4). The net posts are 1.55 metres high and remain perpendicular when the net is stiffened (BWF, 2010:4). The posts are positioned on the doubles side-lines, regardless of either singles or doubles being played (BWF, 2010:4). The net is made of darkened coloured fine-cord, which is formed by a flexible mesh with a thickness of not less than 15 mm and not more than 20 mm. The net measures 760 mm in depth and not less than 6.1 metres in width, and the top of the net is edged with a 75 mm fair-coloured tape doubled over a string or wire running inside the tape (BWF, 2010:4). The distance from the bottom of the floor to the top point of the net is 1.524 m at the centre and 1.55 m at the sides (BWF, 2010:4).

The shuttle that is hit during badminton is made of natural or synthetic components as long as the flight characteristics are identical to the natural feathered shuttle with the cork base sheathed by a slight layer of leather (BWF, 2010:5). Feathered shuttles are, however, used in all tournaments (BWF, 2010:5). A good shuttle has 16 feathers affixed at the base. The feathers have homogenous dimensions ranging between 62 and 70 mm if measured from the apex to the base (BWF, 2010:5). The apex of the feathers is obliqued on a circle form with a diameter ranging from 58 to 68 mm (BWF, 2010:5). The base ranges between 25 and 28 mm in diameter and is circular at the bottom (BWF, 2010:5). The shuttle normally weighs between 4.74 and 5.50 g (BWF, 2010:5).

A badminton racket is a rigid structure not exceeding 680 mm in length and 230 mm in width (BWF, 2010:6). The head unites the stringed area with the shaft, and the shaft connects the

handle to the head (BWF, 2010:6). The throat (if available) joints the shaft with the head (BWF, 2010:6). The stringed area is flat and consists of woven strings which can be either interlaced or bonded (BWF, 2010:6). The stringing pattern must be homogenous and not less compact in the middle than other areas, not exceeding 280 mm in total length and 220 mm in total width (BWF, 2010:7). A racket must be free from any form of device that can make it viable for a player to modify or distort it physically (BWF, 2010:7).

At the start of a game, a toss is performed, with the winning side that chooses either to serve or to receive first or start the game at a certain side of the court (BWF, 2010:7). A match comprises the best of three games with games being won by the first player that scores 21 points, except in cases where the score is 20-all. In these cases, the player that obtains two points more than his/her opponent will win the game (BWF, 2010:7). In cases where the score progresses to 29-all, the player that scores the 30th point first, will win the game (BWF, 2010:7). A point can be obtained by winning a rally. A rally is won, when the opposition makes a mistake or the shuttle drops, or the shuttle does not reach the other side of the court (BWF, 2010:7). The winning side always starts the service first in the subsequent game (BWF, 2010:7). Ends should be changed at the end of the first, second or third games. In the third game, players will change sides when 11 points are reached (BWF, 2010:8).

For the start of each badminton rally, both the serving and the receiving player will stand crosswise (diagonally) opposite the service courts without touching any of the markings (lines) of the service courts (BWF, 2010:8). Both the server and the receiver's feet (or its parts) should remain in contact with the court-surface in a motionless position from the beginning of the serve until the serve is fully delivered (BWF, 2010:8). The server must hit the base of the shuttle with his racket below his/her waist (BWF, 2010:8). At the instant of hitting the shuttle, the racket shaft should be pointing in a downward direction (BWF, 2010:8). The progressive movement of the racket should also continue without a hitch until the execution of the serve is complete (BWF, 2010:8). The parabolic flight of the shuttle should be ascending from the server's racket over the net in such a way (if not attacked or intercepted) that it lands within the receiver's service court (particularly within or on the boundary lines) (BWF, 2010:8). When players are ready for a serve, the first movement of the racket by the server shall be considered the beginning of the serve (BWF, 2010:8). The moment the serving player wins a rally, a point shall be awarded to him/her. The server will then proceed to serve again in the alternate service court (BWF, 2010:9). Similarly, if the receiving player wins a rally, he/she will earn a point. The receiving player will then become the server (BWF, 2010:9).

When a serve is wrongly performed, or if the shuttle hangs or dangles on top of the net, or else, after crossing over the net, is caught or captured by the net, the receiver will earn a point (BWF, 2010:10). Similarly, in cases where the shuttle does not land within the boundary lines of the court or passes through or beneath the net, the opponent will receive the point (BWF, 2010:10). Furthermore, in cases where the shuttle makes contact with the ceiling, sidewalls, person or clothing of a player, or touches any other item, object or individual outside the court, the opponent will receive a point (BWF, 2010:10). It is also considered to be a fault when the shuttle comes in contact with a player's racket but refuses to transit in the direction of the opponent's court (BWF, 2010:11). Similarly, when the shuttle is in play, it is a fault when a player touches, collides or embraces the net or its stands with the racket, clothing or with his/her body (BWF, 2010:11). It is also a fault when a player attacks an opponent's court under or over the net with the racket or if the opponent has been restricted, distracted, hindered or obstructed from executing a proper stroke (BWF, 2010:11).

A 'let' is called by an umpire or by a player (in cases where no umpire is officiating) to pause or suspend play in cases where a server serves in advance before the receiving player is ready, or while serving and both the server and receiver faulted (BWF, 2010:11). A 'let' will also be called if the shuttle hangs or dangles on the top of the net, or else, after crossing over the net, is caught or captured by the net (BWF, 2010:11). Furthermore, a 'let' will also be called if the shuttle breaks-up during a rally (BWF, 2010:11).

In badminton, play continues from the beginning of the first serve until the match is completed, though the badminton laws allow for the following resting periods: a 60-second resting interval during each game, when any of the players' scores reach 11 points (BWF, 2010:12). Furthermore, a recess interval of 120 seconds is allowed between the first and second game, and also between the second and third game (BWF, 2010:12).

3. EXTERNAL LOAD-DETERMINING MATCH-ANALYSIS METHODS

3.1 Introduction

The measurement of players' match-loads provides coaches and sport scientists with objective indicators that can be used for the management of training programs, which allows for greater precision and control of periodised conditioning plans along with a reduced incidence of overtraining (Kiely, 2012:244). Loads that players experience during match-play are categorized as being "external" if it is related to the work that players must perform to execute the different activities during a match (Impellizzeri *et al.*, 2005:583). Also, quantification of the physical

match stimulus separated from the internal response of players indicates the external load as for example indicated by match duration, distance travelled, running speed, and the number of body accelerations (Scott *et al.*, 2013a:195; Scott *et al.*, 2013b:270). In this regard, researchers quantify movements in sport to provide sport scientists and coaches with a better understanding of the external match-loads of sport participants. The application of match-analysis technology to gather, evaluate and analyse external match-load-related data statistically during and after badminton matches or training sessions, is a well-known method to provide valuable information to coaches (Carling *et al.*, 2009:72). Information may also enable coaches to recognize future opponents' tactics and strategies in order to gain a significant advantage by anticipating different playing patterns (Carling *et al.*, 2009:72). The collection of match-analysis data further allows the coach to accurately identify strengths and weaknesses of an individual or team (Hughes, 2008:71; Nevill *et al.*, 2008:419). Match-analysis information can also be used to improve players' specific programmes and training drills in such a manner that opponents' strengths are counterpoised and players' weaknesses improved (Lees, 2003:724; Carling *et al.*, 2009:72). Hence match-analysis data allow coaches to accurately assess different aspects of match-play so that informed judgements can be made on games or playing performance (Maslovat & Franks, 2008:3; Carling *et al.*, 2009:72). Furthermore, match-analysis data can assist a coach in eschewing a personal mind-set, bias and curtail the tendency of emotions, which may disfigure or distort his impressions of a match (Carling *et al.*, 2005:11; Maslovat & Franks, 2008:3; Carling *et al.*, 2009:72).

Match-analysis methods form a fundamental part of sports science and has advanced over the last few years due to technological progress (O'Donoghue, 2004b:184). In this regard, the use of computer and digital video technology during training sessions and competitions to gather data and implement match feedback have become more prominent in recent years at all elite levels of sport (Carling *et al.*, 2005:28; Hughes, 2008:81; Carling *et al.*, 2009:71). Innovations and modernisation in the field of technology provide coaches with accurate, objective, fast and relevant information, which allows them to anatomise, dissect and disjoin each and all aspects of a match (Carling *et al.*, 2009:71). The latest computerised systems simplify and facilitate the tactical, physical and technical analyses of individual and team performances and enhance the scientific advancement of sports (Lees, 2003:713; Carling *et al.*, 2009:71).

Match-analysis can be divided into two major types of analyses, namely: *notational analysis* and *motion analysis* (Carling *et al.*, 2005:2). *Notational analysis* depends on recordings of events so that accurate, objective and perpetual records of activities that had taken place during match-play

can be obtained (O'Donoghue, 2004b; Carling *et al.*, 2005:3; Hughes & Bartlett, 2008:9). *Motion analysis* pays attention to the raw features of a player's actions and movements for the period of the match without doing any qualitative assessment (O'Donoghue & Liddle, 2002:241; Carling *et al.*, 2005:4). Carling *et al.* (2009:86) also asserted that any notational analysis technique conducted in such a manner that the intensity of different movements is determined by means of the process of coding and classifying is known as *motion analysis*. Based on this assertion, it is sometimes difficult to distinguish between notational and motion analyses methods, as it depends on the methodology and equipment used for obtaining the data.

3.2 Modern-day tracking devices

3.2.1 Systems used for outdoor sport analysis

According to Perš *et al.* (2002:308), the future of computerized analysis in sport is electronic tracking systems that are more time efficient and accurate. Electronic tracking systems are faster in recording, capturing and analysing data, and more time efficient due to the fact that performance factors (movements and positions of every player) are recorded up to several hundred times per second (Carling *et al.*, 2005:42). Several additional advantages of electronic tracking systems can also be listed (Carling *et al.*, 2009:90):

- It allows for real-time recording, processing, and analyses that augment instant statistical information.
- It allows for accurate positional data capturing, delivering comprehensive information, which was never before available.

Currently there are only a few devices that have the capability of analysing all players' movements during an entire match (Carling *et al.*, 2009:87). These present-day tracking systems can be classified into video-based and electronic player tracking systems and hold the potential of being used in racket sports. The following is the list of some of these systems:

Video-based player-tracking systems:

- Feedback Sport, UK, Feedback Football, <http://www.feedbacksport.com/>
- Orad, Israel, CyberSet, <http://www.orad.co.il/>
- PGI, UK, DatatracX, <http://www.datatracx.tv/>
- ProZone Holdings Ltd, UK, ProZone, <http://www.pzfootball.co.uk/>
- Red Bee Media, UK, Piero, <http://www.redbeemedia.com/>
- Symah Vision, France, EPSIS Locator, <http://www.epsis.com/>

- Sport-Universal SA, France, AMISCO, <http://www.sport-universal.com/>
- Tracab, Sweden, Tracab, <http://www.tracab.com/>
- Trackmen, Germany, Trackmen, <http://www.trackmen.de/>

Electronic player tracking systems:

- Abatec Electronic GmbH, Austria, LPM, <http://www.abatec-ag.com/>
- Catapult Innovations, Australia, MinimaxX, <http://www.catapultinnovations.com/>
- Cairos Technologies AG, Germany, Cairos, <http://www.cairos/>
- GPSports, Australia, SPI Elite, <http://www.gpsports.com/>
- Trakus Inc, USA, Digital Sports Information, <http://www.trakus.com/>
- Manapps, France, Stadmaster, <http://www.manapps.tm.fr/>
- Sportstec, Australia, TrakPerformance, <http://www.sportstecinternational.com/>

An example of a video-based tracking system is the AMISCO Pro system that was introduced in 1996 by Sport-Universal Process in partnership with the French Football Federation. It is a player-tracking device used by international Rugby Union teams and top European football clubs (Carling *et al.*, 2009:88). The system samples data of players, the referee and the ball at 10 to 25 times per second (Di Salvo *et al.*, 2007:223; Carling *et al.*, 2009:87; Rey *et al.*, 2010:182). The system is proficient in gathering data of approximately 4.5 million diverse situations and over 2 000 divergent ball contacts during a regular soccer match (Di Salvo *et al.*, 2007:223; Rey *et al.*, 2010:182). The advantage of video-based tracking systems such as the AMISCO system is that they were all designed in such a manner that players do not have to be equipped or furnished with an electronic transmitter which may impede movements (Carling *et al.*, 2009:87). This advantage is also emphasised by the prohibition of most sporting federations or institutions against players carrying electronic devices during match-play (Di Salvo *et al.*, 2007:223; Carling *et al.*, 2009:87).

TRACAB is a system that allows coaches and other personnel to track the playing pitch by making use of powerful wireless network technology (ChyronHego, 2015). The TRACAB utilises advanced patented image processing technology to recognize the speed and position of all moving bodies within each connected pitch, at the rate of 25 times per second. The system is capable of generating live and highly accurate X, Y, and Z coordinates for all viewable bodies, which include players, officials and even the ball (ChyronHego, 2015). The output can deliver valuable insight for coaches and allow them to assess player performances and also track certain

metrics such as the distance run, team formations, speeds and more (Carling *et al.*, 2008:846). Furthermore, the TRACAB output can be used to enhance live television analysis of matches with “instant virtual replays” as well as to improve spectators’ experience through second screen presentations (ChyronHego, 2015).

Most video-based systems for tracking players involve the use of numerous cameras fixed and positioned to cover the entire field of play so that all positions can be captured on video (Carling *et al.*, 2009:89). The positions and number of cameras are determined by certain factors such as the size and layout of the playing area (Carling *et al.*, 2009:89). The field of play has to be calibrated according to height, length and width and converted into a two-dimensional model to permit the calculation of players’ positions (x and y coordinates) from the camera viewpoints. Subsequently, mathematical algorithms, complex trigonometry and digital video/image processing techniques are applied to estimate players’ positions and movements that were tracked during the match (Carling *et al.*, 2009:89). Systems may also utilize supportive information such as the colour and number on players’ jerseys, and optical-character recognition and prediction of players’ running patterns to ensure precise identification and recognition of players (Carling *et al.*, 2009:89). Some of these systems still necessitate manual intervention of a performance analyst. An example of this is when tracking is problematic in soccer during, for instance, set-pieces such as corner kicks due to constrictions from the high number of players in a small area (Carling *et al.*, 2009:89).

Currently, most systems that are used in sports such as elite soccer, (i.e. PROZONE AMISCO Pro) do not deliver real-time match data, and results will usually only be available within 24 hours after the match (Carling *et al.*, 2009:90). The time delay does bother some coaches (Carling *et al.*, 2009:90). However, the latest video-based tracking systems, such as the TRACAB and DatatraX can provide real-time analysis via new and improved video technology of image-processing techniques (Carling *et al.*, 2009:90). The DatatraX system utilizes pixel detection to track each player automatically and also voice detection to code match-specific events. In team sports such as soccer, three manual operators are needed to manage the process, two of which will be responsible for correction of real-time tracking mistakes for each of the teams and one operator to man the coding procedure for voice-recognition (Carling *et al.*, 2009:90). However, the procurement of live-match data will allow coaches to evaluate performances, and as a result, to make split-second tactical changes (Carling *et al.*, 2009:90).

3.2.2 Systems used for indoor sport analysis

Indoor sports tracking systems are those that are designed such that human motion that occurs inside a building such as a gymnasium can be captured (Carling *et al.*, 2008:846; Carling *et al.*, 2009:90). Automatic tracking and image processing capabilities are evolving rapidly, and its use in sport has been hindered due to insufficient video and computational facilities at most sporting venues (Barris & Button, 2008:1034). Most indoor sports at an elite level are typically made up of a number of skill-related movements such as sudden forward, backward and lateral foot movements (Abdullahi, 2011:81). These player movements are not easily determined by tracking systems that make use of computerised algorithms (Barris & Button, 2008:1034). Notational methodologies have to some extent addressed these issues through manual tracking by means of observational sheets for individual or single players for each recorded field (Perš & Kovacic, 2000b:282), but is not as sufficient and time effective as indoor tracking systems.

Segen and Pingali (1996:63) developed a stationary camera system that transforms recorded video footages of players' movements into spatio-temporal coordinates. Feature points can be identified in each single video frame and subsequently harmonised across frames to advance feature "paths" (Segen & Pingali, 1996:63). Trajectories comprise of temporal and spatial (horizontal and vertical) coordinates of players' continuous movements in real time (Segen & Pingali, 1996:63). A more advanced system was later designed as a computer vision system that tracks many players accurately in real time with minimum human operator involvement (Perš & Kovacic, 2000a:177; Perš & Kovacic, 2000b:281). The system also allowed for the context-specific analysis of spatial and temporal (spatio-temporal) trajectories of five players during a handball match (Perš & Kovacic, 2000a:179; Perš & Kovacic, 2000b:286).

Kristan *et al.* (2005:322) used the following methodology to examine interactions among multiple players during a handball match that was governed by certain rules and regulations: (a) A static camera was placed in a position that its optical axis was almost vertical or perpendicular to the floor; (b) The playground was bordered so that the model could be computed; (c) The lighting was non-uniform in space and time; (d) Players' textures were known at the start, and varied as the game progressed. The same researchers also made use of different methods that they called the "condensation-based approach" in which a single camera in an indoor court was used to track the movements of football players (Kristan *et al.*, 2005:322). Each individual player was automatically tracked and the sampling probability for the group of samples was considered to be a function of the fitness capacity of each player (Kristan *et al.*, 2005:325). The last-mentioned method allows practitioners and sport scientists to establish distances covered and

speeds obtained during match-play by players by using a single camera (Needham & Boyle, 2001:1).

Semi-automated modern tracking systems which use radio transmitters or satellites and receivers placed around the court to label or tag players can also be used to determine players' whereabouts on the court (Needham & Boyle, 2001:1). Lightweight microchip transmitters can be incorporated into players' jerseys (shirts) or else be worn in a harness-strap around the back (Carling *et al.*, 2009:91). Antennae are then placed around and outside the playing field at different heights for signal identification in a fraction of a second (Carling *et al.*, 2009:91). Henceforth, positional data of each player can be captured simultaneously, evaluated three-dimensionally hundreds of times per second and relayed to a central computer for processing and immediate analysis (Carling *et al.*, 2009:73).

The introduction of Global Positioning Systems (GPS) in the 1990s offered an alternative method for the measurements of time spent on movements as well as the average duration, frequency and speed of movements, with the potential of circumventing some of the shortcomings of notational analyses and minimize others (Townshend *et al.*, 2008:124). The GPS device worn by players in a harness during competition and training attracts signals from four earth-orbiting satellites to provide data with regard to players' positions and movement distances and pathways as well as velocities and altitude (Carling *et al.*, 2009:90). Data is stored automatically in the GPS device before being transferred onto a computer for further analysis by means of designated software (Carling *et al.*, 2009:91). However, some GPS devices also integrate multiple sensors (i.e. tri-axial accelerometer, magnetometer and gyroscope) that are usually worn on the upper back in the form of a sports vest (Gastin *et al.*, 2014:947; Wundersitz *et al.*, 2015:3976). These GPS devices are not dependant on satellite signals and can therefore be used in indoor settings. Nonetheless, the use of a tri-axial accelerometer, magnetometer, and gyroscope in a GPS device for analysing indoor sport matches is still a new phenomenon.

Accelerometers, gyroscopes and magnetometers are devices that allow researchers to monitor and describe movements as well as the intensity and frequency of these movements in various clinical and sports settings (Carling *et al.*, 2009:91). Tri-axial accelerometers are extremely responsive motion sensors that can be used to measure the magnitude and frequency of movement in 3D (medio-lateral, anterior-posterior and longitudinal) (Krasnoff *et al.*, 2008:527). Accelerometers allow researchers to sample at a higher rate and to monitor multiple players indoor (Schelling & Torres, 2016:586). On the other hand, gyroscopes are used to measure

angular rate which is how quickly an object turns measured in reference to one of three axes: yaw, pitch, or roll (Boyd *et al.*, 2011:312; Bergamini *et al.*, 2012:1125).

To date, several studies have utilized GPS in an indoor sport environment. For example, Abian *et al.* (2015:1042) used GPS-containing accelerometers to explore the effects of caffeinated energy drinks on the number of high-intensity accelerations and decelerations performed during an indoor badminton match. They revealed that the use of caffeine-containing energy drink may serve as an effective nutritional supplement to significantly increase players' jump performance and activity patterns during badminton play. Hoffman *et al.* (2012:3) used GPS-containing accelerometers to determine the effect of L-alanyl-L-glutamine on basketball performance in an indoor environment. The study concluded that rehydration with alanine-glutamine dipeptide acts more positively ($p < 0.05$) in the maintenance of basketball skill performance as well as of jump power, shooting accuracy and visual reaction time than water only. In another basketball-related study, Leite *et al.* (2013:216) examined the effects of fatigue and time-outs on physiological, time-motion indicators and spatial organization patterns of 20 min basketball games by using GPS-containing accelerometers in an indoor environment. The study concluded that fatigue and time-outs stimulate and enhance better patterns of spatial organization (Leite *et al.*, 2013:216). Similarly, results indicated that players covered a lower total distance at a slower rate as a result of accumulated fatigue (Leite *et al.*, 2013:216). Montgomery *et al.* (2010:77) used GPS-containing accelerometers to assess physical and physiological responses to basketball-specific drills and practice games. The study determined that accelerometers and predicted oxygen-cost from HR monitoring systems are useful for differentiating the practice and competition demands of basketball (Montgomery *et al.*, 2010:77). Physical and physiological attributes also suggested that live-play is considerably more demanding than a 5-on-5 game play (Montgomery *et al.*, 2010:77).

Several researchers have also investigated the validity, reliability and usefulness of accelerometer, magnetometer, and gyroscope-containing devices to measure different aspects of sport. For example, Gastin *et al.* (2013:589) concluded that accelerometers are valid instruments for determining physical activity levels during indoor basketball practices during which intensity changes constantly. Other researchers also revealed that MinimaxX accelerometers showed acceptable reliability ($<2\%$) for measuring Australian Football players' external workloads and that these accelerometers were capable of detecting differences in physical activity levels (Coe & Pivarnik, 2001:375). Cormack *et al.* (2013:288) found that a Catapult-Sports unit that included a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer, could be used to

differentiate between netball match demands of lower and higher levels of play. Similarly, Chandler *et al.* (2014:2735) concluded that the last-mentioned unit allows researchers to determine the metabolic match demands of collegiate netball.

Therefore in summary, by players both single and multiple object tracking systems can determine players' movements during match-play. However, while the APAS system uses players' centre of mass to give precise data of players' accelerations and also considers movements of the extremities, the multi-object system delivers more global data by presenting acceleration and changes in direction on a larger scale. Overall, the above-mentioned results also suggest that the combined use of a tri-axial accelerometer, magnetometer and gyroscope in a GPS device should provide accurate results with regard to movement data, and the external demands of sport activities. GPS units such as the Catapult-Sports unit can also function in "indoor mode" without depending on satellite signals for data collection (Catapult-sports, 2012a:101). These units also make use of the Catapult Sprint 5.0.9.2 software (Catapult Sports, Victoria, Australia) through advanced Kalman filtering techniques (Catapult-sports, 2012b:13) to analyse the raw data obtained from tri-axial accelerometers, magnetometers and gyroscopes.

3.2.3 Limitations of tracking systems

It is of paramount importance that the methods used in all match-analysis processes need to conform to strict scientific quality-control specifications, which include accuracy, reliability, validity and consistency of results (Drust *et al.*, 2007:788). Thus far, measurement accuracy, validity, objectivity and reliability of several commercial tracking systems have not been determined via independent empirical analyses (Carling *et al.*, 2008:846). Therefore more scientific studies should focus on the accuracy, validity, consistency and reliability of these systems so that practitioners and the academic community can be ensured of accurate and relevant data when using these systems for research purposes (Carling *et al.*, 2009:90). To date, several studies have reported on the validity and reliability of systems used for indoor sport analysis, and will be discussed in the next section.

Perš *et al.* (2002:296 & 305) examined their system's accuracy and validated the capability of their tracking system to analyse player movements during a handball match. Researchers examined the system's accuracy by considering: (i) the consequence of "jitter" (an irregular movement of stationary players) on output trajectories; (ii) the effect of filtering on the accurateness of player positioning; (iii) the effect of filtering on calculated player velocity and (iv) relationships between results of a multi-object and a manual single-object, 3-D tracking

system (Ariel Performance Analysis System (APAS)) (Perš *et al.*, 2001:26; Perš *et al.*, 2002:306). During the study, five players had to initially stand still in different positions on the court after which they performed 180 s of physical activities (Kristan *et al.*, 2005:322). Trajectory smoothing significantly reduced errors in both distance covered and player velocity (Perš *et al.*, 2002:307), but did not have a significant impact on player positional errors (Perš *et al.*, 2002:307; Vuckovic *et al.*, 2005:335). The second experiment revealed that heavy smoothing obscured rapid changes in player trajectories (Perš *et al.*, 2002:307; Kristan *et al.*, 2005:323). The act of smoothing led to average errors of 0.07-0.35 m/sec for player velocity when the value was calculated via the length of the player's circular trajectory and the period utilised to accomplish a single path (Perš *et al.*, 2002:307). A 0.36 m error in position was recorded when players were required to run around three fixed markers (cones) in one corner of the court in a 3.4-second (25-Hz) video sequence (Perš *et al.*, 2002:307).

Perš *et al.* (2002:308) enhanced their tracking system by means of Kalman filtering and by preventing it from switching between players, and subsequently decreased the mean error to 1.16 m (an error of ≤ 0.5 m was considered adequate for hand-tracked data). In another study, Needham and Boyle (2001:6) determined the accuracy of an automated tracking system using a multiple object condensation-based approach by comparing a sequence of manually determined trajectories to the automatically determined trajectories and found a mean difference of 2.5 m. Edgecomb and Norton (2006:26) found that the following aspects gave rise to errors when they evaluated the validity of their automated indoor tracking system: movements of players' extremities, operator mistakes, videotape noise, imperfect camera calibration and quantization errors. The use of a 2-D medium resulted in errors due to the fact that positional variations in extremity or vertical movements are not accounted for (Perš *et al.*, 2001:26). Quantization errors are the consequence of radial distortions on input images, which are predominantly prevalent at boundary regions (Perš *et al.*, 2001:26; Perš *et al.*, 2002:305).

Boyd *et al.* (2011:312) used Catapult GPS units with integrated accelerometers to determine the between-device reliability in Australian Football players that completed a three-hour indoor exercise session (playing volleyball). They revealed acceptable (below 1.5% at the 90% confidence interval (CI)) between-device reliability values for these units (Boyd *et al.*, 2011:319). Researchers therefore concluded that the Minimax GPS (MinimaxX 2.0, Catapult, Australia) unit functions efficiently in indoor halls and can be used to accurately quantify training loads, quantify work-rates and compare individual players with one another (Boyd *et al.*, 2011:312; Chandler *et al.*, 2014:2733). Duffield *et al.* (2010:524) assessed the accuracy and

reliability of GPS measures (distance and speed) by comparing data between a high-resolution motion analysis system (VICON) and GPS units (MinimaxX, Team Sport Model, Catapult, Australia and SPI elite, GPSports, Australia). Inter-unit coefficients of variation (CV) for distance covered ranged between 4% for slower movement speeds, up to 30% for faster movement speeds (Duffield *et al.*, 2010:524). Moreover, GPS devices underestimated the distance covered, particularly at higher speeds and during repeated movement patterns in confined spaces (Duffield *et al.*, 2010:524). They therefore asserted that; where possible, the same GPS device should be used for the same player throughout a match or activity in order to avoid inter-unit error (Duffield *et al.*, 2010:524). Furthermore, they concluded that researchers and practitioners that use this technology should account for the underestimation of distances covered at higher movement speeds (Duffield *et al.*, 2010:524).

3.3 Notational analysis

Notational analysis is the process during which recordings are made so that data can be collected in an efficient and effective manner in order to analyse complex and dynamic match situations (James, 2006:186; O'Donoghue, 2008:181). Purposes of notational analysis are to evaluate tactical and technical aspects of performance, to analyse movements, coach and educate players as well as model performance by using match-analysis databases (Hughes, 2003:211). Notational analysis allows a scientist to classify actions that had occurred during a match (Hohmann *et al.*, 2004:267) so that a justifiable statistical explanation of match situations can be compiled and the value of feedback increased (Carling *et al.*, 2009:71). Sports scientists in general use notational analysis systems to interpret fundamental queries about match-play and performances in all sporting activities (Pradas *et al.*, 2010:181). Notational analysis also allows researchers and practitioners to assess the physiological and psychological demands of a sport (Carling *et al.*, 2009:71). James (2006:197) points out that the level at which notational analysis is growing in elite sport compels sport scientists to equip themselves adequately with knowledge in the field for better advancement of sport performances.

Researchers have used different procedures to carry out notational analysis – from simple observations with written notes to more complex systems that consist of video recording apparatuses and computers (Blomqvist *et al.*, 1998:137). Sanderson and Way (1977:188) first developed a hand notation method for sequential stroke analysis in squash by using illustrative symbols to analyse 17 different strokes and court plans to gather accurate positional information. This method was later modified by Sanderson (1983:20) and used to identify winning and losing patterns in squash match-play. Hughes *et al.* (1989:219) introduced computerized movement

tracking to squash, entering player position data with a digitising pad and using custom-designed software to calculate distances travelled as well as velocity and acceleration time series. A more sophisticated notational system was developed by Hughes and Clarke (1995:272) for studying the effect of court surface on elite tennis strategies. Players' court positions, the time taken per shot and the type of events were recorded using a graphical user-interface to analyse video recordings after the event. This analysis provided both temporal and positional information as well as frequency distribution of shots and rally-ending conditions (Hughes & Clarke, 1995:275). Hong *et al.* (1996:18) used a notational analysis method to study game strategies of 12 of the world's top-ranked male squash players. Participants were filmed using a 3-CDD video camera. The aim of the study was to provide players with a competition strategy profile and to make suggestions whereby players could improve their playing strategies (Hong *et al.*, 1996:18).

The next section will deal with notational analysis studies that focussed on badminton as a sport.

3.3.1 Notational analysis variables of badminton match-play

Badminton match performance analysts usually focus on the time duration of different match activities, positions on the court and types of strokes and foot movements executed (Ming *et al.*, 2008:218; Abian-Vicen *et al.*, 2013:311; Phomsoupha & Laffaye, 2015:474). In this regard, researchers have identified the following badminton strokes during match-play through notational analysis:

- *Clear*: An overhead stroke with a flat (offensive clear) or rising trajectory (defensive clear) towards the back of the opponent's court (Abian-Vicen *et al.*, 2013:313).
- *Drive*: An attacking stroke in which the shuttle is hit fast so that the opponent barely has time to react, and is usually played from near the right and left side lines, in about the middle between the net and the back of the court (Brahms, 2014:55). Abian-Vicen *et al.* (2013:313) further described the stroke as a powerful stroke executed in the middle of the court with a flat trajectory.
- *Drop*: A smooth stroke from above the head with a downward trajectory towards the front of the court (Abian-Vicen *et al.*, 2013:313).
- *Serve*: The act of putting the shuttle into play. Service strokes are further categorized into 'short' - shuttle is served low over the net, landing close to the front of the service line – and 'deep' serves – shuttle is served high, and hit to the back of the court (Chen *et al.*, 2011:9).
- *Smash*: A hard-hitting or aggressive overhead stroke with a downward trajectory (Abian-Vicen *et al.*, 2013:313).

- *Net-stroke*: An accurate stroke from near the net, which comprises the net-drop or the lob – it is an offensive shot with a flat trajectory towards the back of the opponent's court or a defensive shot with a rising trajectory (Abian-Vicen *et al.*, 2013:313).

The different badminton foot movements identified through notational match-analysis are as follows:

- *Chasse step*: This movement usually occurs when a player steps on one foot to the side, followed closely by the other foot. One foot leads the movements while the other foot comes in behind the leading foot as the change in position takes place (Hopley, 2016).
- *Scissors kick*: Also known as “scissors jump”. It is often used as the last movement when hitting overhead forehands, in which legs swap position while in the air. It is a technique by means of which the player hits the shuttle as he jumps explosively backwards, which saves the player a lot of time, and allows him/her to immediately run forward to reach the shuttle again (Brahms, 2014:76).
- *Shuffle step* (sometimes called hitches or hops): This type of foot movement is often used when moving forwards or backwards towards the backhand side. For example, when a player wants to reach a shuttle at the net on the forehand side the non-dominant leg will move forward and across to the forehand side with the body facing the corner of the court. It is a fast, short movement along the ground (Hopley, 2016).
- *Split-step*: This is a very low jump, in which the feet come off the ground and spread a little apart, while the player is bending forwards before pushing off towards the target (Leitch, 2013).
- *Lunging*: This is a sudden forward or sideways thrust of the body, usually with an outstretched arm (Brahms, 2014:60).

Time-related (temporal) variables that have also been evaluated by means of notational analyses are as follows:

- *Match duration*: The time that elapses from the first service until the shuttle touches the floor on the last point, which includes rest times between points and games (Chen & Chen, 2008:36; Chen *et al.*, 2011:14; Abian-Vicen *et al.*, 2013:312).
- *Real time played*: The period during which the shuttle is in play, from the first to the last point of the match (Chen & Chen, 2008:36; Abian-Vicen *et al.*, 2013:312).
- *Percentage of real time played*: The real time played multiplied by 100 and divided by match duration (Chen & Chen, 2008:36; Abian-Vicen *et al.*, 2013:312).

- *Rally time*: Periods from when the service is executed, until the shuttle touches the ground at the end of each point (Chen & Chen, 2008:36; Abian-Vicen *et al.*, 2013:312).
- *Rest time*: Periods that elapse from when the shuttle touches the ground until the next service is executed (Chen & Chen, 2008:36; Abian-Vicen *et al.*, 2013:312).
- *Work density*: The rally time divided by rest time (Chen *et al.*, 2011:9; Abian-Vicen *et al.*, 2013:312). It is also described as the ratio of performance time to rest time (Manrique & Gonzalez-Badillo, 2003:63; Chen & Chen, 2008:36).

Researchers have also identified the following notational analysis-related variables:

- *Total points played*: The total number (frequency) of points played by both players (Abian-Vicen *et al.*, 2013:312).
- *Strokes per rally*: The total number (frequency) of strokes played per rally counted from when one player has served until the shuttle has touched the ground (Abian-Vicen *et al.*, 2013:312).
- *Stroke frequency*: The number of strokes divided by real time played (Abian-Vicen *et al.*, 2013:312), or the number of strokes per rally time indicated as strokes per second (Chen *et al.*, 2011:9).

3.3.2 Notational analysis results of badminton match-play

Notational match-analysis results obtained from different studies are summarised in tables (Tables 1 to 4). Table 1 depicts results of time-related (temporal) variables that have been reported in scientific literature.

Table 1: Results of match duration-related variables determined from male badminton singles matches

Authors	Variable	Participants	N	Average values
Abián <i>et al.</i> (2014) ^{RM} [^]	Match duration (s)	OG*	40	1124.6 ± 229.9 s
		OG**	40	1260.3 ± 267.1 s
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	2378.0 ± 387.9 s
Cabello <i>et al.</i> (2004) ^{RM} [^]		TN	79	2090 ± 921 s
Chen and Chen (2008) SM [^]		I	16	1949.7 ± 147.6 s
Chen and Chen (2008) SM X		I	16	2754.6 ± 178.9 s
Chen <i>et al.</i> (2011) SM X		I	10	2520 ± 600 s
Chen <i>et al.</i> (2011) SM [^]		I	10	1740 ± 180 s
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]		I	11	1689.33 ± 312.89 s
Ming <i>et al.</i> (2008) ^{RM} [^]		YN	16	1047 ± 187 s
Ming <i>et al.</i> (2008) ^{RM} ☐ X		YN	16	1446 ± 158 s
Abián <i>et al.</i> (2014) ^{RM} [^]		OG*	40	9.0 ± 1.1 s
	Rally time (s)	OG**	40	10.4 ± 2.1 s
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	Set 1: 9.0 ± 0.9 s Set 2: 9.1 ± 1.4 s
Cabello <i>et al.</i> (2004) ^{RM} [^]		TN	79	7.3 ± 1.3 s
Chen and Chen (2008) SM [^]		I	16	8.2 ± 0.2 s
Chen and Chen (2008) SM X		I	16	7.9 ± 0.2 s
Chen <i>et al.</i> (2011) SM [^]		I	10	6.0 ± 0.6 s
Chen <i>et al.</i> (2011) SM X		I	10	6.2 ± 1.0 s
Faude <i>et al.</i> (2007) ^{RM} [^]		I	12	5.5 ± 4.0 s
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]		I	11	6.4 ± 1.25 s
Ming <i>et al.</i> (2008) ^{RM} [^]		YN	16	4.62 ± 0.86 s
Ming <i>et al.</i> (2008) ^{RM} X		YN	16	4.63 ± 0.49 s
Abián <i>et al.</i> (2014) ^{RM} [^]	Rest time (s)	OG*	40	24.7 ± 4.3 s
		OG**	40	26.7 ± 4.6 s
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	Set 1: 24.1 ± 3.8 s Set 2: 25.2 ± 4.6 s
Cabello <i>et al.</i> (2004) ^{RM} [^]		TN	79	14.2 ± 3.4 s
Faude <i>et al.</i> (2007) SM [^]		I	12	11.4 ± 6.0 s
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]		I	11	12.93 ± 2.68 s
Ming <i>et al.</i> (2008) ^{RM} [^]		YN	16	9.71 ± 1.32 s
Ming <i>et al.</i> (2008) ^{RM} X		YN	16	10.29 ± 1.42 s

SM = Simulated match, RM = Real match, **X** = Old scoring system (scoring-by-service of 15 points per game), [^] = New scoring system, I = International players, OG = Olympic Games participants (* = 2008 Olympic Games, ** = 2012 Olympic Games), YN = Young national players, TN = Top national players

a. Match durations

Abián *et al.* (2014:46) compared the notational structures amongst elite male singles players during games between the Olympic Games in Beijing and those in London in order to investigate

how badminton had advanced from 2008 to 2012. Twenty (20) games of each of the last-mentioned Olympic Games were analysed by means of video footage. Match durations were found to be 1124.6 ± 229.9 s and 1260.3 ± 267.1 s for the Beijing and London Olympic Games respectively. Abián *et al.* (2014:45) further asserted that game duration increased significantly ($p < 0.05$) from the Beijing to the London Olympic Games. Abian-Vicen *et al.* (2013:312) also compared the notational and temporal structures of games and matches for world top-level, singles, male badminton players. Official videos of ten (10) matches played during the 2008 Beijing, Olympic Games were analysed. Average match duration of 2378.0 ± 387.9 s was found for this analysis (Abian-Vicen *et al.*, 2013:313).

Cabello *et al.* (2004:5) conducted a study on temporal and physiological characteristics of a large sample of 32 top male Spanish national players and found an average match duration of 2090 ± 921 s. Chen and Chen (2008:36) compared effects of the new and old scoring systems on the match durations of national tournaments. They reported an average match duration of 1949.7 ± 147.6 s and 2754.6 ± 178.9 s for new and old scoring systems respectively (Chen & Chen, 2008:38). The average match durations for 15 elite men's singles badminton matches were between 1680 s and 2880 s and were significantly longer ($p < 0.05$) under the old scoring system compared to those of the new system (Chen & Chen, 2008:40). In another study Chen *et al.* (2011:7) obtained match duration values of 2520 ± 600 s and 1740 ± 180 s for the old and new scoring systems respectively when the matches of ten (10) elite male badminton players that had at least 10 years' badminton experience were analysed.

Manrique and Gonzalez-Badillo (2003:63) analysed twelve competitive badminton matches of ten male players from four different countries (France, Italy, Portugal and Spain) that played according to the new scoring system. The average match duration was found to be 1689.33 ± 312.89 s (Manrique & Gonzalez-Badillo, 2003:63). Another study compared the new and old scoring system through simulated matches of male singles state-level badminton players ($n = 8$) and reported match duration values of 1047 ± 187 s and 1446 ± 158 s for the old and new scoring systems respectively (Ming *et al.*, 2008:219). However, no significant difference was found between the values of the two scoring systems (Ming *et al.*, 2008:220).

Obtained match duration values seem to differ from one study to the next. For example, Abian-Vicen *et al.* (2013:313) obtained a much higher average value (2378.0 ± 387.9 s) in the one study than another study (1124.6 ± 229.9 s and 1260.3 ± 267 s) (Abián *et al.*, 2014:45) which may, amongst other things, be attributed to differences in the number of matches analysed (40 vs.

10 matches). Overall, match duration results suggest that matches played under the old scoring system delivered higher values (2520 ± 600 s and 2754.6 ± 178.9 s) than those played under the new scoring system (Ming *et al.*, 2008:220; Chen *et al.*, 2011:16).

b. Rally time

Abián *et al.* (2014:46) obtained significantly different rally time values (9.0 ± 1.1 s; $p < 0.05$) for the Beijing Olympic Games from the London Olympic Games values (10.4 ± 2.1 s). Similarly, ten (10) matches from the official videos of the Beijing 2008 Olympic Games revealed rally time values of 9.0 ± 0.9 s for the first and 9.1 ± 1.4 s for the second set respectively (Abian-Vicen *et al.*, 2013:313). Analyses of the Spanish male national players ($n = 31$) recorded an average rally time of 7.3 ± 1.3 s (Cabello *et al.*, 2004:5). An analysis of matches played under the old and new scoring systems showed that the average rally time was longer when the new (8.2 ± 0.2 s) scoring system was used during matches than when the old scoring system (7.9 ± 0.2 s) was used (Chen & Chen, 2008:36). However, only the second and third games of matches recorded significant differences ($p < 0.05$) in average rally times between the new (8.7 ± 0.3 s and 9.7 ± 0.3 s) and old (7.9 ± 0.1 s and 8.4 ± 0.4 s) scoring systems respectively (Chen & Chen, 2008:38). Non-significant different average rally time values of 4.63 ± 0.49 s and 4.62 ± 0.86 s were obtained for the old and new scoring systems respectively in a study performed by Ming *et al.* (2008:219). The study did, however, make use of simulated matches to compare the new and old scoring systems in male singles state-level badminton players (Ming *et al.*, 2008:217). A more recent study (Chen *et al.*, 2011:7) found higher non-significant different average rally time values of 6.2 ± 1.0 s and 6.0 ± 0.6 s for matches played by elite male badminton players under the old and new scoring systems respectively. Another study that utilised simulated badminton singles matches reported an average rally time value of 5.5 ± 4.0 s (Faude *et al.*, 2007:481).

Manrique and Gonzalez-Badillo (2003:63) reported an average rally time of 6.4 ± 1.25 s for competitive matches played under the new scoring system. Rally times ranged between 4.57 s and 8.86 s (Manrique & Gonzalez-Badillo, 2003:64). A high significant correlation ($r = 0.87$, $p < 0.001$) achieved between rally time and rest time verifies the assumption that the longer the duration of points, the longer the time interval required for recovery during matches (Manrique & Gonzalez-Badillo, 2003:65).

c. Rest time

Faude *et al.* (2007:481) utilised badminton singles simulated matches to reveal an average rest time of 11.4 ± 6.0 s. Abian-Vicen *et al.* (2013:312) studied the temporal and notational structures

of men singles games and matches that took place during the 2008 Beijing Olympic Games and reported average rest time values of 24.1 ± 3.8 s and 25.2 ± 4.6 s for the first and second games respectively. In another study, Abián *et al.* (2014:46) revealed average rest time values of 24.7 ± 4.3 s and 26.7 ± 4.6 s for matches played during the 2008 and 2012 Olympic Games respectively. Average rest times between rallies did not deliver any significant differences between matches of the last-mentioned Olympic Games (Abián *et al.*, 2014:46). Average rest time value of 14.2 ± 3.4 s was observed by Cabello *et al.* (2004:5) when they analysed matches of Spanish national male players ($n = 31$). A further analysis also showed that a significant difference ($p < 0.05$) existed when matches played by players of different playing levels were analysed. A significant correlation ($r = 0.42$, $p < 0.01$) between average rest time and number of rallies played also suggests that rest time increases as the volume and frequency of rallies during a match increase (Cabello *et al.*, 2004:7). Significant correlations were also found between rest time and average work time ($r = 0.67$; $p < 0.01$) as well as between rest time and rally time ($r = 0.87$, $p < 0.001$), supporting the assumption that an increase in work and rally time during a match will lead to a corresponding increase in rest time (Cabello *et al.*, 2004:7).

Players in the study of Manrique and Gonzalez-Badillo (2003:63) revealed an average rest time of 12.93 ± 2.68 s, with values that ranged between 9.20 s and 18.70 s when matches were played under the new scoring system. Non-significant different rest time values of 9.71 ± 1.32 s and 10.29 ± 1.42 s were also obtained for simulated singles badminton matches that played under the new and old scoring systems respectively (Ming *et al.*, 2008:219).

Table 2 presents results of notational analysis-related studies that examined stroke frequency, strokes per rally and work density of badminton male singles matches.

Table 2: Results of shots frequency, shots per rally and work density determined from male badminton singles matches

Authors	Variable	Participants	N	Average values
Abián <i>et al.</i> (2014) ^{RM} [^]	Shot frequency	OG [*]	40	1.09 ± 0.03 s ⁻¹
		OG ^{**}	40	1.07 ± 0.04 s ⁻¹
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	Set 1: 1.08 ± 0.04 s ⁻¹ Set 2: 1.09 ± 0.03 s ⁻¹
Chen and Chen (2008) SM [^]		I	16	1.05 ± 0.02 s ⁻¹
Chen and Chen (2008) SM X		I	16	0.98 ± 0.01 s ⁻¹
Chen <i>et al.</i> (2011) SM [^]		I	10	1.03 ± 0.07 s ⁻¹
Chen <i>et al.</i> (2011) SM X		I	10	1.05 ± 0.08 s ⁻¹
Faude <i>et al.</i> (2007) SM [^]		I	12	0.92 ± 0.31 s ⁻¹
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]		I	11	0.93 ± 0.11 s ⁻¹
Ming <i>et al.</i> (2008) ^{RM} [^]	Shots per rally	YN	16	1.03 ± 0.22 s ⁻¹
Ming <i>et al.</i> (2008) ^{RM} ☐ X		YN	16	1.03 ± 0.47 s ⁻¹
Abián <i>et al.</i> (2014) ^{RM} [^]		OG [*]	40	9.8 ± 1.1
		OG ^{**}	40	11.1 ± 2.2
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	Set 1: 9.7 ± 0.8 Set 2: 9.9 ± 1.4
Chen and Chen (2008) SM [^]		I	16	8.4 ± 0.2
Chen and Chen (2008) SM X		I	16	7.5 ± 0.1
Chen <i>et al.</i> (2011) SM [^]		I	10	5.9 ± 0.8
Chen <i>et al.</i> (2011) SM X		I	10	6.0 ± 1.2
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]	Work density	I	11	6.0 ± 1.2
Ming <i>et al.</i> (2008) ^{RM} [^]		YN	16	4.74 ± 0.78
Ming <i>et al.</i> (2008) ^{RM} ☐ X		YN	16	4.77 ± 0.47
Abián <i>et al.</i> (2014) ^{RM} [^]		OG [*]	40	0.37 ± 0.05
		OG ^{**}	40	0.39 ± 0.05
Abian-Vicen <i>et al.</i> (2013) ^{RM} [^]		OG	20	Set 1: 0.38 ± 0.06 Set 2: 0.36 ± 0.04
Cabello <i>et al.</i> (2004) ^{RM} [^]		TN	79	0.53 ± 0.12
Chen <i>et al.</i> (2011) SM [^]		I	10	0.57 ± 0.06
Chen <i>et al.</i> (2011) SM X		I	10	0.63 ± 0.11
Faude <i>et al.</i> (2007) SM [^]	Work density	I	12	0.51 ± 0.34
Manrique and Gonzalez-Badillo (2003) ^{RM} [^]		I	11	0.49 ± 0.06
Ming <i>et al.</i> (2008) ^{RM} [^]		YN	16	0.46 ± 0.07
Ming <i>et al.</i> (2008) ^{RM} ☐ X		YN	16	0.48 ± 0.07

SM = Simulated match, ^{RM} = Real match, **X** = Old Scoring (scoring-by-service of 15 points per game), [^] = New Scoring system, I = International players, OG = Olympic Games participants (* = 2008 Olympic Games, ** = 2012 Olympic Games), YN = Young national players, TN = Top national players

d. Stroke frequency

Faude *et al.* (2007:481) exploited simulated badminton matches to obtain an average stroke frequency value of $0.92 \pm 0.31 \text{ s}^{-1}$. Matches of the 2008 Beijing Olympic Games revealed stroke frequency values of $1.08 \pm 0.04 \text{ s}^{-1}$ and $1.09 \pm 0.03 \text{ s}^{-1}$ for the first and second games of matches respectively (Abian-Vicen *et al.*, 2013:314). Abián *et al.* (2014:46) also reported stroke frequency values of $1.09 \pm 0.03 \text{ s}^{-1}$ for the 2008 Olympic Games and $1.07 \pm 0.04 \text{ s}^{-1}$ for the 2012 Olympic Games. No significant differences ($p > 0.05$) were found when stroke frequencies of each of the last-mentioned competitions were compared (Abián *et al.*, 2014:46)

Chen and Chen (2008:36) used notational analysis to classify the type and frequencies of strokes played during male singles matches under the new and old scoring systems. Average stroke frequency was found to be lower under the new than under the old scoring system for the first game ($0.97 \pm 0.01 \text{ s}^{-1}$ vs. $1.08 \pm 0.03 \text{ s}^{-1}$), third game ($1.01 \pm 0.01 \text{ s}^{-1}$ vs. $1.08 \pm 0.02 \text{ s}^{-1}$) and for the overall match ($0.98 \pm 0.01 \text{ s}^{-1}$ vs. $1.05 \pm 0.02 \text{ s}^{-1}$). However, no significant difference existed in shot frequency for rallies performed under the new or old systems of scoring (Chen & Chen, 2008:38). In another study, Chen *et al.* (2011:7) noted average stroke frequencies of $1.03 \pm 0.07 \text{ s}^{-1}$ and $1.05 \pm 0.08 \text{ s}^{-1}$ for elite male badminton matches played under the new and old scoring systems respectively. Ming *et al.* (2008:219) compared the effects of the new and old scoring systems using simulated male singles badminton matches and obtained stroke frequencies of $1.03 \pm 0.22 \text{ s}^{-1}$ and $1.03 \pm 0.47 \text{ s}^{-1}$ respectively (Ming *et al.*, 2008:219). On the other hand, singles matches played under the 3 sets, 15-points system delivered an average stroke frequency of $0.93 \pm 0.11 \text{ s}^{-1}$ (Manrique & Gonzalez-Badillo, 2003:63). These researchers also revealed that a high correlation ($r = 0.75$, $p < 0.007$) between work output and stroke frequency would suggest that player effort increases as stroke frequency increases (Manrique & Gonzalez-Badillo, 2003:65).

e. Strokes per rally

Notational analysis of the world's top singles badminton players during the 1996 Hong Kong Badminton Open revealed an average stroke per rally value of 7.37 (Tong & Hong, 2000:190). Male singles matches of the Beijing 2008 Olympic Games revealed strokes per rally values of 9.7 ± 0.8 and 9.9 ± 1.4 for the first and second games respectively (Abian-Vicen *et al.*, 2013:314). In another study, Abián *et al.* (2014:46) assessed how badminton progressed from 2008 to 2012 by analysing the Olympic Games and found that strokes per rally increased significantly ($p < 0.05$) from 9.8 ± 1.1 in 2008 to 11.1 ± 2.2 in 2012. They further concluded that lengthier rallies, a shortened stroke time, together with an increased number of strokes per rally

led to a more competitive 2012 Olympic Games compared to the Olympic Games of 2008 (Abián *et al.*, 2014:46). They attributed these changes in match characteristics to better racket technology, enhanced training methods and an improvement in the physical and mental health of players (Abián *et al.*, 2014:46).

In an earlier study, Chen and Chen (2008:36) employed notational analysis to categorize the type and frequencies of different strokes played under the new and old scoring systems during elite, male singles badminton tournaments. Strokes per rally were found to be statistically more ($p < 0.05$) under the new compared to the old scoring system (new: 8.4 ± 0.2 ; old: 7.5 ± 0.01). The increase in strokes per rally suggests that matches played under the new scoring system were more competitive than those played under the old scoring system (Chen & Chen, 2008:41). However, statistical non-significant different strokes per rally values of 4.74 ± 0.78 and 4.77 ± 0.47 were obtained by Ming *et al.* (2008:219) for the new and old scoring systems respectively. The study used simulated matches to examine and compare the time-motion and notational analysis variables of new and old scoring systems in eight male singles' state-level badminton players (Ming *et al.*, 2008:217). However, a more recent study by Chen *et al.* (2011:7) opposed the notion that strokes per rally are more when the new compared to the old scoring system is used. They noted that the average strokes per rally values decreased non-significantly ($p = 0.79$) from 6.0 ± 1.2 to 5.9 ± 0.8 when the new compared to the old scoring system was used (Chen *et al.*, 2011:12). However, the sum of rally strokes (service excluded) under the new scoring system (1040) was less than under the old scoring system (1532) (Chen *et al.*, 2011:11). A similar average strokes per rally value (6.0 ± 1.2) was found in an older study of Manrique and Gonzalez-Badillo (2003:63) when matches played under the new scoring system were analysed.

f. Types and effectiveness of strokes played

Table 3 presents the percentage distribution results of a study that made use of notational analysis to determine the effectiveness of six strokes and their position of placement within the playing court (Tong & Hong, 2000:188).

Table 3: Percentage distribution results of the effectiveness of six strokes played to different areas of the court (Tong & Hong, 2000:188)

Fore-court	Mid-court	Rear-court	Entire court
E: 74.99 ± 5.18	E: 64.73 ± 8.19	E: 69.80 ± 7.80	E: 70.34 ± 4.82
IE: 10.95 ± 4.8	IE: 14.62 ± 6.04	IE: 16.94 ± 6.75	IE: 14.02 ± 4.69
UW: 4.51 ± 2.08	UW: 9.02 ± 2.77	UW: 4.63 ± 2.92	UW: 5.76 ± 1.91
CW: 0.07±0.24	CW: 0.24±0.52	CW: 0.10±0.38	CW: 0.13±0.20
FF: 2.29±1.30	FF: 6.41±2.23	FF: 0.19±0.36	FF: 2.82±0.76
UF: 7.18±3.01	UF: 4.98±3.48	UF: 8.33 ± 3.99	UF: 6.92 ± 2.75

E = Effective, IE = Ineffective, UW = Unconditional Winner, CW = Conditional Winner, FF = Forced Failure, UF = Unforced Failure

Tong and Hong (2000:185) analysed matches played during the 1996 Hong Kong Badminton Open, and found that players preferred the low serve as an offensive strategy, and a high number of strokes were returned to the forecourt area (Tong & Hong, 2000:190). Furthermore, the most common strokes were the lob, smash, net and clear (Tong & Hong, 2000:190). The study pointed out that the most effective strokes were found to be returns to the fore-court, while the most ineffective strokes were returns from the rear-court. The study also found that of all returns, 51.94% were played from the backhand side, revealing that offensive players preferred to return more shots to the opponent's backhand side (left forecourt, left mid and left rear court for the right-handed players); thus putting pressure on the opponent's backhand. The study further revealed that among the six court-areas, returns from the left rear court had the highest "ineffective" rate, indicating that even at high-level competition the backhand performed in the rear court tends to be the weakest developed of all strokes (Tong & Hong, 2000:187).

The earlier-mentioned researchers also used notational analysis to determine the percentage effectiveness of the primary badminton strokes during a match. Table 4 presents these results.

Table 4: The percentage effectiveness of the primary badminton strokes performed during a match (Tong & Hong, 2000:188)

Shot	Effective	Ineffective
Block	82.20 ± 8.01	7.80 ± 8.01
Clear	74.57 ± 28.21	25.43 ± 28.21
Drive	82.90 ± 28.55	17.10 ± 28.55
Drop	91.12 ± 12.95	8.88 ± 12.95
Hit	59.26 ± 46.17	40.74 ± 46.17
Lob	69.18 ± 23.19	30.82 ± 23.19
Net	95.79 ± 24.88	4.21 ± 24.88
Push	78.83 ± 33.99	21.17 ± 33.99
Smash	77.87 ± 17.99	22.13 ± 17.99
Clear	74.57 ± 28.21	25.43 ± 28.21

Table 4 indicates that the net shot had the highest effectiveness percentage, as a good net return earned points. A good net block will force the opponent to lift the shuttle, which will most probably compel the opponent to lob, thereby providing a good opportunity for a smash, which was found to be the topmost killing shot (Tong & Hong, 2000:187). In most cases, when a player executed an “ineffective” net return, the opponent gained an opportunity to smash the shuttle down at the fore-court. Likewise, the underhand drop or the block shot was considered to be the second most “effective” shot (Tong & Hong, 2000:187). The shot is typically used to return a smash shot from an opponent, which is commonly executed from the opponent’s mid-court or rear court. By playing the block shot to make a net return, the opponent is forced to make a long-distance move from either the mid- or rear-court to play, which puts the opponent in an off-balance situation and causes him to expend substantial energy in the process (Tong & Hong, 2000:187). The drop-shot was ranked as the third most effective shot. It is mostly executed from the mid- or rear-court, with the intention of striking the shuttle softly to the opponent’s fore-court in a downward trajectory (Tong & Hong, 2000:188). The return of a perfect drop-shot requires the efficient utilisation of tricky or deceptive shots to create a situation that is to players’ advantage. For example, faking a smash when the shuttle is high in the mid- or rear-court would leave the opponent in a defensive stance, which makes swift and speedy movements to the fore- or rear-court difficult (Tong & Hong, 2000:188). Therefore the offensive player has the options of either playing an attacking drop or attacking clear stroke to force a weaker return (Downey, 1982:121).

The study also compared straight and cross-court strokes and revealed that 66.81% of returns were straight strokes while only 33.19% were determined to be cross-court strokes. Breen and Paup (1983, cited by Tong & Hong, 2000:188) noted that one of the most important aspects in

the tactics of single badminton play is players' ability to manipulate the flight direction of a shuttle. For example, the best return for straight strokes is a cross-court stroke as a change in the shuttle's direction will force the opponent to run further, and the cross-court stroke is more difficult to return. However, when the cross-court clear is not played deep or high enough, the opponent can resort to an easy smash (Tong & Hong, 2000:188). The simplest error-free shot to play is the straight return of the shuttle, and allows a player to obtain a better position for subsequent strokes. The study further indicated that $84.16 \pm 10.33\%$ of straight-court strokes were "effective" compared to $81.19 \pm 12.02\%$ of cross-court strokes, which suggests that most high-level single badminton players prefer the more risk-free strokes as they execute more straight strokes instead of the higher-risk cross-court strokes (Tong & Hong, 2000:188).

Table 5 presents results of notational analysis-related studies that examined different types of strokes performed during competitive badminton male singles matches.

Table 5: Percentage distribution of different types of strokes performed during competitive badminton male singles matches

Authors	Subj./N	Smash	Clear	Drop	Drive	Net
Abián <i>et al.</i> (2014)*	OG/20*	29.09 ± 8.43	NI	2.31 ± 1.74	NI	16.03 ± 6.6
	OG/20**	27.84 ± 8.14	NI	3.92 ± 4.31	NI	13.32 ± 5.4
Abian-Vicen <i>et al.</i> (2013)	OG/20	29.1 ± 8.4	12.1	3.8 ± 3.5	6.3 ± 3.9	NS
Lee <i>et al.</i> (2005)	I/20	14.2	12.1	13.2	NI	20.7
Ming <i>et al.</i> (2008)	YN/16	13	16	13	NI	17
	YN/16 ✕	14	14	13	NI	17
Tong and Hong (2000)	I/11	14	13	16	15	17

NOTE: All matches were real matches that made use of the new scoring system (with the exception where ✕ is indicated), ✕= old scoring system (scoring-by-service of 15 points per game), I= International players, OG= Olympic Games participants, YN= Young national players, TN= Top national players, *= 2008 Olympic Games, **= 2012 Olympic Games, NI= Not indicated.

Lee *et al.* (2005:387) analysed ten male singles badminton matches from different championships, which also included the Olympic Games of 2004. The following strokes were performed for the indicated percentages: smash (14.2%), clear (12.1%), drop (13.2%) and net strokes (20.7%). They also pointed out that the most frequently utilized strokes by male singles badminton players were the net, smash and drop strokes (Lee *et al.*, 2005:388). Abián *et al.* (2014:46) compared the percentage of strokes performed during the 2008 and 2012 Olympic Games and found the following average percentages for the named strokes: smash - $29.09 \pm 8.43\%$ and $27.84 \pm 8.14\%$ were compared; drop - $2.31 \pm 1.74\%$ and $3.92 \pm 4.31\%$ respectively; net strokes - $16.03 \pm 6.6\%$ and $13.32 \pm 5.4\%$ respectively. Despite differences in the percentage

of strokes performed during the mentioned Olympic Games, none of the differences were significant (Abián *et al.*, 2014:45). However, they concluded that the smash stroke was the most frequently and regularly used stroke at the end of most rallies (Abián *et al.*, 2014:45). Analysed videos of the 2008 Beijing Olympic Games revealed that the afore-mentioned strokes were performed at the following percentages: smash ($29.1 \pm 8.4\%$), drop ($3.8 \pm 3.5\%$) and drive strokes ($6.3 \pm 3.9\%$) (Abian-Vicen *et al.*, 2013:312).

Ming *et al.* (2008:217) investigated and compared the notational and time-motion determined variables of the new and old scoring systems among male badminton singles state-level players ($n=8$) by using simulated matches. Percentages of stroke distributions were reported as follows: smash (13% vs. 14%), clear (16% vs. 14%), drop (13% vs. 13%) and net stroke (17% vs. 17%) for the new and old scoring system respectively (Ming *et al.*, 2008:219). The study further pointed out that the clear, drop and net strokes were among the most frequently used during male singles match-play (Ming *et al.*, 2008:221).

Lastly, O'Donoghue (2008:189) determined and examined inter-rally times, rally lengths and strokes played during badminton matches and reported that rallies during which the most number of strokes were played, were shorter in duration than rallies during which a lower number of strokes were played.

g. Work density

The temporal structure of a competitive badminton match is established by the total work time, total playing time and particularly, the work density (Cabello *et al.*, 2004:1). The 2008 Beijing Olympic Games delivered work density values of 0.38 ± 0.06 and 0.36 ± 0.04 for the first and second games respectively (Abian-Vicen *et al.*, 2013:314). In another study, Abián *et al.* (2014:46) determined the work density values for the 2008 and 2012 Olympic Games to be 0.37 ± 0.05 and 0.39 ± 0.05 respectively. No significant differences were found between the last-mentioned values (Abián *et al.*, 2014:46). Faude *et al.* (2007:481) determined the average work density to be 0.51 ± 0.34 when simulated badminton matches of four male participants were analysed. Cabello *et al.* (2004:5) found an average work density value of 0.53 ± 0.12 for matches of top male Spanish national players ($n = 31$). However, a correlation between match duration and work density revealed a significant negative value ($r = -0.430$; $p = 0.001$), which indicates that match duration has a significantly negative effect on work density (Cabello *et al.*, 2004:8).

Chen *et al.* (2011:7) reported average work density values of 0.57 ± 0.06 and 0.63 ± 0.11 for the new and old scoring systems respectively when elite male badminton players' matches were analysed. Overall results revealed that the average work density of matches played under the new scoring system was significantly smaller ($p = 0.041$) than the average work density of those played under the old scoring system (Chen *et al.*, 2011:15). In another study, which compared the new and old scoring systems, work density values of 0.48 ± 0.07 and 0.46 ± 0.07 were attained respectively, for male participants (Ming *et al.*, 2008:219). The study used a simulated match to examine and compare the notational and time-motion determined variables of scoring systems among male badminton singles state-level players ($n=8$) (Ming *et al.*, 2008:217). The study showed no significant differences between the new and old scoring system values in terms of work density (Ming *et al.*, 2008:220). Participants in a study of Manrique and Gonzalez-Badillo (2003:63) that played under the new scoring system, showed an average work density value of 0.49 ± 0.06 during competitive matches. They also noted that work density is an indicator of player effort during competitive matches (Manrique & Gonzalez-Badillo, 2003:63).

Over the last few years, various types of notational match analyses have been used to describe the demands and requirements of male badminton singles matches. In the subsequent section, each of these methods will be explained briefly.

3.3.3 Different types of notational match-analysis methods

a. Hand-based notational match-analysis

Occasionally simple notational systems that give attention to a small number of actions that are very important is of greater value than the ones that produce large amounts of data (Carling *et al.*, 2009:72). In this regard, manual hand-based notational analysis systems can easily be designed to provide answers to questions posed by coaches and sport scientists (most especially at the grassroots levels of the game) (Carling *et al.*, 2009:72). Coaches usually choose the information that is useful based on their personal philosophy, past experience or players' previous performances (Franks *et al.*, 1983; Carling *et al.*, 2009:73). It is a wise idea to analyse performances at a general level, before concentrating on any specific aspects of the game (Carling *et al.*, 2009:73).

Manual hand-based notational analysis systems are inexpensive as they may only need a tally sheet, a pen and paper or basic word-processing or graphics software packages such as Microsoft Excel to record match actions, and can easily be adapted to meet the requirements of coaches and/or sport scientists (Carling *et al.*, 2009:72). On the other hand, these systems give more

attention to technical and tactical features of performance (Carling *et al.*, 2009:73). Graphical court illustrations are usually used for more precise information with regard to players' positions on the court (Carling *et al.*, 2009:73). Action time can also be recorded as the precise period (time) at which the action occurs or action frequencies can be determined by counting the actions for separate segments (e.g. every 5 min for a badminton match) (Carling *et al.*, 2009:73). More complex analysis systems will probably require measurements of the events sequence and time (Carling *et al.*, 2009:73).

Hand-based notational systems comprise four basic stages. Stage 1 is determining the amount and kind of information required and the reason for the specific required information; stage 2 is designing the system (hand-based notational system); stage 3 is examining the accuracy and correctness of the data and stage 4 is collecting and presenting results of findings (Carling *et al.*, 2009:73).

b. Video-based motion analysis

Those methods applied for estimating physical performance and/or work rates and that involve the subjective evaluation of ranges or distances and exercise bouts recorded on an audiotape recorder or done manually are considered to be video-based motion analyses (Vučković *et al.*, 2004:245). According to Carling *et al.* (2009:87), video-based motion analysis is all about establishing certain player features or characteristics according to certain distinctive exercise intensities. The data are then translated into movement distances or velocities. Reilly (2003:60) also recommended that coded narrations or commentaries of matches on audiotape by a skilled observer should be used alongside video recordings.

As mentioned earlier, video-based tracking devices generally necessitate the installation of several cameras which are placed such that the entire court and all players are covered at all times (Carling *et al.*, 2009:87; Harley *et al.*, 2011:2334). The number and positioning of cameras are dependent on, amongst other things, the proportions and layout of the court area (Carling *et al.*, 2009:89). The dimensions (height, width, length) of the hall (venue) and court area of play are used to set up a two-dimensional model which enables the computation of players' locations and positions in the form of x and y coordinates (Liebermann *et al.*, 2002:761). Complex mathematical algorithms and digital video/image processing or extracting procedures enable analysts to track each player's position and movements during every single moment of the game (Liebermann *et al.*, 2002:766; Carling *et al.*, 2005:7; Edgecomb & Norton, 2006:27; Carling *et al.*, 2009:89). Systems may also allow analysts to obtain supportive data such as

optical-character recognition and individual movement characteristics (Carling *et al.*, 2009:89). An example of a video-based system is the SAGIT, a squash computer-tracking software system, which uses a single video camera with a wide-angle lens which can be fixed on a gantry above the court, with the view of the entire court (Racz *et al.*, 2013:194). After background subtraction, algorithms extract each player from the image of the court, and an approximation of their position on the floor plane is tracked in each video frame (Vuckovic *et al.*, 2005:335).

c. Time-motion analysis

According to Carling *et al.* (2005:4), time-motion analysis focuses on raw features of an individual's activities and movements during a match without an attempt to qualitatively evaluate any aspect of the match. They further categorized the following as part of time-motion analysis: work-rate as indicated by the distance covered in a game; the intensity of effort as sprinting and cruising (running sub-maximally with obvious purpose and effort), jogging, walking and assuming a stationary posture; jumps, moving side- and backwards, making angled runs and the ratio of high-intensity to low-intensity exercises (Carling *et al.*, 2005:6). Reilly (2007:20) defined time-motion analysis as the technique used in coding and classifying match activities by employing notational techniques that, amongst other things, categorise the intensities of different movements. The intensities of activities over the course of a competition are determined by translating the acquired data into velocities or distances covered during movement execution or time expended in various movement activities (O'Donoghue, 2004b:189). Time-motion analysis analyses movements over certain time periods during competition participation in order to examine players' activity levels to better understand the physiological and physical requirements of a given sport (O'Donoghue, 2008:181). Carling *et al.* (2009:86) point out that 'information with regard to rally and recovery times in between rallies provide researchers with information regarding the requirements of racket sports at various levels of competition. Rally and inter-point periods are also used to calculate the work to rest ratios of racket sports such as badminton, squash and table tennis (O'Donoghue, 2004a:208). However, researchers must realize that rally duration on its own is not an absolute indicator of work output during rallies (O'Donoghue, 2008:186).

d. Computerized notational analysis

Computerized match-analysis can decrease the potential work load in analysing matches and also give the desired information that can be kept in databases together with related video footage (Carling *et al.*, 2009:72). However, computerized systems that are used to do these analyses are costly and only remain an option for bigger clubs at the elite levels of different sports (Carling *et*

al., 2009:72). Nonetheless, there has been a call to utilize more technological advanced notational analysis techniques when analysing racket sports such as badminton so that more precise and objective results of real-time and post-event analyses can be provided (O'Donoghue & Ingram, 2001:111). The need to apply computerized techniques to study badminton has also previously been recognized by other researchers (Liddle *et al.*, 1996:159). In the analysis method Liddle *et al.* (1996:162) used, results were obtained by using grids to estimate the distance travelled by players during notational analysis. Data was used for post-match video analysis, and was reliable to determine distances covered by players. These distances were established by entering the route or path travelled against a court diagram and by pausing the videotape at each instance where a player had changed direction (Liddle *et al.*, 1996:162). Other researchers also used a line that was drawn to depict the current trajectory or phase of each movement (Edgecomb & Norton, 2006:26). A ruler can also be used to measure the path travelled on a court diagram set up according to scale (O'Donoghue, 2008:189).

Although the above-mentioned notational analysis systems are useful for understanding the demands and requirements of male badminton singles matches, certain limitations of these systems need to be considered when interpreting results.

3.3.4 Limitations of different types of notational match-analysis

One of the primary limitations of notational match-analysis is that the data may not be reliable enough to draw accurate conclusions concerning the demands of match-play (Carling *et al.*, 2009:87). For example, shuffling is usually categorised as a high-intensity movement, but can also be performed at low speeds, which can influence the energy cost of the movement in such a way that it should rather be categorised as a low-intensity movement (Blomqvist *et al.*, 1998:137). A further limitation of notational match-analysis is that it can be very time consuming when each player has to be monitored for the duration of an entire match over a period of several matches (Hong *et al.*, 1996:22). Furthermore, researchers showed that notational match analyses were only moderate to poorly reliable to analyse total time spent on individual movements, the average duration of individual movements and the frequency of individual movements (Duthie *et al.*, 2003:260). However, Duthie *et al.* (2003:983) proved that notational match-analysis was valid and reliable to assess playing duration, player position and position type, amount and distances of strokes, but not as reliable to determine the types of strokes executed. In another racket sport-related notational analysis study a satisfactory error of 1.85% was found when squash-related strokes were categorised according to the outcome of each stroke (effective or ineffective) (O'Donoghue, 2008:198).

The major limitations of adopting the manual performance analysis method are the apparent difficulty and the noteworthy investment of time required to code and analyse data, as well as interpret findings (James, 2006 cited by Carling *et al.*, 2009:75). Hand-notational analysis systems are often unified and used with videocassette analogue recordings of match performances, and the combination of these two methods for gathering data is very time-consuming, wearisome and tedious (Carling *et al.*, 2009:75). Researchers need to do manual searches by rewinding and fast-forwarding videocassettes before the data can be analysed (Carling *et al.*, 2009:75). Furthermore, archiving data is problematic as records are occasionally written on paper sheets (Carling *et al.*, 2009:75). Some of the notational analysis' data collection methods are also prone to inaccuracies, particularly when positional information is recorded (Carling *et al.*, 2009:75). The fundamental problem notational analysts face is to decide on the best way to transform an ocean of data into meaningful and expressive interpretations (Hughes & Franks, 2004:259).

Another limitation of notational analysis procedures is that analysts are not able to do analyses in real time due to visual errors as a result of gait changes or inconsistencies in game movements and the fact that only one player can be analysed at a time (Drust *et al.*, 2007:789; Carling *et al.*, 2008:841). A reduction in the analysis of activities to only one player at a time does not allow an analyst to determine and evaluate relationships between concomitant work:rate ratio profiles of partners or opposing players (Carling *et al.*, 2009:87). Furthermore, it does not allow the analyst to gain a thorough understanding of work-rate (Drust *et al.*, 2007:788).

The above-mentioned limitations of notational analysis as a means to determine the external match-loads of sport participants have given rise to a renewed focus on other match-load-determining methods. In view of this, the next section will deal with HR analysis as a means of determining the internal match-loads of sport participants.

4. INTERNAL LOAD-RELATED MATCH-ANALYSIS METHODS

4.1 Introduction

Player load is categorised as being internal when measurements are taken to determine the physiological responses of players when they perform different activities during match-play (Impellizzeri *et al.*, 2005:586). The internal load signifies the physiological stress encountered by players in response to the match or training stimulus (Scott *et al.*, 2013a:195; Scott *et al.*, 2013b:270). In this regard, HR monitoring is one of the most common and effective methods researchers use for determining the internal load of sport participants during match-play as it is

an easy and inexpensive method to use (Cabello-Manrique & Gonzalez-Badillo, 2003:63; Halson, 2014:140).

4.2 Heart rate monitoring in badminton

The basis on which HR monitoring during sport or exercise participation rests is the established linear relation between HR and oxygen consumption ($\dot{V}O_{2max}$) during exercise (Hopkins, 1991:162; Liddle *et al.*, 1996:162). According to Cabello-Manrique and Gonzalez-Badillo (2003:64), maximum HR (HR_{max}) values during badminton match-play range between 186 and 201 bpm, which are very close to each player's real HR_{max} and average values between 162 and 187 bpm. The same researchers also reported that players' average HR in relationship to their HR_{max} increased with more than 3% as matches progressed. A literature review of Phomsoupha and Laffaye (2015:481) which focused on the game characteristics, anthropometry, physiology, visual attributes and biomechanics of badminton reported a HR_{max} value of 191 bpm for male badminton players. The average match HR values for different levels of male badminton players ranged between 198.7 bpm (juniors), 194.0 bpm (sub-elite) and 188.0 bpm (elite) (Phomsoupha & Laffaye, 2015:481). Other researchers that have analysed the HR of badminton players revealed average match HR of between 166 and 188 bpm, while HR_{max} of between 191 and 195 bpm have been observed during normal and simulated badminton matches (Cabello-Manrique & Gonzalez-Badillo, 2003:63; Wonisch *et al.*, 2003:116). Researchers also observed average match HR for male badminton singles players of over 90% of the HR_{max} (Docherty, 1982:98; Majumdar *et al.*, 1997:343; Cabello-Manrique *et al.*, 2004:8; Faude *et al.*, 2007:484; Chen *et al.*, 2011:15).

The percentage of HR_{max} values is used for both prescription and monitoring of exercise intensity (Borresen & Lambert, 2008:781). In this regard, players' HR can be categorized into low (60 – 69%), medium (70 – 79%) and high ($\geq 80\%$) intensity zones based on each player's HR_{max} , and in addition to this the amount of time spent in each of the HR zones can be determined (Liddle *et al.*, 1996:167; Pearce, 2002:52; Chen *et al.*, 2011:8).

4.3 Limitations of using heart rate monitoring

Despite the popularity of using HR to determine the internal load of sport participants during match-play, HR can be influenced by several factors that are not related to players' fitness levels. Factors such as the condition of the court, the temperature, humidity (weather), dehydration and emotional stress may lead to estimation errors with regard to players' internal match-load

(Esposito *et al.*, 2004:167; Alexandre *et al.*, 2012:2901). For example, the demands of badminton match-play such as the high levels of concentration needed may lead to high stress levels, causing epinephrine (adrenaline) secretion of the suprarenal gland to increase (Cabello-Manrique & Gonzalez-Badillo, 2003:65). This may cause HR to accelerate over and above that which is provoked by actual effort (Cabello-Manrique & Gonzalez-Badillo, 2003:65). Consequently these factors need to be monitored closely when using HR to describe the internal match-loads of players. Similarly, HR shows a delayed response to sudden high intensity movements, which may lead to an underestimation of match-loads and intensities (Jeukendrup & Diemen, 1998:91). Furthermore, HR usually takes some time to return to pre-activity levels, which means that intensity or loads will be overestimated during match-play due to HR inflation (Coe & Pivarnik, 2001:373). In view of these shortcomings, with regard to the use of HR as an internal load-determining method, and the need for more accurate and up-to-date match-load profiles, it is important to quantify both internal and external match-load measures and assess relationships between them (Scott *et al.*, 2013b:271).

In view of this statement, studies that have investigated relationships between internal and external load-determining methods will be discussed in the next section.

5. RELATIONSHIPS BETWEEN RESULTS OF INTERNAL AND EXTERNAL LOAD-DETERMINING METHODS IN SPORT

The majority of studies that investigated relationships between results of internal and external load-determining methods used team sports participants as study participants. For example, Scanlan *et al.* (2014:2402) determined relationships between internal and external training load models of basketball and observed moderately significant ($p < 0.05$) relationships between external training load (as determined from accelerometer data), players' session rating of perceived exertion (sRPE) ($r = 0.49$) and training impulse (TRIMP = Duration (minute) $\times$ $(\text{HR}_{\text{exercise}} - \text{HR}_{\text{rest}})/(\text{HR}_{\text{exercise}} - \text{HR}_{\text{rest}}) \times (0.64 \times 2.712^{192 \times (\text{HR}_{\text{exercise}} - \text{HR}_{\text{rest}})/(\text{HR}_{\text{exercise}} - \text{HR}_{\text{rest}})})$) ($r = 0.38$). Furthermore, a large significant correlation was found between external training load and the summated-heart-rate-zones model ($\text{SHRZ} = (\text{duration in HR zone 1} \times 1) + (\text{duration in HR zone 2} \times 2) + (\text{duration in HR zone 3} \times 3) + (\text{duration in HR zone 4} \times 4) + (\text{duration in HR zone 5} \times 5)$) ($r = 0.61$) (Scanlan *et al.*, 2014:2403). Another study revealed that physical measures of total distance, the volume and time spent in low-speed activities as well as high- and very-high-speed running, and player load (as obtained from GPS and accelerometer data) correlated significantly ($r = 0.40\text{--}0.84$; $p < 0.01$) with HR- (TRIMP) and sRPE-based values across 97 individual, in-season, field-based training sessions in soccer players (Scott *et*

al., 2013a:199). A study on Australian football showed significant correlations ($p < 0.05$) between external training load (GPS-determined distance, high-speed running and player load) and both the sRPE 10-point (CR10) ($r = 0.81, 0.71$, and 0.83) and 100-point scale (CR100) ($r = 0.78, 0.69$, and 0.80) for 38 training sessions.

The above-mentioned findings indicate that measures of external and internal match-loads are related in team sport participants, but it is not clear whether similar relationships will be observed in racket sport participants. The assessment of the commonality of popularized internal load-determining measures with externally derived measures of the match stimulus may provide insight into the construct validity of internal load-determining models for racquet sport such as badminton (Scott *et al.*, 2013b:271).

6. CONCLUSIONS AND RECOMMENDATIONS

The objectives of the literature review were firstly, to present the history and a detailed description of badminton as a sport; secondly, to describe the various badminton match-analysis methods that resort under the broad categories of external and internal match-load-determining methods respectively as well as to present results of research that has used each of these methods to analyse badminton; thirdly, to investigate the limitations of current match analysis methods in order to make recommendations to address these limitations; and fourthly, to discuss research that has investigated relationships between results of internal and external load-determining methods in sport.

The game of badminton was invented more or less 2000 years ago and came from the game called battledore, in which two players hit a feathered shuttlecock back and forth with a bat without allowing it to touch the ground. In the year 1873 the Duke of Beaufort introduced the version of the game called 'Poona', which he saw in India, to his guests at his country place called "Badminton" in Gloucestershire. During that time the game had no name, but it was referred to as "The Game of Badminton" and, thereupon, Badminton became its official name. The standard rules of the game were developed in England. The most common form of the game is singles (with one player per side) during which players strike the shuttle with a racket with the purpose of landing it within the opposing side's half of the court to score points. Each side may only strike the shuttle once before it passes over the net. Play ends once the shuttle has struck the floor or when the umpire or service judge has called a fault. The shuttle is feathered or in informal matches, a plastic projectile, which flies differently from the balls used in many other racket sports.

Badminton match-analysis methods were discussed under two categories, namely those that allow researchers to measure the external match-loads and those that allow researchers to measure the internal match-loads of badminton players. Loads that players experiences during match-play that are related to the work that they must perform to execute different activities during a match are categorised as external loads. Literature reveals that external match-loads can be assessed by making use of semi-automated video tracking, manual video tracking and global positioning system (GPS) technology. However, modern-day tracking devices are considered to be the future of computerized analysis in sport due to their time efficiency, accurate data capturing and delivery, real-time recording and instant statistical information processing capabilities. Systems can also be classified into video-based and electronic player tracking systems, which can be used to analyse competitive racket sports.

Systems used for indoor sport analysis include wearable tracking devices (e.g. MinimaxX GPS) that integrate multiple sensors (tri-axial accelerometer, gyroscope and magnetometer) into a single device. Accelerometers, gyroscopes, and magnetometers are devices that allow researchers to monitor and describe players' movements, frequency, and intensity of movements during matches in indoor facilities. In this regard, research showed that the combination of accelerometers, gyroscopes, and magnetometers in a GPS device provides accurate results with regard to movement data and the external demands of sport activities, irrespective of the environment. Acceptable between-device reliability values were also obtained when Catapult GPS units with integrated accelerometers were used in an indoor-sport setting. Similarly, MinimaxX GPS units were efficient to quantify training loads and work-rates and to compare individual players' performances in an indoor hall. However, a comparison in measures of distance and speed between MinimaxX GPS units and a high-resolution motion analysis system (VICON) revealed that GPS units underestimated distances covered, especially at higher speeds and during repeated movement patterns. Despite these findings, researchers regard GPS units to be an alternative method for the measurements of time spent on movements as well as the average duration, frequency and speed of movements, with the potential of circumventing some of the shortcomings of notational analyses and minimizing others.

Notational analysis is the method by means of which recordings are made so that data can be collected in an efficient and effective manner in order to analyse complex and dynamic match situations. Notational analysis can be classified into hand-based notational match-analysis, video-based motion analysis, time-motion analysis, and computerised notational analysis

methods. In badminton, notational analysis is used to determine match durations, rally time, rest time, stroke frequency, strokes per rally, types of strokes played, and work density, amongst others. In this regard, studies that utilised notational analysis to analyse the last-mentioned variables of male badminton singles matches have indicated the following: average match durations vary between 1047 s and 2754.6 s; average rally time between 4.62 s and 10.4 s; average in-between points rest time between 9.71 s and 25.2 s. Results of average match stroke frequency varied between 0.92 s^{-1} and 1.09 s^{-1} whereas strokes per rally varied between 4.74 and 11.1. Work density values of between 0.36 and 0.63 were reported in general for badminton matches. The percentage distribution of the mentioned strokes during badminton matches was reported to be as follows: the smash (13 - 29.1%), the clear (12.1 - 16%), the drop (2.31 - 16.0%), the net stroke (13.32 - 20.7%), and the drive (6.3 - 15%).

Literature further pointed out that the clear, drop and net strokes were among the most popular performed strokes in male singles match-play. Additionally, literature revealed that male singles players preferred to use the low serve as an offensive strategy, and most of their strokes were returned to the forecourt area. The most effective strokes were returns to the fore-court, and the most ineffective strokes were returns from the rear-court. Returns from the left rear court had the most “ineffective” rate compared to the other areas of the playing court, which is an indication that the backhand performed in the rear court tends to be the weakest stroke among high-level badminton players.

In 2006, the scoring system of badminton was changed from the traditional 3 games of 15 points (i.e., scoring-by-service) system to the new 3 games of 21 points (i.e., rally-point scoring) system for all disciplines. To date, only two studies have compared the effects of the old and new scoring systems on male badminton singles match characteristics by using notational analysis (Chen & Chen, 2008; Ming *et al.*, 2008). The following results were found for the mentioned variables by each of the research groups: average match durations of $2754 \pm 178.9\text{ s}$ vs. $1949.7 \pm 147.6\text{ s}$ and $1443.6 \pm 142.8\text{ s}$ vs. 1036.2 ± 160.2 ; average rest time of $10.29 \pm 1.42\text{ s}$ vs. $9.71 \pm 1.32\text{ s}$; shot frequency of $0.98 \pm 0.01\text{ s}^{-1}$ vs. $1.05 \pm 0.02\text{ s}^{-1}$ and $1.03 \pm 0.47\text{ s}^{-1}$ vs. $1.03 \pm 0.22\text{ s}^{-1}$ for the old and new scoring systems respectively. Some of the variables obtained significantly higher values for the old compared to the new scoring system. However, researchers postulated that the shorter playing time under the new scoring system would lead to changes in tactical strategies applied during match-play. This, in turn, would result in higher physiological demands (i.e., exercise intensity) of singles matches.

Unfortunately, video-based system analysis holds certain limitations that need to be considered when interpreting match-analysis results. Numerous cameras have to be fixed, positioned and also calibrated according to the width, height and length of the screened area. Furthermore, video-tape noise, imperfect camera calibration and quantization errors as well as operator mistakes can negatively influence analysis results. Some systems also require extra information such as players' jersey colours and numbers as well as a prediction of players' running patterns. Most systems also do not provide real time match data as it usually takes results about 24 hours to process. One of the major limitations of semi-automated and manual video analysis systems is that these systems only focus on the external match-loads of players. Researchers will only obtain reliable and accurate information with regard to the match-loads of players if these methods are combined with methods that are used to measure the internal match-loads of players, such as the HR monitoring method. Similarly, notational match-analysis data may not be reliable enough to draw conclusions regarding match-play characteristics and profile. Researchers also regard this method to be moderately to poorly reliable in determining total time spent, average duration, and frequency of individual players' movements and the types of strokes executed. Yet another limitation is that only one player can be analysed at a time, which does not allow for the determination of relationships between work rates of partners or opposing players.

Player load is categorised as being internal when measurements are taken to establish the physiological responses players experience when they perform different activities during match-play. HR monitoring is one of the most common and efficient methods researchers use to determine the internal load of sport participants during match-play, due to the linear relation between HR and oxygen consumption ($\dot{V}O_{2max}$) during exercise. It is also an easy and inexpensive method for determining the internal match-loads of badminton players. Research suggests that average badminton match HR_{max} values range between 186 and 201 bpm, and the average HR values between 162 and 187 bpm. In relationship to HR_{max} players' average HR increases with more than 3% as matches progress. According to literature, HR can be categorized into low- (60 – 69%), medium- (70 – 79%) and high- ($\geq 80\%$) intensity zones based on each player's HR_{max} . However, despite the acceptance and use of HR as an internal load-determining parameter, certain limitations linked to using this parameter need to be considered. For example, factors such as court and weather conditions as well as hydration status and stress may lead to HR changes that are not related to external match demands alone. Furthermore, HR may occasionally show a delayed response when players perform movements or cease to perform movements, which may lead to an under- or overestimation of internal match-loads.

Based on these limitations with regard to the use of HR as an internal load-determining method, and the need for more comprehensive match-load profiles, it is essential to quantify both internal and external match-load measures and assess relationships between these two measures.

Overall, literature suggests that significant relationships ($r = 0.69\text{--}0.85$, $p = 0.001$) do exist between sRPE- and HR-based training-load models in indoor-related sports such as basketball. Similarly, researchers found moderate significant relationships between basketball players' external accelerometer-determined training load, sRPE ($r = 0.49$, $p < 0.05$) and TRIMP ($r = 0.38$, $p < 0.05$). A large significant correlation was also established between external training load and the SHRZ model ($r = 0.61$) in the same group of basketball players. Significant correlations ($r = 0.71\text{--}0.84$; $p < 0.05$) were also observed between accelerometer-determined physical measures, HR- and sRPE-based values among soccer players. Although these findings indicate that measures of external and internal match-loads are related in team sport participants, no studies have investigated the possible relationship between the external and internal match-load measures in racket sport participants such as badminton players.

In summary, this review showed that almost all available literature focussed on notational analysis (external load-determining method) to describe the match profiles of male badminton singles players. This, despite the fact that available wearable tracking device technology such as the MinimaxX that integrates multiple sensors (e.g. triaxial accelerometer, magnetometer and gyroscope) into a single unit may provide badminton researchers with an alternative, more time efficient and accurate method for determining the match characteristics of players. Furthermore, although HR monitoring methods are deemed to be the most accepted methods for determining the internal load of badminton matches, only a few researchers have attempted to study badminton players' HR profiles during match-play.

However, the above-mentioned findings suggest that practitioners should incorporate different methods that will allow them to simultaneously obtain both internal and external match-loads of badminton players in order to compile a more accurate and reliable match-play profile. On the other hand, a match profile alone will not give researchers an indication of the match profile characteristics that are related to badminton performance. Hence there is a need to identify match-analysis characteristics that discriminate between different levels (successful and less successful) of badminton players. Discriminating match-analysis characteristics may enable coaches and sport scientists to identify and develop these characteristics with a view to enable players to perform successfully. Another aspect on which researchers do not focus is the possible

relationships between specific notational singles match-analysis components. Relationships between match-analysis components such as strokes and foot movements may provide researchers and practitioners with important information regarding the influence of different strokes on players' foot movements or vice versa. Researchers and practitioners will then be able to focus their attention directly on the most important and influencing components that need to be addressed during physical and skills training.

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CHAPTER 3

Notational Singles Match-Analysis of Male Badminton Players who Participated in the African Badminton Championships



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Abstract

Purposes of this study were firstly, to determine the notational singles match-analysis results of male badminton players and secondly, to determine relationships between notational singles match analysis-determined strokes and foot movements in male badminton players that participated in the African Badminton Championships. Twenty male singles matches from the team and individual events of the 2014 All Africa Badminton Championships were recorded live via video cameras and analysed using the Dartfish video analysis software package. Average match duration (1470.4 s), real time (432.9 s) and percentage of real time played (29.8%), number of rallies per match (68.4) and shots per rally (6.5) were calculated. Average shots per rally were found to be 6.5 and the work density, 0.4. Average stroke frequency per match, was: drive - 122.1, clear - 118, smash - 56.2, net strokes - 54.3, drop-shot - 24.2 and the round-the-head stroke - 1.2. Foot movements provided the following average results per match: chasse-step - 174.6, shuffle- 161.7, split-step - 61.6, half-lunge - 52.20, forward-lunge - 46.1 and scissors kick - 38.3. Significant Spearman Rank Correlation Coefficients were found to exist between various foot movements and strokes. The study confirmed the applicability of computerised-notational analyses in determining singles badminton match characteristics.

Keywords: badminton, foot movements, notational analysis, strokes.

1. Introduction

Badminton is one of the major racket sports (Lees, 2003), characterised by high-speed movements and shot executions which demand high tactical, technical, and psychological abilities as well as a high level of physical conditioning (Omosegaard, 1996). However, researchers and sport practitioners are only able to determine the exact demands of badminton matches if they precisely analyse the different match movements and movement patterns (Hughes, 2008). In this regard, computerised-notational analysis is one of the analysis methods that can be applied to determine the match characteristics of badminton (Hughes *et al.*, 2007). In computerised-notational analysis, researchers record different badminton matches *via* a digital video camera (Hughes *et al.*, 2007; Ming *et al.*, 2008). Thereafter, they use a video analysis software package such as Dartfish to analyse the video footage in detail, and to display the match-analysis results in digital format (Hughes and Franks, 2004; O'Donoghue, 2014; Wilson, 2008). Despite the benefits of this analysis method, only a hand-full of researchers have thus far used this method to analyse badminton matches (Abian-Vicen *et al.*, 2013; Ming *et al.*, 2008). Furthermore, no researchers have analysed the match characteristics of African badminton players. The need for more up-to-date research in this area has also been accentuated by the change in the badminton scoring system during 2006 from the traditional 3 sets, 15-points system to the new 3 sets, 21-points system (Ming *et al.*, 2008).

Several studies have used notational analysis to investigate the characteristics of badminton match-play. For example, temporal structure analyses of 14 matches played during a 1999 Spanish International Tournament revealed the following characteristics: the average game duration was 1689.3 ± 313 s, with 6.06 ± 1.08 shots performed per rally time; the real time played was 548.7 ± 98.6 s, while the performance time was 6.4 ± 1.3 s; the work density was found to be 0.5 ± 0.1 ; the total rallies played was 83.3 ± 11.0 , with total shots averaging 510.7 ± 109.8 (Cabello-Manrique and Gonzalez-Badillo, 2003). In another study, Abian-Vicen *et al.* (2013) assessed the temporal and notational structures of matches played during the 2008 Beijing Olympic Games and found the following average results for the first and second games of the men's singles matches respectively: the duration of games was 1128 ± 256.5 s and 1121.0 ± 214.0 s; and the real time played was 310.5 ± 40.7 s and 303.3 ± 52.3 s. Players only spent $28.1 \pm 3.4\%$ and $27.3 \pm 2.4\%$ of the total time on match-play activities; rally time was found to be 9.0 ± 0.9 and 9.1 ± 1.4 s; shots per rally were 9.7 ± 0.8 and 9.9 ± 1.4 ; rest time was 24.1 ± 3.8 s and 25.2 ± 4.6 s; work density was 0.38 ± 0.06 and 0.36 ± 0.04 ; and shot frequencies per rally, 1.08 ± 0.04 and 1.09 ± 0.03 . Cabello *et al.* (2004) analysed a large sample ($n = 79$) of national,

international and world-class Spanish male badminton players and revealed an average total playing time of 2090 ± 921 s, an average total work time (total time when the shuttle was in play) of 707 ± 261 s, an average work time of 7.3 ± 1.3 s, an average rest time of 14.2 ± 3.4 s, an average work:rest ratio of 0.53 ± 0.12 as well as an average number of rallies' value of 98 ± 32 .

In a different study, Ming *et al.* (2008) used notational and time-motion analyses to investigate differences in simulated badminton match characteristics, when state-level male Malaysian badminton players made use of the new (21 points) and old scoring systems (15 points) respectively. They reported 17.3 ± 2.7 vs. 24.1 ± 2.4 min for match durations; 8.6 ± 1.3 vs. 12.0 ± 1.2 min for average game duration; 4.6 ± 0.9 s vs. 4.6 ± 0.5 s for rally time; 9.7 ± 1.3 s vs. 10.3 ± 1.4 s for rest time; 0.5 ± 0.1 vs. 0.46 ± 0.07 for work density; 331.3 ± 44.7 vs. 463.5 ± 21.4 for number of shots per match; 70.3 ± 1.3 vs. 97 ± 6.7 for the number of rallies per match and 4.7 ± 0.8 vs. 4.8 ± 0.5 for the average shots per rally respectively when the last-mentioned scoring systems were used. Although the last-mentioned notational analysis results do provide sport practitioners in the badminton fraternity with information regarding the singles match characteristics of male players, it is unclear whether African badminton players will display the same match-characteristic profile as their international counterparts. Over the last two decades, studies have only focussed on badminton players from Spain (Cabello *et al.*, 2004), Malaysia (Ming *et al.*, 2008), and the top international players that participated in the 1996 Hong Kong Badminton Open (Tong and Hong, 2000) and 2008 as well as 2012 Olympic Games (Abian-Vicen *et al.*, 2013).

Yet another aspect that does not receive attention from researchers is the possible relationships between specific notational singles match-analysis results. Relationships between match-analysis components such as strokes and foot movements may provide researchers and practitioners with important information regarding the influence of different strokes on players' foot movements or *vice versa*. Researchers and practitioners will then be able to focus their attention directly on the most important and influencing components that need to be addressed during physical and skills training.

Since notational analysis enables players, coaches, sport scientists and other sport-related professionals to assess the physiological and psychological demands of badminton in such a manner that measurable and subjective outcomes that are specific and unprejudiced can be obtained (Hughes and Bartlet, 2008), it is important to apply this method to analyse African badminton player matches. This method of analysis can also be applied to furnish coaches with

data and clues concerning performance weaknesses in distinct areas (Carling *et al.*, 2009; James, 2008; Liebermann and Franks, 2007). At the end, a better understanding of players' weaknesses as well as the physiological and psychological demands of badminton may enable sport scientists to compile conditioning programmes specifically in accordance with the demands of match-play. Conditioning programmes tailored in this manner will improve match-play performances and overall success.

It is against this background that the objectives of this study were firstly, to determine the notational singles match-analysis results of male badminton players who participated in the African Badminton Championships and secondly, to determine the relationships between notational singles match analysis-determined strokes and foot movements in male badminton players that participated in the African Badminton Championships.

2. Methods

2.1. Design

The design of the study was a selected group, observational, descriptive, and *ex post facto* design. Ethical approval for the study was obtained from the Ethics Committee of the institution in which the research was conducted (NWU-00199-14-A1). In addition, permission to conduct the research was also obtained from the managers of participating African teams, coaches of the participating players, the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), Badminton South Africa (BSA) and the Botswana Badminton Association (BBA).

2.2. Participants

Twelve male single players (age: 24.4 ± 4.6 years) that participated in the team and individual events of the All Africa Senior Badminton Championships of 2014, which was held in Lobatse, Botswana, willingly volunteered to participate in this study. Players represented the following African countries during participation: Botswana, Cameroon, Egypt, Mauritius, Nigeria, Seychelles, South-Africa, Zambia and Zimbabwe. Only in cases where the manager and coach of a certain player as well as the player himself provided voluntary written consent to participate in the study, that player was allowed to participate. Furthermore, only badminton players actively involved and competing as members of their respective national badminton federations in the above-mentioned tournament as well as those that were totally injury-free at the time of testing were eligible to participate in the study. All participants were considered to be the best players of their respective African countries during the time of the tournament.

The competitive badminton playing experience of these players varied between 4 and 12 years, with an average of 9.3 ± 2.7 years. They trained for 4.3 ± 1.2 days a week on average, with training that consisted of court- and resistance-training sessions.

2.3. Procedures

Three months prior to the start of the tournament, permission to conduct the research was requested *via* email from the BWF, the BCA, BSA and the BBA. A day before the tournament started, the managers' meeting was attended by the researchers and detailed information with regard to the study design, purpose, procedures and possible risks of participation was provided to the managers of each of the participating teams. This opportunity was also used to inform the head referee of the relevant tournament of the study and to obtain permission from him to conduct the research during the tournament. On the first day of the tournament, informed consent was obtained from the participating players and permission was also obtained from each of the coaches involved with players. During this time, players also completed a general information questionnaire regarding their exercising habits, injury incidence, and competing level.

Prior to the start of each match, a Sony Handycam with full HD (Sony HDR-PJ790VE Handycam, Sony Corporation, Tokyo, Japan) was stationed on a tripod stand behind each of the courts on a gallery that was on the first floor of the hall in which all the matches were played. The warm-up period was then used to adjust the cameras, and to check whether the video footage was recorded accurately. Video recordings of each match were downloaded onto a laptop computer and analysed by means of the Dartfish Team Pro video analysis software package (version 5.5, Rte de la Fonderie 6, CP 53 - 1705, Fribourg 5, Switzerland). The qualified sport scientist that has been participating in badminton at an international level performed all analyses. A month before the analyses was performed, the sport scientist received training from an analyst that has been doing match-analysis for a variety of sports and is currently training university students to use Dartfish. Twenty-five percent of the matches were randomly selected and re-analysed a month later by the same sport-scientist in order to prevent interpersonal variability in the different observations and interpretations of activities and to verify the accuracy of the original analyses.

2.4. Measures

2.4.1. Computerised notational analysis

Video footage was recorded for twenty men's singles matches from the team and individual events of the All Africa Senior Badminton Championships. All matches were recorded live. The video recordings of each match were downloaded onto a laptop computer and analysed by means of the Dartfish Team Pro analysis software package (version 5.5, Rte de la Fonderie 6, CP 53 - 1705, Fribourg 5, Switzerland). Dartfish was used to do the analyses due to the wide range of features that can be used. These features include the capacity to track and break down movements and badminton strokes for analyses as well as the capacity to record the duration of different movements and phases of the match. The video footage was therefore coded and the frequency and duration of all movements, strokes, and match periods were analysed.

The following match-related variables were analysed:

Badminton strokes

Clear: a shot that took the shuttle over the head of the opponent with a flat or rising trajectory towards the baseline of the rival court (Abian-Vicen *et al.*, 2013; Brahms, 2014).

Drive: a hard shot that was executed while the racket head was at the mid part of the body and took the shuttle to the middle of the court with a flat trajectory (Abian-Vicen *et al.*, 2013; Brahms, 2014).

Drop: a smooth shot executed in such a manner that the shuttle followed a downward trajectory towards the front of the court (Abian-Vicen *et al.*, 2013; Brahms, 2014).

Net: a precise shot from near the net, which also included the push, kill and brush (Abian-Vicen *et al.*, 2013; Brahms, 2014).

Smash: an aggressive overhead shot that moved the shuttle in a downward trajectory (Abian-Vicen *et al.*, 2013; Brahms, 2014).

Round-the-head: a forehand overhead stroke on the overhead backhand side, which was used instead of attempting a backhand overhead shot (Brahms, 2014; Grice, 1996).

Serve: the act of starting the game or putting the shuttle into play. The server hit the shuttle beneath waist height in such a manner that it landed in the receiver's service court (Blomqvist *et al.*, 2000; Brahms, 2014).

Foot movements

Chasse-step: This movement usually occurred when a player stepped on one foot to the side, followed closely by the other foot. One foot led the movement, while the other foot came in behind the leading foot as the position changed (Grice, 1996).

Scissors-kick: This was often used as the last movement when hitting overhead forehands, in which the legs swapped positions while in the air (Brahms, 2014).

Shuffle-step: This type of step was often used when moving forward or backwards towards the backhand side. For example, when a player wanted to reach a shuttle at the net on the forehand side the non-dominant leg would move forward and across to the forehand side with the body facing the corner of the court (Grice, 1996).

Split-step: This was a very low jump, in which the feet came off the ground and spread a little apart, while the player was bending forward before he pushed off towards the target (Leitch, 2013).

Lunging is an essential foot movement of competitive badminton players (Cronin *et al.*, 2003; Kuntze *et al.*, 2010). A lunge is defined as a position in which one leg is positioned forward, while the knee is bent and the foot placed flat on the ground whereas the other leg is positioned at the back. Due to multifarious lunging movements in badminton, lunges were classified into the following categories: lunge-to-left (to reach a shuttle on the left-hand side); lunge-to-right (to reach a shuttle on the right-hand side); lunge-forward (to reach a shuttle to the front of the body); lunge-backward (to reach a shuttle behind the player) and half-lunges (this occurred when a player made an incomplete lunge to get to the shuttle).

Time-related variables

Match duration: the time that elapsed from the first service until the shuttle touched the ground during the last point, which also included: rest periods between points and games (Abian-Vicen *et al.*, 2013).

Percentage real time played: real time played multiplied by 100 divided by the match duration (Abian-Vicen *et al.*, 2013).

Rally durations: the periods realised for the length of each rally. A rally was defined as the time period that started when the service took place until the shuttle touched the ground (Abian-Vicen *et al.*, 2013).

Real time played: the time that the shuttle was in play from the first to the last point of the match (Abian-Vicen *et al.*, 2013).

Rest time: the time that elapsed from when the shuttle touched the ground until the next service was performed; that is: periods during which the shuttle was not in play (Abian-Vicen *et al.*, 2013).

Shots per rally time: number of shots divided by real time played (Abian-Vicen *et al.*, 2013).

Work density: total rally time divided by total rest time observed during the game (Abian-Vicen *et al.*, 2013; Cabello *et al.*, 2004; Ming *et al.*, 2008).

Each match was analysed according to the different rallies and sets that were played as well as the time periods of the match. The clock function of the Dartfish Team Pro video analysis software package was used to determine all the time-related variables.

2.5. Statistical analysis

After completion of the match analyses the raw data for each of the variables were entered into Microsoft Excel (Microsoft Office Professional Plus, 2013). Firstly, all variables were corrected for match duration by dividing the specific variable by match duration into seconds. The Statistical Data Processing package (StatSoft Inc., 2015) was used for the rest of the analyses. Descriptive statistics (averages, standard deviations, minimum and maximum values) for each of the relevant variables were calculated. Cronbach's Alpha and Intraclass Correlation analyses were used to determine the reliability of match-analysis results between data of the original analysis and 25% of the randomly selected matches. The 95% confidence intervals (*CI*) for the Intraclass Correlation analyses were also determined. Spearman Rank Correlation Coefficient, rho was used to determine relationships between values of different shots and foot movements. Lastly, a Fisher *r* to *z* transformation was calculated to determine the 90% confidence intervals (*CI*) from the correlation coefficients (*r*). The level of significance was set at $p \leq 0.05$. The strength of correlations was categorized based on the following criteria: <0.1 (trivial), <0.3 (small), <0.5 (moderate), <0.7 (large), <0.9 (very large) and <1 (nearly perfect) (Hopkins *et al.*, 2009).

3. Results

Reliability of notational analysis

A total of 5 randomly selected matches (25% of the total matches previously analysed) were re-analysed for both shots played (strokes), foot movements and time-related variables (match duration, rally duration, work density and rest time). The average Cronbach's Alpha values were 0.97 for strokes played, 0.99 for foot movements and 0.99 for time-related variables. On the other hand, Intraclass Correlation analyses revealed values of 0.95 (95% *CI*: 0.69-0.99) for

strokes played, 0.97 (95% *CI*: 0.44-0.95) for foot movements, and 0.99 (95% *CI*: 0.89-1.00) for time-related variables.

Foot movement-related variables

Table 1 contains the descriptive statistics of all foot-movement-related variables identified by the match analyses of the male singles African badminton players.

Table 1: Descriptive statistics of all foot-movement-related variables performed during single matches of male African badminton players

Variables	Mean	Minimum	Maximum	SD
<i>Values not corrected for match duration</i>				
Chasse steps per match	174.6	55.0	297.0	73.6
Scissors kicks per match	38.3	12.0	70.0	15.7
Shuffle steps per match	161.7	36.0	306.0	66.1
Split steps per match	61.6	28.0	104.0	23.9
Half lunges per match	52.2	22.0	82.0	18.4
Lunges forward per match	46.1	10.0	76.0	18.3
Lunges backward per match	12.2	0.0	53.0	12.8
Lunges to left per match	21.8	7.0	48.0	13.8
Lunges to right per match	15.5	5.0	30.0	8.5
<i>Values corrected for match duration (sec)</i>				
Chasse steps/sec during match	0.12	0.06	0.18	0.04
Scissors kicks/sec during match	0.03	0.01	0.04	0.01
Shuffle steps/sec during match	0.11	0.03	0.15	0.04
Split steps/sec during match	0.04	0.02	0.07	0.02
Half lunges/sec during match	0.04	0.02	0.05	0.01
Lunges forward/sec during match	0.03	0.01	0.06	0.01
Lunges backward/sec during match	0.01	0.00	0.03	0.01
Lunges to left/sec during match	0.01	0.01	0.03	0.01
Lunges to right/sec during match	0.01	0.00	0.02	0.00

SD = Standard deviation

From Table 1 it is clear that the chasse-step (174.6 ± 73.6 ; 0.12 ± 0.04) and shuffle foot movements (161.7 ± 66.1 ; 0.11 ± 0.04) were performed much more often during match-play than any other foot movements. The split-step (61.6 ± 23.9 ; 0.04 ± 0.02), half-lunge (52.20 ± 18.44 ; 0.04 ± 0.01), forward-lunge (46.1 ± 18.3 ; 0.03 ± 0.01), and scissors kick (38.3 ± 15.7 ; 0.03 ± 0.01) were the next most executed foot movements.

Stroke-related variables

Results with regard to the different badminton stroke-related variables executed during 20 single matches are presented in Table 2.

Table 2: Descriptive statistics of all stroke-related variables performed during single matches of male African badminton players

Variables	Mean	Minimum	Maximum	SD
<i>Values not corrected for match duration</i>				
Number of shots per match	444.3	264.0	633.0	101.1
Shots per rally	6.5	4.8	8.9	1.3
Clears per match	118.0	63.0	199.0	32.4
Drives per match	122.1	66.0	183.0	27.4
Drops per match	24.2	2.0	47.0	13.6
Net shots per match	54.3	17.0	92.0	19.7
Round-the-head shots per match	1.2	0.0	4.0	1.3
Serves per match	68.5	55.0	111.0	12.8
Smashes per match	56.2	25.0	113.0	23.1
<i>Values corrected for match duration (sec)</i>				
Shots/sec during match	1.03	0.89	1.13	0.06
Clears/sec during match	0.08	0.05	0.13	0.02
Drives/sec during match	0.08	0.05	0.12	0.02
Drops/sec during match	0.02	0.00	0.03	0.01
Net shots/sec during match	0.04	0.02	0.06	0.01
Round-the-head shots/sec during match	0.00	0.00	0.00	0.00
Serves/sec during match	0.05	0.04	0.06	0.01
Smashes/sec during match	0.04	0.02	0.06	0.01

SD = Standard deviation

The drive (122.1 ± 27.4 ; 0.08 ± 0.02) and clear (118.0 ± 32.4 ; 0.08 ± 0.02), followed by the serve (68.5 ± 12.8 ; 0.05 ± 0.01), smash (56.2 ± 23.1 ; 0.04 ± 0.01) and net strokes (54.3 ± 19.7 ; 0.04 ± 0.01) were identified as the most frequently performed strokes during badminton singles match-play. The drop shot was only performed 24.2 ± 13.6 (0.02 ± 0.01) times on average during a match, whereas the round-the-head strokes were rarely (1.2 ± 1.3 ; 0.00 ± 0.00) executed during match-play. Similarly, results revealed that a total of 444.3 ± 101.1 shots were executed during each match, leading to shots per rally and shots frequency values of 6.5 ± 1.3 and 1.03 ± 0.06 respectively.

Time-related variables

Time-related variables' results obtained from the single matches are presented in Table 3.

Table 3: Descriptive statistics of all time-related variables identified by the badminton match analyses of male African badminton players

Variables	Mean	Minimum	Maximum	SD
Rally frequency	68.4	55.0	111.0	12.8
Rally duration (s)	5.6	1.6	20.9	5.8
Real time played (s)	432.9	261.1	602.3	91.6
Match duration (s)	1470.4	966.0	2263.0	341.9
Percentage of real time played	29.8	23.1	42.3	4.5
Rest time in-between rallies (s)	17.3	10.5	28.2	4.6
Work density	0.4	0.3	0.7	0.1

According to the tabulated results, the average match duration for African male badminton players was 1470.4 ± 341.9 s, and the real time and percentage of real time played were 432.9 ± 91.6 s and $29.8 \pm 4.5\%$ respectively. The average for rallies was 5.6 ± 5.8 s, players performed an average of 6.5 ± 1.3 shots per rally during each match and work density was determined to be 0.4 ± 0.1 on average during matches. Lastly, on average, players rested for 17.3 ± 4.6 s in-between rallies during each match.

Relationships between shots and foot movements

Results concerning the Spearman Rank Correlation Coefficients and 90% confidence intervals between the different badminton shot- and foot-movement-related variables that were corrected for match duration are presented in Table 4.

Spearman Rank Correlation Coefficients (Table 4) indicate moderately significant relationships between players' chasse steps and clearing shots ($r = 0.44$, $p = 0.05$), split steps and drive ($r = 0.47$, $p < 0.05$) and lunges-to-the-right direction and smash shots ($r = 0.48$, $p < 0.05$). Very large significant relationships are observed between the chasse step foot movements and smash shots ($r = 0.71$, $p < 0.05$) and between backward lunges and net shots ($r = 0.71$, $p < 0.05$). Large significant relationships exist between scissors kick foot movements and smash shots ($r = 0.50$, $p < 0.05$), shuffle-steps and clear shots ($r = 0.54$, $p < 0.05$) and split-steps and clear shots ($r = 0.63$, $p < 0.05$). Similarly, large significant relationships are observed between forward lunges and net shots ($r = 0.55$, $p < 0.05$), lunges-to-the-left direction and net shots ($r = 0.50$, $p < 0.05$), backward lunges and smash shots ($r = 0.53$, $p < 0.05$) and between lunges-to-the-right

direction and net shots ($r = 0.58$, $p < 0.05$). Lastly, a trivially significant relationship is detected between split steps and drop shots ($r = -0.51$, $p < 0.05$).

Table 4: Results of the Spearman Rank Correlation Coefficients and 90% confidence intervals (in brackets) between the different badminton shot- and foot-movement-related variables (corrected for match duration) identified during match-play

	Clear	Drive	Drop	Net	Round-the-head	Serve	Smash
Chasse steps	0.44* ^M (0.08 - 0.70)	0.44 (0.07 - 0.70)	0.05 (-0.33 - 0.42)	0.39 (0.01 - 0.67)	-0.16 (-0.51 - 0.23)	-0.30 (-0.61 - 0.09)	0.71* ^{VL} (0.45 - 0.86)
Scissors kicks	0.01 (-0.37 - 0.40)	-0.20 (-0.54 - 0.20)	-0.18 (-0.52 - 0.21)	-0.42 (-0.69 - -0.05)	0.02 (-0.36 - 0.39)	-0.24 (-0.57 - 0.15)	0.50* ^L (0.15 - 0.74)
Shuffle steps	0.54* ^L (0.20 - 0.76)	0.23 (-0.16 - 0.56)	-0.36 (-0.65 - 0.02)	-0.01 (-0.39 - 0.37)	-0.17 (-0.51 - 0.23)	0.12 (-0.27 - 0.48)	0.12 (-0.27 - 0.48)
Split steps	0.63* ^L (0.33 - 0.82)	0.47* ^M (0.11 - 0.72)	-0.51* ^T (-0.74 - -0.16)	-0.32 (-0.62 - 0.07)	-0.42 (-0.69 - -0.04)	0.06 (-0.32 - 0.43)	0.20 (-0.20 - 0.54)
Half lunges	0.10 (-0.29 - 0.46)	-0.01 (-0.38 - 0.37)	0.09 (-0.30 - 0.45)	0.15 (-0.24 - 0.50)	0.10 (-0.29 - 0.46)	-0.11 (-0.47 - 0.28)	0.18 (-0.21 - 0.52)
Forward lunges	0.17 (-0.22 - 0.52)	0.36 (-0.02 - 0.65)	0.18 (-0.22 - 0.52)	0.55* ^L (0.22 - 0.77)	-0.05 (-0.42 - 0.34)	-0.11 (-0.47 - 0.28)	0.42 (0.04 - 0.69)
Backward lunges	0.15 (-0.2 - 0.50)	0.24 (-0.15 - 0.57)	0.20 (-0.19 - 0.54)	0.71* ^{VL} (0.45 - 0.86)	0.25 (-0.15 - 0.57)	-0.27 (-0.59 - 0.12)	0.53* ^L (0.19 - 0.76)
Lunges to left	0.04 (-0.35 - 0.41)	0.20 (-0.20 - 0.54)	0.30 (-0.09 - 0.61)	0.50* ^L (0.15 - 0.74)	-0.04 (-0.41 - 0.35)	-0.10 (-0.46 - 0.29)	0.42 (0.04 - 0.69)
Lunges to right	0.17 (-0.22 - 0.52)	0.25 (-0.14 - 0.58)	0.30 (-0.09 - 0.61)	0.58* ^L (0.25 - 0.78)	0.07 (-0.31 - 0.44)	-0.17 (-0.52 - 0.22)	0.48* ^M (0.12 - 0.73)

Note: * = $p \leq 0.05$; <0.1 (trivial), <0.3 (small), <0.5 (moderate), <0.7 (large), <0.9 (very large) and <1 (nearly perfect); where T = trivial, S = small, M = moderate, L = large, VL = very large and NP = nearly perfect.

4. Discussion

Overall, the study showed that computerised-notational analysis is a reliable method for determining the singles match characteristics of male badminton players that participated in the African Badminton Championships. Results with regard to the singles match characteristics that are related to time revealed that the average match duration was 1470.4 s, of which 17.3 s was spent resting in-between rallies. The average real time and percentage of real time played were calculated to be 432.9 s and 29.8% respectively. The average work density was 0.4. Overall, players performed 68.4 rallies per match and 6.5 shots per rally time, with an average rally duration of 5.6 s per match. Analyses with regard to different strokes played during matches revealed that the drive (122.1 times) and clear (118.0 times), followed by the serve (68.5 times), smash (56.2 times) and net strokes (54.3 times) were performed most often. However, the drop shot was only performed 24.2 times on average during matches, whereas the round-the-head strokes were rarely (1.2 ± 1.3) performed. On average of 444.3 shots were played per match with a shot frequency of 1.03 shots per second. A further analysis showed that chasse-steps (174.6 times), followed by shuffles (161.7 times) were the foot movements that were performed the most compared to split-steps (61.6 times), half-lunges (52.2 times), forward-lunges (46.1 times) and scissors-kicks (38.3 times) that were performed less often. Lunges to the right (15.5) and lunges backward (12.2) were rarely performed.

Compared to other studies, the average match duration for this study was lower (1470.4 s) than the reported values of previous studies, which varied between 2378 s (Abian-Vicen *et al.*, 2013), 2090 s (Cabello *et al.*, 2004) and 1689.3 s (Manrique and Gonzalez-Badillo, 2003). However, a study by Ming *et al.* (2008) reported a lower value of 1047 s for the matches analysed by them. Differences in match duration results between studies may be attributed to differences in players' level of play and the methodology used to analyse match duration. For example, most elite badminton players have developed great anticipation skills together with fast reaction and movement times which enable them to accurately predict and respond to almost any shot an opponent is about to perform (Loureiro Jr and Freitas, 2012). In addition, players learn to adapt to opponents' playing styles when playing against them more regularly (Blomqvist, 2001). All of these factors will lead to longer rallies, which would lead to higher match durations. With regard to differences in study methodology, Ming *et al.* (2008) for example made use of simulated matches, instead of actual matches, which may have negatively influenced the reported average match duration value.

A more or less similar average percentage for real time played was reported by Abian-Vicen *et al.* (2013) for players that participated in the 2008 Beijing Olympic Games (29.8% *versus* 26.0%). However, the absolute real time played average for this study was considerably lower (432.9 s) than values reported by other researchers: 613.7 s (Abian-Vicen *et al.*, 2013), 548.8 s (Manrique and Gonzalez-Badillo, 2003) and 707 s (Cabello *et al.*, 2004). Therefore players in this study spent much less time being active during matches than did players of other studies. One of the main factors that determine the percentage of real time played is the average rest time per match. Players in this study rested on average for 17.3 s in-between rallies, compared to Olympic players that rested on average for 24.1 s and 25.2 s in-between rallies during the first and second games of men's single matches (Abian-Vicen *et al.*, 2013). In contrast, Cabello *et al.* (2004) analysed a large sample ($n = 79$) of top national male badminton players and revealed an average rest time for periods in-between rallies of 14.2 s. An average value of 12.9 s was reported for international players (Cabello-Manrique and Gonzalez-Badillo, 2003), 9.7 s for young national players (Ming *et al.*, 2008) and 11.4 s for international players (Faude *et al.*, 2007). These studies concluded that more experienced players such as Olympians rested more in-between rallies than top national and young national players. These findings suggest that more experienced players have the ability to slow down match momentum and to optimally use the available rest periods in order to recover more effectively between rallies.

Players on average performed 68.4 rallies per match at a frequency of 6.5 shots per rally which led to an average work density of 0.4 with 5.6 s as an average for rally duration. However, other researchers observed higher average work-density values for badminton players: 0.5 (Cabello *et al.*, 2004; Faude *et al.*, 2007; Manrique and Gonzalez-Badillo, 2003). In contrast, Abian-Vicen *et al.* (2013) presented a lower average work-density value for players in their study (0.4). These results suggest that players competing at a higher level obtain higher work-density values during match-play than those that compete at a lower level. Work density increases relative to work-time increases and also as the level of competitions increases (Cabello *et al.*, 2004). Cabello *et al.* (2004) also noted that rest periods increased as match durations became longer. Therefore the lower average work-density value for players in this study may partly be explained by the lower average rallies per match (68.4) that were performed, compared to that of players of other studies (83.3) (Cabello *et al.*, 2004). Moreover, players only spent 5.6 s on average per rally, which would negatively influence the work density. Although Faude *et al.* (2007) reported a similar value of 5.5 s for average rally time, they used simulated instead of actual competition matches. Yet another factor that may also influence work density is the average number of shots played per rally as it also affects average rally time. Comparatively, players in this current study played

a much lower average number of shots per rally (6.5) than more elite players that participated in the 2008 Olympic Games (1st set = 9.7 and 2nd set = 9.9) (Abian-Vicen *et al.*, 2013). On the other hand, various researchers reported lower average values for number of shots played per rally than those we observed: 6.1 for younger international badminton players (aged 21.8 ± 3.3) from France, Italy, Portugal and Spain (Manrique and Gonzalez-Badillo, 2003); 4.7 and 4.8 for young men (age: 14 to 17 years) when analysing simulated badminton singles matches played according to the 21 and 15 point system respectively (Ming *et al.*, 2008).

Consequently, factors that determine work density differences between studies include the use of different scoring systems (old 15-point versus the new 21-point system) during match-play, the level of play, differences in playing level between opponents and interrelations between different time-related variables. In this regard, research showed that the new 21-point system led to a higher average work density value than did the old 15-point system (0.48 versus 0.46) (Ming *et al.*, 2008). In addition, above-mentioned results suggest that higher levels of play deliver higher average work-density values than do lower levels of play. Manrique and Gonzalez-Badillo (2003) also indicated that longer rally times and a larger quantity of rallies, which will give rise to higher average work-density values, are observed when players of similar playing levels compete against each other, compared to when opponents' playing levels differ. Significant inter-relationships ($r = 0.42$, $p < 0.01$) between average rest time and number of rallies played as well as between average work and rest time during badminton matches ($r = 0.67$; $p < 0.01$) (Cabello *et al.*, 2004), would also lead to changes in work density between matches and between different studies. Different time-related variables may also influence results of different match-analysis' characteristics. For instance, Cabello *et al.* (2004) showed that an increase in the number of rallies played forced players to rest longer during matches. In our study, an increase in work time also led to an increase in rest time, which would suggest that the last-mentioned assumption is correct.

Results with regard to strokes executed during each of the matches revealed that players performed the drive (122.1 times) and clear strokes (188.0 times) most frequently. Other strokes were performed at much lower frequencies, with values ranging between 68.5 times (serve) and 1.2 times (round-the-head) per match. Therefore the round-the-head stroke was the least performed stroke with many players that did not perform it even once during matches. The drive can either be used as an offensive stroke in situations where a player, for example, wants to pass his opponent, or as a defensive shot in situations, where a player, for example, wants to return a smash. In some situations the drive can also be used to surprise the opponent by driving the

shuttle down the side line. On the other hand, clear shots are used to drive the shuttle to the opponent's baseline by making use of either a rising or flat trajectory. What is interesting to note, is that an attacking shot such as the smash was only performed 56.2 times on average during matches. This may be due to the fact that the smash is categorized as an energy-tapping shot which may lead to higher fatigue levels if performed continuously over a long period.

Foot movement data showed that the chasse-step (174.6) and the shuffle-step (161.7) were the most frequently used foot movements during match-play. This was followed by the split-step (61.6), the half (52.2) and the forward-lunge (46.1). The chasse- and shuffle-steps are simple foot movements that allow players to move to the shuttle in an effective and time-efficient manner. These foot movements also enable players to recover quickly and maintain their stable positions so that they can move to the mid-court in the shortest possible time in order to receive the next shot. Kuntze *et al.* (2010) made use of a video-based experimental study to show that the lunge is the most frequently used foot movement in badminton. They showed that almost 15% of all foot movements during competitive singles matches were lunges (Kuntze *et al.*, 2010). In our study, lunging-related foot movements contributed 25.3% to the total amount of foot movements during matches with half-lunges performed most (8.9%), and backward-lunges performed the least number of times (2.1%). A full lunge to either side of the court may be energy tapping if performed frequently and extensively; therefore players utilise half-lunges more often as it is a more energy-efficient movement that enables players to respond faster to the next anticipated shot. Backward lunges are performed the least number of times during a match as most shuttles that travel to the backward part of the court would be intercepted before players would have to move backwards. The backward-lunge leads to a weight transfer to the back leg which would place a player in a dangerous position and vulnerable to especially drop shots due to the fact that it would take him longer to transfer his weight back to the front foot and accelerate to the front to intercept a front-court shot.

In this current study researchers also determined relationships between different badminton shot- and foot movement-related variables. No other studies have established relationships between these last-mentioned variables, which make it difficult to directly compare results of this study to similar studies. Results revealed that split steps were significantly correlated to three badminton shots, namely the clear, drive and drop shots, whereas chasse steps (clear and smash), backward lunges (net and smash) and lunges to the right (net and smash) were all significantly correlated to two shots. All other foot-movement-related variables, except for half lunges, were significantly

correlated with one badminton shot. The round-the-head and serve shots delivered no significant correlations with foot-movement-related variables.

Results indicate that split steps have the biggest influence on especially attacking badminton strokes such as clears, drives, and drops. Split steps are characterised by a very low jumping movement, in which the feet come off the ground and spread a little apart which allows players to move swiftly on the court. It is obvious that in badminton, taller players have some advantages. They can produce a more effective smash from the baseline due to the height of the contact point. They can also deliver perfect low serves easily compared to what shorter players can deliver. Players rarely smash a shuttle during a split step, as it is easier to perform a drop, clear, or drive stroke from this position. Three other foot movements namely chasse steps, backward lunges and lunges to the right were also significantly related to the smash shot. The chasse step occurs when a player steps on one foot to the side, followed closely by the other foot. One foot leads the movement, while the other foot comes behind the leading foot. It is obvious that smashing is an explosive and aggressive attacking stroke in which the performer needs to accelerate before execution. Chasse step, lunges backward, and lunges to the right (racket arm) are all movements that allow players to accelerate so that they can propel their bodies in order to smash the shuttle more effectively. On the other hand, both backward lunges and lunges to the right were also significantly related to the net shot. In many cases lunging movements will be used to deceive players in thinking that a smash shot is going to be played, but instead, players play a net shot such as a drop.

5. Conclusion

In conclusion, computerised-notational analysis revealed that male badminton players that participated in the African Badminton Championships were active for 29.8% of the total match time, which relates to 1470.4 s, and spent 17.3 s on average during a match on rest in-between rallies; they performed 68.4 rallies per match at an average duration of 5.6 s, during which a stroke was performed every 1.03 sec; the real time played was 432.9 s, which relates to a work density of 0.43; they executed the drive (122.1) and clear strokes (118.0) most often during a match and performed the shuffle (161.7) and chasse-step (174.6) most frequently during match-play. The study also revealed moderately significant relationships between players' chasse steps and clearing shots, split steps and drive, and also lunges to the right direction and smash shots. Very strong relationships were observed between the chasse step foot movements and smash shots, and between backward lunges and net shots. A large significant relationship also existed between scissors kick foot movements and smash shots, shuffle-steps and clear shots, and

between split-steps and clear shots. Similarly, strong significant relationships were observed between forward lunges and net shots, lunges to the left direction and net shots, backward lunges and smash shots, and between lunges to the right direction and net shots. Lastly, a trivially significant relationship was detected between split steps and drop shots.

This is the first study to provide sport practitioners (sport scientist and coaches) with information concerning the badminton singles match characteristics of African players. However, the study does not provide information with regard to the internal demands of match-play. Future studies will thus need to also consider parameters such as heart rate together with notational analysis results to more precisely describe the demands of badminton singles match-play. Furthermore, this study only focussed on badminton players that participated in the All Africa Senior Badminton Championship of 2014. Hence future studies should include larger samples of African badminton players to verify the notational analysis results. In the meantime, African badminton players should be provided with opportunities to develop and exploit their performance potential, especially in view of findings that values of several singles match-analysis characteristics differed from those of international players.

6. Practical applications

Overall, the results suggest that a typical conditioning programme for badminton players should develop drills and activities that take place for durations of 5.57 s at a time at a work:rest ratio of 1:3 – a rally duration time of 5.57 sec divided by the average rest in-between rallies of 17.3 s. Drills and activities should continue for a total duration of 3-5 minutes after which a break of 2 minutes must be allowed before continuing with another set of 3-5 min. This will simulate the real time played, which ranges between 7 and 10 minutes with a 2-minute break which is the rest period players receive between sets during match-play. The intensity of activities must be quite high and incorporate especially chasse-steps, shuffle-steps, split-steps and half- and forward lunges. Conditioning drills should also include the drive, clear, serve, smash and net strokes as these are the most often performed strokes during match-play.

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CHAPTER 4

Global positioning system (GPS) determined match characteristics that predict successful and less successful male singles badminton players' group classification



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Abstract

The study aimed at establishing the global positioning system (GPS) determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification. Twenty-two (22) male single players (aged: 23.39 ± 3.92 years; body stature: 177.11 ± 3.06 cm; body mass: 83.46 ± 14.59 kg) that represented 10 African countries participated in the study. Players were categorised as successful and less successful players according to the results of five championships of the 2014/2015 season. GPS units (MinimaxX V4.0), Polar Heart Rate Transmitter Belts and digital video cameras were used to collect match data. GPS-related variables were corrected for match duration and independent *t*-tests, a cluster analysis and a binary forward stepwise logistic regression were calculated. A Receiver Operating Characteristic Curve (ROC) was used to determine the validity of the group classification model. High-intensity accelerations per second was identified as the only GPS-determined variable that showed a significant difference 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 GPS-based logistic regression formula. The ROC showed a value of 0.87. The identification of the last-mentioned GPS-related variables for the attainment of badminton performances emphasizes the importance of using badminton drills and conditioning techniques to not only improve players' physical fitness levels but also their abilities to accelerate at high intensities.

Key words

Badminton, global positioning system, match-analysis, inertial movement analysis, intensity, effort

Introduction

The popularity and competitiveness of badminton have led to 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.¹ Match-analysis-related studies in racket sports have therefore increased in recent years due to the value of match-analysis results in evaluating and improving match performance.²⁻⁴ However, while badminton is generally acknowledged as the fastest moving racket sport, distinguished for its high-paced and vigorous rallies, scholars have not given this sport much attention with regard to match-analysis characteristics and the possible link between these characteristics and players' match performances. Furthermore, to date no other researchers have investigated the possible link between global positioning system- (GPS) determined match characteristics of badminton players and match performance.

Up until the present, the preferred method for determining the match-analysis characteristics of badminton players is by applying video analyses.⁵⁻⁹ Despite the value of video analyses-determined match-analysis characteristics to provide 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. Discriminating match-analysis characteristics may enable coaches and sport scientists to identify and develop these characteristics in players to enable them to perform successfully. In this regard, Blomqvist et al.¹⁰ concluded that successful badminton players play a more effective and aggressive game compared to less successful players. Furthermore, successful players make less forced or unforced errors while playing.^{11,12}

The introduction of the GPS in the 1990s offered an alternative method for the measurement of average duration, frequency and speed of movements, with the potential of circumventing some of the shortcomings of notational analyses and minimising others.¹³ These shortcomings include, amongst others, the time-consuming nature of notational analyses,¹⁴ the inaccuracy of notational analyses to analyse total time spent on individual movements, the frequency of individual movements,¹⁵ and the inability to assess the specific demands of certain activities.¹⁶ However, as mentioned before, to date no research has made use of GPS devices to do this type of analyses on badminton players. The use of a triaxial accelerometer, magnetometer and gyroscope in a GPS device for analysing badminton matches is still a new phenomenon. Accelerometers, gyroscopes and magnetometers are devices that allow researchers to monitor and describe movements as well as the intensity and frequency of these movements in various clinical and sports settings.¹⁷ In this regard, Coe and Pivarnik¹⁸ concluded that accelerometers appear to be valid instruments for determining physical activity levels during activities such as

indoor basketball practises in which intensity is changing constantly. Other researchers also revealed that MinimaxX accelerometers' showed acceptable reliability (<2%) for measuring Australian Football players' external workloads and that they were capable of detecting differences in physical activity levels.¹⁹ Wundersitz et al.²⁰ used a simulated team sport circuit to demonstrate that wearable tracking devices that make use of accelerometer and gyroscope data are accurate for classifying sporting activities in sport scenarios. These findings would suggest that available wearable tracking device technology such as the MinimaxX that integrates multiple sensors (e.g. triaxial accelerometer, magnetometer and gyroscope) into a single unit may provide badminton researchers with an alternative, more time-efficient and accurate method for determining the match characteristics of badminton players.

Despite the potential benefits of the GPS match-analysis method, no researchers have made any attempt to utilise this method to determine the relationship between GPS determined match characteristics and the championship results of badminton players. Therefore the purpose of this study was to establish the GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification. Study results may identify the match characteristics that act as predictors of players that are more successful in winning matches and those that are not.

Method

Study design

An observational, descriptive and *ex post facto* research design was used for this study. Approval for the study was obtained from the Health Research Ethics Committee of the institution in South Africa at which the research was conducted (NWU-00199-14-A1). Furthermore, permission to conduct the study was obtained from the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), the Botswana Badminton Association (BBA), and Badminton South Africa (BSA).

Participants' characteristics

The participants in this study were male single players that participated in the following championships during the 2014/2015 season: 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. Altogether twenty-two players (age: 23.39 ± 3.92 years; body stature: 177.11 ± 3.06 cm; body mass: 83.46 ± 14.59 kg) were measured before, during, and after 46 matches.

Each player was therefore measured more or less twice with several players being measured three times. All championships took place over a period of two to three days, except for the Free-State National Championships that took place within one day, which meant that players were monitored and measured on consecutive days.

Players represented 10 African countries, namely: Botswana, Cameroon, Congo, Egypt, Namibia, Nigeria, South Africa, Uganda, Zambia and Zimbabwe. Only players that were actively involved and were competing as members of their respective teams and national badminton federations in the above-mentioned tournaments as well as those that were totally injury free at the time of testing were eligible to participate in the study. Players' competitive badminton playing experience ranged from 4 to 12 years (8.96 ± 2.8 years). The following information with regard to their training regimen was also 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 were grouped according to tournament results. Players that reached the quarterfinals, semi-finals or finals of each tournament were categorised as successful players whereas the rest of players were categorised as less successful players.

Test components

Demographic and general information questionnaire

Players' demographic and personal information was collected by means of the above-mentioned questionnaire. Players' ages, exercising habits, injury incidence, competing levels and best performance were also obtained by means of this questionnaire.

Anthropometric measurements

Body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd., U.K.) and body stature to the nearest 0.1 cm, using a Harpeden portable stadiometer (Holtain Ltd., U.K.) in order to describe the specific cohort of badminton players.

GPS match analyses

A GPS unit (MinimaxX V4.0, Catapult Innovations, 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. GPS units recorded data every 100 m.s^{-1} (10 Hz) during each match. The GPS apparatus allowed researchers to obtain data with regard to the following match-related variables:^{21,22}

Inertial Movement Analysis (IMA) which included the following: 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.

Individual Match-analysis which included the following: Total duration of a match; player load; equivalent distance ran during the entire match; peak player load; player load per minute; 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; HR exertion index (the amount of time a player spent in a heart-rate zone); the amount of time within the play period that a player remained active and did not take long breaks; the total accumulated player-load 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 performed under each of the player-load zones; the average, minimum and maximum length of time spent in each effort performed under each of the player-load zones; recovery times; the absolute and relative amount of time 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 GPS units were downloaded to a PC and analysed using the Catapult Sprint 5.0.9.2 software (Catapult Sports, Victoria, Australia). MinimaxX GPS Doppler data was used to analyse the GPS-related variables.

Heart-rate monitoring

In addition to the GPS unit-derived values, the heart rate (HR) of each player was recorded using 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 the 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 GPS match analyses.

Testing Procedures

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 after which they filled in the Demographic and General Information questionnaire. 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 GPS harness with a GPS monitor with which they warmed-up in order to become accustomed to the equipment and so that the HR monitor belt and GPS harness could be adjusted according to each player's preference. Prior to 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 manner that the entire court was in view. The warm-up period was also used to check the signals of both the GPS and HR monitor before each match started. Data from the GPS and HR monitors as well as the video footage were downloaded to a laptop computer for further analyses.

Statistical analyses

The Statistical Data Processing package (Statsoft Inc., 2015) was used to process the data. Firstly, all GPS-related variables were corrected for match duration by dividing the specific GPS-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 GPS-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 GPS-related variables, which was performed to detect clusters of measures that appear 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 GPS-related (independent) variables in predicting players' group classification (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^{23,24}. 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 using the Receiver Operating Characteristic Curve (ROC).

Results

Demographic and inertial movement analysis (IMA) components

The descriptive statistics as well as the statistical significance of differences in the demographic and GPS inertial movement analysis components between the successful and less successful groups of players are presented in Table 1.

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

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

*p ≤ 0.05; COD = Change of direction

From the tabulated results, it is clear that a large number of differences exist with regard to the demographic and GPS IMA results between the successful and less successful player groups. Despite these differences, only the number of high-intensity accelerations performed during matches corrected for match duration revealed a statistically significant difference with the

successful players that obtained significantly higher values ($p = 0.05$) 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 GPS-determined player load and effort-related components between successful and the less successful players are presented in Table 2.

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

Variables	Total group (n = 22)	Successful players (n = 10)	Less successful players (n = 12)
Match duration (min)	30.54 (9.82)	29.75 (10.20)	31.20 (9.89)
Player load per sec	5.82 (0.75)	5.83 (0.92)	5.81 (0.62)
Distance covered per sec	0.91 (0.12)	0.92 (0.14)	0.91 (0.09)
Peak player load per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Player load per minute	5.81 (0.77)	5.84 (0.96)	5.78 (0.62)
Work-rest ratio	0.74 (0.08)	0.75 (0.10)	0.73 (0.07)
0 - 1 Total load per sec	0.05 (0.01)	0.05 (0.01)	0.05 (0.01)
0 - 1 Distance per sec	0.48 (0.08)	0.49 (0.09)	0.48 (0.07)
0 - 1 % Distance per sec	54.17 (8.41)	53.88 (8.62)	54.42 (8.62)
0 - 1 % Time per sec	88.32 (3.18)	88.40 (3.17)	88.26 (3.33)
0 - 1 Time per sec	26.73 (8.68)	26.11 (9.59)	27.24 (8.23)
0 - 1 Efforts per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
1 - 2 Total load per sec	0.03 (0.01)	0.03 (0.01)	0.04 (0.01)
1 - 2 Distance per sec	0.33 (0.09)	0.32 (0.09)	0.34 (0.10)
1 - 2 % Distance per sec	35.45 (6.78)	34.70 (6.65)	36.08 (7.12)
1 - 2 Time per sec	2.97 (1.44)	2.73 (1.03)	3.17 (1.73)
1 - 2 % Time per sec	10.34 (2.75)	10.10 (2.60)	10.53 (2.96)
1 - 2 Efforts per sec	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
2 - 3 Total load per sec	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
2 - 3 Distance per sec	0.07 (0.03)	0.08 (0.03)	0.07 (0.03)
2 - 3 % Distance per sec	7.93 (2.67)	8.74 (2.92)	7.26 (2.36)
2 - 3 Time per sec	0.22 (0.17)	0.22 (0.13)	0.23 (0.21)
2 - 3 % Time per sec	1.13 (0.55)	1.25 (0.63)	1.03 (0.46)
2 - 3 Efforts per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3 - 4 Total load per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
3 - 4 Distance per sec	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)

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

Variables	Total group (n = 22)	Successful players (n = 10)	Less successful players (n = 12)
3 - 4 % Distance per sec	2.23 (1.51)	2.42 (1.59)	2.07 (1.49)
3 - 4 Time per sec	0.03 (0.03)	0.03 (0.02)	0.03 (0.03)
3 - 4 % Time per sec	0.01 (0.05)	0.00 (0.00)	0.02 (0.07)
3 - 4 Efforts per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4 - 6 % Distance per sec	0.34 (0.49)	0.30 (0.41)	0.38 (0.56)
4 - 6 % Time per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4 - 6 Total load per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4 - 6 Distance per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)
4 - 6 Time per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)
4 - 6 Efforts per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
4 - 6 Efforts per sec	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Low-intensity efforts per sec	0.29 (0.22)	0.33 (0.30)	0.25 (0.11)
Medium intensity efforts per sec	0.09 (0.09)	0.11 (0.11)	0.08 (0.07)
High intensity efforts per sec	0.12 (0.16)	0.15 (0.19)	0.10 (0.14)
All efforts per sec	0.49 (0.46)	0.58 (0.61)	0.43 (0.31)

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

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.

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	Total group (n = 22)	Successful players (n = 10)	Less successful players (n = 12)
HR minimum	115.39 (21.41)	115.15 (24.31)	115.58 (19.78)
HR mean	166.76 (13.84)	168.00 (13.47)	165.73 (14.65)
HR maximum	192.78 (11.31)	195.35 (10.58)	190.64 (11.91)
HR exertion index	89.41 (46.02)	93.90 (56.11)	85.67 (37.87)
120 -160 time	7.69 (7.61)	6.47 (5.32)	8.72 (9.21)
120 -160 %	26.58 (22.64)	23.25 (18.19)	29.36 (26.25)
120 -160 average	145.81 (6.12)	146.45 (5.11)	145.27 (7.02)
160 - 170 time	4.97 (3.67)	4.62 (2.34)	5.25 (4.59)
160 - 170 %	17.35 (10.52)	17.55 (11.09)	17.17 (10.52)
160 - 170 average	162.56 (2.58)	163.15 (0.88)	162.07 (3.39)
170 -180 time	5.76 (3.73)	6.06 (3.97)	5.50 (3.67)
170 -180 %	19.14 (10.93)	20.25 (10.49)	18.21 (11.66)
170 -180 Average	172.66 (1.49)	172.85 (1.41)	172.50 (1.59)
180 -185 time	3.24 (2.78)	3.32 (2.94)	3.17 (2.78)
180 -185 %	10.91 (8.39)	10.75 (7.49)	11.04 (9.41)
180 -185 average	163.64 (52.97)	162.10 (56.96)	164.92 (51.94)
185 -220 time	7.97 (8.11)	7.51 (6.46)	8.35 (9.55)
185 -220 %	23.98 (22.76)	25.15 (22.77)	23.01 (23.72)
3 D per sec	0.10 (0.01)	0.10 (0.01)	0.10 (0.01)
2 D per sec	0.07 (0.01)	0.07 (0.01)	0.07 (0.01)
1 D Forward per sec	0.04 (0.01)	0.04 (0.01)	0.04 (0.01)
1 D Side per sec	0.04 (0.01)	0.04 (0.01)	0.04 (0.00)
1 D Up per sec	0.06 (0.01)	0.06 (0.01)	0.06 (0.01)

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

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

In an attempt to first identify the variables that relate to each other and only retain the relevant variables for the stepwise logistic regression, a cluster analysis was executed. GPS variables were reduced from 91 to 12 variables by means of the cluster analysis. GPS variables that remained were: work:rest ratio, peak player load per sec, 0 – 1 total load per sec, 0 – 1 distance percentage, 1 – 2 time, 3 – 4 distance per sec, 2 dimensional as well as low-intensity efforts per sec as well as low-, medium- and high-intensity accelerations per sec.

Binary forward stepwise logistic regression results

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

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 sec	4.76 (70.51-1312.87)	0.03*
Low-intensity efforts per sec	4.34 (0.41-13.71)	0.04*

*p ≤ 0.05

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

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.

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

Group	Value of the predicted probability		
	Successful players group	Less successful players group	Percentage correct
Successful players	7	3	70
Less successful players	2	10	83.33
Total	9	13	76.88

The classification table indicates that 76.88% of players could be classified into their original groups by making use of the GPS based logistic regression formula. The ROC showed a value of 0.87.

Discussion

To the researchers' knowledge, this is the first study to investigate the predictive value of GPS-determined match characteristics to classify badminton players into successful and less successful groups according to championship results. However, only high-intensity accelerations per sec and low-intensity efforts per sec were identified as significant predictors of group allocation with 76.88% of players that could be classified into their original groups by making use of the GPS-based logistic regression formula. Furthermore, the ROC (0.87) revealed that the classification model is valid model for classifying players into successful and less successful

player groups. An additional analysis by means of the independent *t*-test showed that high-intensity accelerations per sec was the only GPS-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 sec than did the less successful player group. Badminton is portrayed by its sporadic moderate- to high-intensity efforts, instigated by short and repetitive actions^{25,26} that occur during series of high-intensity, brief²⁷ and lengthier, moderate- or high-intensity rallies.^{28,29} Consequently, badminton involves various sprinting movements, in the form of continual short sprints with changes in direction,³⁰ which accentuate the importance of high-intensity accelerations. Badminton's swift pace, the precision and complexity of players' 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.³¹ Previous time and motion analysis-related studies also showed that players' ability to sprint repetitively and change direction while sprinting forms the basis of sport performances.^{32,33} In a study by Chow et al.³⁴ on a dynamic system perspective to understanding badminton singles game play, they revealed that participants' relative speed during match-play and distance at racket-shuttle contact point served as important factors to win points.³⁴ Furthermore, Tiwari et al.³⁵ revealed a significant relationship between the qualities of sub-elite and elite players and agility ($r = 0.83$, $p < 0.05$). Moreover, research suggests that successful players respond more rapidly than less successful players due to a better reaction time and efficacy of effort.³¹ Researchers have not only highlighted the importance of movement speed and high levels of agility but also the speed of nervous system conductivity for badminton players.³¹ Therefore badminton requires players to react quickly and precisely on different cues during match-play³⁶ and to be capable of accelerating effectively at a high intensity to reach the shuttle at various locations on the court. In view of the last-mentioned findings, it is not surprising that high-intensity accelerations per sec was identified as a significant predictor of group allocation.

However, successful players did not only perform more high-intensity accelerations per sec during matches but also more low-intensity efforts per sec than did 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 did 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 longer distance per sec than did less successful players. Therefore more successful players had to exert themselves more as the tournaments progressed.³⁷

The fact that low efforts were also highlighted as a group predictor suggests that more successful players were more capable of anticipating opponents' tactics and the trajectory of the shuttle than were less successful players, which may benefit them in terms of the intensity of efforts that they need to perform. The last-mentioned assertion contributes to findings of Alder et al.³⁸ that successful players' visual search strategies allow them to perceive and anticipate their opponents' movements more accurately.

The identification of high-intensity accelerations per sec and low-intensity efforts per sec for the attainment of badminton performances emphasizes the importance of using badminton drills and conditioning techniques to not only improve players' physical fitness levels but also their abilities to accelerate at high intensities. Although athletic coaches do spend a large amount of time on speed training which is focused on developing acceleration and top speed sprinting,^{39,40} this type of training is not common among badminton coaches. However, it is evident that badminton coaches need to spend more time on speed and acceleration training in order to improve players' abilities to accelerate at high intensities so that they can achieve more success in badminton.

The findings of this study provide insight into an area of research where uncertainty still prevail as it brings clarity with regard to the usefulness of GPS 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 GPS-based logistic regression formula. The ROC value also showed that the classification model is valid for classifying players into successful and less successful player groups. Therefore coaches and sport scientists should not exclusively focus on the development of high-intensity accelerations during match-play but also on the physical conditioning and anticipation of players which allows them to perform more efforts at a low intensity during a match. It is therefore imperative that coaches, sport scientists and other sport-related professionals set up and apply training and conditioning drills that 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 only, but also on players' physical and motor performance components.

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 African badminton singles 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 GPS 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 of badminton performance,⁴¹ 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-mentioned components as part of the testing protocol.

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CHAPTER 5

Relationships Between Results of an Internal and External Match-Load-determining Method in Male Singles Badminton Players



This article was submitted to the *Journal of Strength and Conditioning Research* and it has been accepted.

ABSTRACT

The study was aimed at determining relationships between results of an internal and external match-load-determining method in male singles badminton players. Twenty-one players that participated in selected badminton championships during the 2014/2015 season served as subjects. The heart rate (HR) values and GPS data of each player were obtained via a fix Polar HR Transmitter Belt and MinimaxX GPS devices. Moderate significant correlations were found between HR and absolute duration ($r = 0.43$ at a low-intensity (LI) and 0.44 at a high-intensity (HI)), distance covered ($r = 0.42$ at a HI) and player load (PL) ($r = 0.44$ at a HI). Results also revealed an opposite trend for external and internal measures of load as the average relative HR value was found to be the highest for the HI zone (54.1%) compared to the relative measures of external load where average values (1.29-9.89%) were the lowest for the HI zone. Distance covered, match duration and PL showed no significant correlations with HR for the medium intensity (MI) zone ($r = -0.30$ to 0.04 for absolute and relative values respectively). In conclusion, our findings show that results of an internal and external badminton match-load-determining method are more related to each other in the HI zone than in other zones and that the strength of relationships depends on the duration of activities that are performed in especially LI and HI zones.

KEY WORDS: Racket sport, heart rate, GPS, match-analysis, player load

INTRODUCTION

Badminton is a fast-paced net-based racket sport for two or four participants at a time, with a time-based structure that is described by actions of short duration and high intensity (35). The inclusion of badminton in the 1992 Olympic Games significantly boosted participation with approximately 200 million enthusiasts globally (35). Despite the popularity of badminton, only a small number of researchers have more recently investigated the match-analysis characteristics of the sport (28). The badminton scoring system changed in 2006 from the traditional 3 sets, 15-points system to the new 3 sets, 21-points system (32), and has accentuated the need for more up-to-date research in this area. Researchers currently use various methods to investigate, amongst other things, the match-loads of indoor sport participants such as badminton players. External match-loads are determined through manual video tracking (9), semi-automated video tracking (8) and global positioning system (GPS) analyses (43), whereas internal match-loads are determined by means of blood lactate (10,11) and heart rate (HR) analyses (10,11,30) as well as by using gas exchange values obtained during graded maximal tests (2,33,41). Despite the acceptance and use of these methods, researchers have to date not investigated the relationships between match-analysis results of external and internal match-load-determining methods in badminton players. A more accurate and up-to-date external and internal match-load profile, will allow conditioning coaches to compile match-specific training and recovery programs, which in turn may lead to a decrease in injuries and improvement in performance.

Most researchers prefer notational analysis to evaluate the match characteristics of badminton players by either notating observations or by using complex systems, which consist of video-recording apparatuses and computers (5,28). Notational analysis-related studies that investigated the timing characteristics of badminton matches showed that matches consist of short-duration, high-intensity events or actions interspersed by brief rest periods (35). A typical badminton match consists of an effective playing period of 31% of match time and an average rally period of 7 s, with an average resting period of 15 s (35). Research also suggests that mean rest durations are longer than average rally durations for all forms of the game. The average duration for men's singles rallies was found to be 9.15 ± 0.43 s, whereas the average resting time was reported to be 13.84 ± 1.16 s (31). The duration of rallies varied between 4.57 and 8.86 s on average, whereas work density, which is described as the ratio of work to rest time, yielded values of 0.4 to 0.6 (10). Despite the use of this analytical method, data from notational analysis may not be reliable enough to draw accurate conclusions concerning match-play demands as large inter-observer variations in frequency, total time and mean period of movements have been reported (4). Furthermore, this method is limited in its ability to assess the specific demands of

certain activities and can be very time-consuming when each player has to be monitored for the duration of an entire match over a period of several matches (24).

The introduction of GPS in the 1990s offered an alternative method for measurements of time spent on movements as well as the average duration, frequency and speed of movements, with the potential of circumventing some of the shortcomings of notational analyses and of minimizing others (42). The use of a triaxial accelerometer, magnetometer and gyroscope in a GPS device for analysing indoor sports is still a new phenomenon (29). Accelerometers, gyroscopes and magnetometers are devices that allow researchers to monitor and describe movements as well as the intensity and frequency of these movements in various clinical and sports settings (18). In this regard, accelerometers appear to be valid instruments for determining physical activity levels during activities such as indoor basketball practices, in which intensity is changing constantly (14). Other researchers also revealed that MinimaxX accelerometers showed acceptable reliability (<2%) for measuring the external work-loads of Australian Football players and that these accelerometers are capable of detecting differences in physical activity levels (7). The use of a simulated team sport circuit allowed Wundersitz et al. (45) to show that wearable tracking devices that make use of accelerometer and gyroscope data are accurate for classifying sporting activities in sport scenarios. These findings suggest that available wearable tracking device technology such as the MinimaxX that integrates multiple sensors (triaxial accelerometer, magnetometer and gyroscope) into a single unit may provide researchers with an alternative, more time efficient and accurate external match-load-determining method to assess the match-loads of badminton players (16).

The most common method for determining the internal loads of athletes is through HR monitoring and analyses (21). The basis on which HR monitoring during sport or exercise participation rests is the established linear relationship between HR and oxygen consumption ($\dot{V}O_{2max}$) during exercise (22). The percentage of maximal HR (HR_{max}) values are then utilized for both prescription and monitoring of exercise intensity (6). Overall, researchers that have analysed the HR of badminton players show that average heart rates of between 166 and 188 bpm occur during match-play, while maximal heart rates of between 191 and 195 bpm have been observed during normal and simulated matches (10,44). Although researchers support the use of HR analysis to accurately determine players' internal loads, HR shows a delayed response to sudden high-intensity movements which may lead to an underestimation of match-loads and intensities (27). Furthermore, HR usually takes some time to return to pre-activity levels, which

means that intensity or loads will be overestimated during match-play due to HR inflation (14). In view of these shortcomings, with regard to the use of HR as an internal load-determining method, and the need for more comprehensive match-load profiles, it is important to quantify both internal and external match-load measures and assess relationships between them (39).

A study on relationships between internal and external training load models of basketball training observed moderately significant ($p < 0.05$) relationships between external training load and players' session rating of perceived exertion (sRPE) ($r = 0.49$) and training impulse (TRIMP) ($r = 0.38$) (37). Furthermore, a strong significant correlation was found between external training load and the summated-heart-rate-zones (SHRZ) model ($r = 0.61$) (37). Another study revealed that physical measure of total distance (TD), the volume of low-speed activity (LSA), and player load correlated significantly ($r = 0.71$ – 0.84 ; $p < 0.05$) with HR- and sRPE-based values in soccer players (38). Volume of high-speed running and very high-speed running also obtained significant ($r = 0.40$ – 0.67 ; $p < 0.05$) correlations with measures of internal training load (38). Although these findings indicate that measures of external and internal match-loads are related in team sport participants, no studies have investigated the possible relationship between the external and internal match-load measures in racket sport participants such as badminton players.

In view of this shortcoming and the need for more up-to-date research in the badminton fraternity, the purpose of this study was to determine relationships between results of an internal and external match-load-determining method in male singles badminton players. A better comprehension of the specific match-loads badminton players experience during match-play, may allow sport scientists to compile more badminton-specific conditioning programs to prepare players for the requirements of match-play (22).

METHODS

Experimental Approach to the Problem

An observational, descriptive and *ex post facto* research design was used for the study. The specific hypothesis under scrutiny was that a significant relationship would exist between results of an internal and external match-load-determining method in male singles badminton players.

Before each tournament, a brief meeting was summoned in which the researcher explained in detail the study design, purpose and possible risks to players, managers and coaches. Thereafter, written informed consent was obtained from all players, after which they filled in the general

information questionnaire. 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 GPS harness with a GPS monitor that with which they warmed-up in order to become accustomed to the equipment. The warm-up period was also used to adjust the HR monitor belt and GPS harness according to each player's preference. 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 manner that the entire court was under view. The warm-up period was also used to check the signals of both GPS and HR monitors before each match started. Data from GPS and HR monitors as well as the video footage were downloaded onto a laptop computer for further analyses. All-together, 42 matches were recorded and analysed in order to determine the internal and external match-loads. After data collection, players' movements were categorized according to different player load zones and expressed as absolute and relative distances, times and loads whereas heart rates were categorized into three intensity zones: low, moderate and high based on literature-based criteria (1,15,20). After these categorizations relationships between the absolute and relative distances, times and loads under each player load zone, and the corresponding HR zone were determined.

Subjects

Subjects comprised twenty-one male singles badminton players (age: 23.2 ± 3.6 years; body stature: 176.1 ± 3.4 cm; body mass: 79.6 ± 12.3 kg) that participated in the following championships during the 2014/2015 season: 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. These players represented the following 10 African countries: Botswana, Cameroon, Congo, Egypt, Namibia, Nigeria, South Africa, Uganda, Zambia and Zimbabwe. Only players actively involved and competing as members of their respective teams and national badminton federations, as well as those that were completely injury-free at the time of testing participated in the study. Subjects' competitive badminton playing experience ranged between 4 and 12 years (9.6 ± 2.6 years). The following information with regard to the training regimen of the badminton players was also obtained: players trained for 4.3 ± 1.4 days a week which consisted of on-court training for 3.7 ± 1.0 days a week, and weight training for 1.9 ± 1.4 days a week.

The Health Research Ethics Committee of the institution at which the research was conducted granted approval for the study (NWU-00199-14-A1). Equally, permission to conduct the study

was obtained from the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), the Botswana Badminton Association (BBA), and Badminton South Africa (BSA). The study was conducted in accordance with the ethical guidelines and principles of the International Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council of South Africa.

Test component

Demographic and general information questionnaire: Players' demographic and personal information was collected by means of a questionnaire. Players' age, exercising habits, injury incidence, competing levels and best performances were also obtained by means of this questionnaire.

Anthropometric measurements: Body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd., U.K.) and body stature to the nearest 0.1 cm, using a Harpenden portable stadiometer (Holtain Ltd., U.K.) in order to describe the specific cohort of badminton players.

GPS match analyses: A GPS unit (MinimaxX V4.0, Catapult Innovations, Victoria, Australia) was fitted to the upper back of subjects by using a harness supplied by the manufacturer just before the match warm-up period. The GPS apparatus allowed researchers to obtain data with regard to the following match-related variables (12,13):

Individual Match-analysis (IMA), which included the following: total duration of a match; player load; equivalent distance ran during the entire match; peak player load; player load per minute; the minimum, mean and maximum heart rates achieved during the match; 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 average, and the absolute and relative amount of time a player spent within a specific HR band. Player load is an estimate of physical demand combining the instantaneous rate of change in acceleration in the following three planes: anterior-posterior X, mediolateral Y, and longitudinal Z (36). The player load zones were set as follows: 0-1, 1-2, 2-3, 3-4, 4-6 and 6-10, where 0-1 represented a low-intensity (LI) work load, 1-2 a medium-intensity (MI) work load and 2-10 a high-intensity (HI) work load (12,13). Literature determined that the HR intensity zones for elite badminton players were (1,15,20): LI = <60% of HR_{max} , MI = 60.1-80% of HR_{max} and HI = >80.1% of HR_{max} . Therefore these HR zones were used for classification of players' heart rates.

Recordings from the GPS units were downloaded to a PC and analysed using the Catapult Sprint 5.0.9.2 software (Catapult Sports, Victoria, Australia). MinimaxX GPS Doppler data was used to analyse the GPS-related variables.

Heart rate monitoring: In addition to the GPS unit-derived values, the HR of each player was recorded using 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 the 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 GPS match analyses.

Statistical analysis

Statistical analyses were conducted using the Statistical Data Processing package (Statsoft Inc., 2015). Firstly, players' movements were categorised according to different player load zones and expressed as absolute and relative distances, times and loads. In addition, HR's were categorized into three intensity zones: low, moderate and high, based on the mentioned criteria. Next, descriptive statistics (averages, standard deviations, minimum and maximum values) of each variable were calculated. In a further step, a Spearman's rank correlation, rho was used to determine relationships between the absolute and relative distances, times and loads under each player load zone, and the corresponding HR zone. Lastly, a Fisher r to z transformation was calculated to determine the 95% confidence interval (CI) from the correlation coefficient (r). The level of significance was set at $p \leq 0.05$. The strength of correlations was also categorized based on the following criteria: <0.1 (trivial), <0.3 (small), <0.5 (moderate), <0.7 (large), <0.9 (very large) and <1 (nearly perfect) (23).

RESULTS

Descriptive statistics (averages $\pm$ SD, minimum and maximum) for the external and internal match-load-related results as well as match characteristics are presented in Tables 1 and 2 respectively.

TABLE 1. Descriptive statistics of the external match-load-related results

Variables	Average $\pm$ SD	Min	Max
Match duration (s)	2129 $\pm$ 862	979	5162
Match duration (min)	35.31 $\pm$ 14.40	16.19	86.20
Distance covered (m)	1763 $\pm$ 751.43	681	4449
Distance covered per sec	0.83 $\pm$ 0.16	0.34	1.14
PL	187 $\pm$ 79.62	72	472
PL per sec	5.34 $\pm$ 1.06	2.16	7.28
Peak PL	10.81 $\pm$ 13.86	3.80	72
PL per minute	5.31 $\pm$ 1.05	2.16	7.22
Peak PL per sec	0.01 $\pm$ 0.01	0.00	0.03
LI distance covered (m)	978.09 $\pm$ 331	503	2033
LI distance covered (%)	58.33 $\pm$ 12.21	39.54	88.39
LI match duration (s)	1854.54 $\pm$ 811	266.10	4632.70
LI match duration (%)	89 $\pm$ 8.89	39.62	98.91
MI distance covered (m)	616 $\pm$ 387	65	1697
MI distance covered (%)	32.78 $\pm$ 9.55	9.54	53.45
MI match duration (s)	192 $\pm$ 118.47	19.90	523
MI match duration (%)	9.89 $\pm$ 7.58	0.99	51.31
HI distance covered (m)	170.07 $\pm$ 134.72	8	727
HI distance covered (%)	8.88 $\pm$ 4.51	0.65	18.93
HI match duration (s)	24.57 $\pm$ 20	1	108.90
HI match duration (%)	1.29 $\pm$ 1.40	0.04	9.07
LI-PL	103.67 $\pm$ 35.10	53.35	215.52
LI-PL (%)	58.34 $\pm$ 12.21	39.54	88.35

LI = low intensity; MI = medium intensity; HI = high intensity; PL = player load (PL are in arbitrary units)

TABLE 1 (cont.). Descriptive statistics of the external match-load-related results

Variables	Average $\pm$ SD	Min	Max
MI-PL	65.26 $\pm$ 41.05	6.90	179.91
MI-PL%	32.77 $\pm$ 9.55	9.56	53.45
HI-PL	18.05 $\pm$ 14.28	0.83	77.06
HI-PL%	8.89 $\pm$ 4.51	0.64	18.94

LI = low intensity; MI = medium intensity; HI = high intensity; PL = player load (PL are in arbitrary units)

Descriptive statistics of the external match-load-related results (Table 1) reveal that the average match duration was 2129 ± 862 s (35.3 ± 14.4 min), whereas the longest time duration was spent in the LI zone (1854.5 ± 811 s, $89 \pm 8.9\%$), followed by the MI zone (192 ± 118.5 s, $9.9 \pm 7.6\%$) and the HI zone (24.6 ± 20 s, $1.3 \pm 1.4\%$). An average distance of 1763 ± 751.4 m (0.83 ± 0.2 m.sec⁻¹) was covered during matches with the furthest distance covered in the LI zone (978.1 ± 331 m, $58.3 \pm 12.2\%$) followed by the MI zone (616 ± 387 m, $32.8 \pm 9.5\%$) and the HI zone (170.1 ± 134.7 m, $8.9 \pm 4.5\%$). Players obtained an average PL of 187 ± 79.6 (5.3 ± 1.1 per sec, 5.3 ± 1.1 per min), an average peak PL of 10.8 ± 13.9 and 0.01 ± 0.01 for peak PL per sec. Players achieved the highest average PL for the LI zone (103.7 ± 35.1 , $58.3 \pm 12.2\%$) followed by the MI zone (65.3 ± 41.1 , $32.8 \pm 9.5\%$), while the HI zone delivered the lowest average PL values (18.1 ± 14.3 , $8.9 \pm 4.5\%$).

Descriptive statistics of the internal match-load-related results are presented in Table 2.

TABLE 2. Descriptive statistics of the internal match-load-related results

Variables	Average $\pm$ SD	Min	Max
HR _{min} (bpm)	91.24 $\pm$ 17.44	53	124
HR _{avg} (bpm)	157.10 $\pm$ 13.86	119	180
HR _{max} (bpm)	188.73 $\pm$ 11.68	165	214
LI-HR zone (%)	10.67 $\pm$ 12.51	0.15	52
LI-HR zone (s)	241.15 $\pm$ 303.48	3.20	1046.50
MI-HR zone (%)	35.19 $\pm$ 18.99	6.34	82.79
MI-HR zone (s)	732.21 $\pm$ 480.93	168.20	2113.50
HI-HR zone (%)	54.14 $\pm$ 24.51	0.22	92.79
HI-HR zone (s)	1129.20 $\pm$ 661.78	4.50	2760.60

HR = Heart rate; HR_{max} = Average maximum heart rate; HR_{avg} = Average heart rate; HR_{min} = Average minimum heart rate; LI = low intensity; MI = medium intensity; HI = high intensity

Players obtained an HR_{min} of 91.2 $\pm$ 17.4 bpm, HR_{avg} of 157.1 $\pm$ 13.9 bpm and an HR_{max} of 188.73 $\pm$ 11.7 bpm during match-play. The most absolute and relative time was spent in the HI-HR zone during matches (1129.2 $\pm$ 661.8 s, 54.14 $\pm$ 24.5%), followed by time in the MI-HR zone (732.21 $\pm$ 481 s, 35.2 $\pm$ 19%) and the LI-HR zone (241.2 $\pm$ 303.5 s, 10.7 $\pm$ 12.5%).

Table 3 presents the correlational values between the external (distance, duration and player load) and internal (HR) match-load-related intensity zones.

TABLE 3. Spearman's rank correlations between values of the external and internal match-load-determining intensity zones

Zone	Distance vs. HR		Duration vs. HR		PL vs. HR	
	<i>R</i>	95% CI	<i>R</i>	95% CI	<i>R</i>	95% CI
LI zone (s)	0.17 ^S	0.73 to 0.79	0.43* ^M	1.22 to 1.37	0.16 ^S	-0.03 to 0.03
LI zone (%)	0.25 ^S	0.88 to 0.96	0.38* ^M	1.11 to 1.24	0.25 ^S	-0.04 to 0.04
MI zone (s)	0.04 ^T	0.56 to 0.57	0.04 ^T	0.55 to 0.56	0.04 ^T	-0.01 to 0.01
MI zone (%)	-0.30 ^M	0.02 to 0.12	-0.30 ^M	-0.05 to 0.05	-0.30 ^M	-0.05 to 0.05
HI zone (s)	0.42* ^M	-0.07 to 0.07	0.44* ^M	-0.07 to 0.07	0.44* ^M	-0.07 to 0.07
HI zone (%)	0.05 ^T	-0.01 to 0.01	0.18 ^S	-0.03 to 0.03	0.05 ^T	-0.01 to 0.01

* = $p \leq 0.05$; T = trivial (<0.1); S = small (<0.3); M = moderate (<0.5); HR = Heart rate; LI = low intensity; MI = medium intensity; HI = high intensity; PL = player load (arbitrary unit); 95% CI = 95% confidence intervals; *R* = Spearman's rank correlation coefficient;

Moderate significant correlations were found between absolute distance ($r = 0.42$, $p < 0.05$) covered, time spent ($r = 0.44$, $p < 0.05$) and PL in the HI zone ($r = 0.44$, $p < 0.05$) and HI zone HR. Furthermore, absolute ($r = 0.43$, $p < 0.05$) and relative match duration in the LI zone ($r = 0.38$, $p < 0.05$) also correlated significantly with LI zone HR. Non-significantly trivial to moderate correlations were evident for absolute and relative distance covered as well as PL in the LI and MI zone and HR in the mentioned zones. Only non-significantly trivial correlations were observed between relative distance covered, match duration and PL in the HI zone and HR in the mentioned zone.

DISCUSSION

This is the first study to establish relationships between results of an internal and external match-load-determining method in male singles badminton players. Previous research only compared results of HR- and GPS-based values in soccer and basketball players during training (37,38). Findings of this study revealed that only the following (GPS-derived) measures of external match-load obtained significant relationships with HR-related measures: absolute distance covered ($r = 0.42$), time spent ($r = 0.44$) and PL in the HI zone ($r = 0.44$) as well as absolute ($r = 0.43$) and relative match duration in the LI zone ($r = 0.38$). Hence results suggest that measures of internal badminton match-loads are more related to measures of external match-loads at an LI and HI than at the MI. Furthermore, the duration of activities which can be used as a measure of external match-loads, was more related to measures of internal match-loads than any of the other external match-load-related parameters (distance covered or PL).

These findings are in contrast with those of Scott et al. (38) that found significant correlations between all measures of internal (sRPE and TRIMP) and external training load (total distance, volume of low speed activities, high-speed running, very high-speed running and PL). They also observed that the strength of correlations decreased as the criterion speed of internal training-load measures increased (38). The absolute and relative distance covered, match duration and PL in our study showed non-significant correlations with HR in the MI zone ($r = -0.30$ to 0.04). However, in our study the majority of significant correlations were found between HR and absolute duration, distance and PL in the HI zone. This would mean that HRs were more associated with absolute external match-load-related values in the HI zone than in other zones. In addition, HR seems to be more related to time spent (duration) in a certain intensity zone (LI and HI) than in other external load-related variables. What this suggests, amongst other things, is that external and internal match-load-related measures are especially related to each other, if the duration of an activity in a certain zone is of a sufficiently long duration in order for HR to be able to respond to that activity. From a physiological point of view we would expect this because HR shows a delayed response to sudden, brief-duration high-intensity movements, which may lead to an underestimation of match-loads and intensities (27,38).

As opposed to this, absolute and relative distance covered, match duration and PL in our study showed non-significant correlations with HR in the MI zone, where the absolute values only delivered trivial values whereas the relative values delivered moderate values. This suggests that HRs were more associated with relative external match-load-related values than were absolute external match-load in the MI zone. What this suggests is that external and internal load-related measures were less related to one another due to the fact that players spent negligible time in the MI zone compared to that in other intensity zones. In other words, the duration of activities in the MI zone was not adequate for HR to respond. We would anticipate this since HR usually shows a delayed response to sudden and short-duration movements or intensities (27,38).

Differences in results between the current study and that of Scott et al. (38) may be related to the dissimilarities between the type, intensities and duration of activities performed in soccer compared to badminton. For example, the execution of different shots during badminton match play causes HR to fluctuate. In this regard, Ghosh (19) reported HR_{avg} values of 183 ± 5 bpm, 180 ± 6 bpm and 178 ± 8 bpm for the overhead smash, overhead drop and overhead toss respectively. They attributed changes in HR_{avg} due to shot execution to the high cardiovascular and metabolic demands these actions place on players. On the other hand, soccer consists of kicking movements, which will have a very different physiological response than that of stroke

play in badminton due to differences in muscle recruitment patterns and type of muscles being recruited. Furthermore, during soccer matches of 90 minutes in duration players sprint more or less 110 m (14) compared to badminton matches of 35 min in duration during which players sprint more or less 170 m (see Table 1). The work density (amount of work performed over a certain time) will therefore be much higher for a badminton match compared to that of a soccer match, which may also explain differences in results between studies.

Furthermore, Scott et al. (38) utilized a typical training session of 60 to 90 min to compare the results of the sRPE method and two HR-based methods (Edwards' and Banisters' TRIMP) against the PL (player movements and accumulated accelerations) of soccer (team sport) players. Our study monitored players during actual competition participation. Higher stress levels during competition participation due to the psychological states of individual players may cause players to shift towards sympathetic predominance compared to periods of training, which would explain why relationships between internal and external match-loads in this study showed dissimilar results (17). This notion was also supported by Steele and Chad (40) who indicated that HR responses at threshold intensity, movement patterns, maximal oxygen uptake, metabolic thresholds and lactate levels were higher during match-play than during training sessions of team sport participants (40).

Interestingly, results also revealed an opposite trend for external and internal measures of load as the average relative HR value was found to be the highest for the HI zone (54.1%) compared to the relative measures of external load where average values (1.29-9.89%) were the lowest for the HI zone. On the other hand, relative measures of external load for the LI zone varied between 32.78 and 89.00% compared to the LI-HR zone that revealed a value of 10.67%. These results suggest that match situations may lead to more pronounced cardiovascular responses to activities and movements that take place at lower movement speeds. It is also imperative to know that internal and external match-loads are derived from inherently different methods of match intensity (38). Researchers also suggest that a profile of internal loads may be most appropriate for monitoring purposes (i.e., the load endured by athletes), whereas an external load profile is more important for training prescription and planning purposes (39). Individuals' physiological responses to different exercises and activities (internal load) are also regarded to be a more accurate acute marker of load than are external load-determining measures, but the combination of both load types make up a complete load profile (25,26).

Since only a few significant correlations were found (5 out of a possible 18) between results of an internal and external match-load-determining method, the hypothesis that significant relationships will exist between results of an internal and external match-load-determining method in male singles badminton players is only partially accepted. Only absolute distance covered, time spent and PL in the HI zone as well as absolute and relative match duration in the LI zone revealed significant relationships with HR in the mentioned zones. However, our findings show that results of an internal and external badminton match-load-determining method are more related to each other in the HI zone than in other zones and that the strength of relationships depend on the duration of activities performed in especially LI and HI zones. Finally, due to the limitations of other methods for monitoring badminton players' match-load such as the need for technical expertise or time inefficiency, we suggest that HR- and GPS-analysis provide practical methods for monitoring competitive matches in badminton.

Furthermore, the study findings suggest that more research is required to examine the possible relationship between measures of internal and external loads in racket sports. More emphasis also needs to be placed on markers of individual racket players' responses to different match activities.

PRACTICAL APPLICATIONS

Study results suggest that practitioners should incorporate different methods that will allow them to simultaneously obtain both internal and external match-loads of badminton players in order to compile a more accurate and reliable match-play profile. Findings also support the suggestion that wearable tracking device technologies such as the Polar HR monitor and MinimaxX that integrate multiple sensors into a single unit may provide researchers with alternative, more time-efficient internal and external match-load-determining methods to establish the match-loads of badminton players. Furthermore, absolute distance covered, match duration and PL in high intensity zones could serve as suitable external indicators of badminton players' match-loads. In addition, dissimilarities between results of this and other studies suggest that practitioners should rather make use of actual competitive matches to evaluate and analyse loads instead of simulated matches or training activities. This is an important point as load monitoring may enable practitioners to acquire more accurate profiles of match responses, which will assist them in designing suitable training programs for improved match performances.

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CHAPTER 6

Summary, Conclusions, Limitations and Recommendations



1. SUMMARY

Despite the popularity and the demands of badminton as well as the need for accurate match-analysis data that will enable coaches and other sport-related professionals to determine the match characteristics of badminton, very few researchers have focused their attention on this aspect of badminton. Hence the purposes of this study were fourfold; firstly, to determine the notational singles match-analysis results of male badminton players who participated in the African Badminton Championships; secondly, to determine relationships between notational singles match-analysis-determined strokes and foot movements in male badminton players who that participated in the African Badminton Championships; thirdly, to establish the GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players' group classification and fourthly, to determine relationships between results of an internal and external match load-determining method in male singles badminton players.

Chapter 1 contained a brief introduction as well as the statement of the problem, which formed the base for the research questions, objectives and hypotheses of this study.

Chapter 2 consisted of the literature review titled: "Match analyses of badminton players". The objectives of the literature review were firstly, to provide a history and a detailed description of badminton as a sport; secondly, to describe the various badminton match-analysis methods that resort under the broad categories of internal and external load-determining methods respectively as well as present results of research in which each of these methods were applied to analyse badminton; thirdly, to investigate the limitations of current match analyses methods in order to make recommendations to address these limitations; and fourthly, to discuss research that has investigated relationships between results of internal and external load-determining methods in sport.

The date of inception the archaic game, originally known as 'battledore', can presumably be traced as far back as more than 2000 years ago, but procured its designated name from Badminton House - home of the Duke of Beaufort - located in the heart of South Gloucestershire in the United Kingdom. The most common form of the game is singles (with one player per side) during which a player strikes a shuttle with a racket in an attempt to land it within the opposing side's half of the court in order to score points. Each side may only strike the shuttle once before it passes over the net. Literature showed that badminton matches are analysed via two categories of analysis methods, namely: those that allow researchers to measure the external match-loads,

and those that allow researchers to measure the internal match-loads of players. The literature further revealed that external match-loads could be assessed by using semi-automated video tracking, manual video tracking and global positioning system (GPS) technology. Modern-day tracking devices are further classified into video-based and electronic player tracking systems. Researchers regard wearable tracking devices that integrate multiple sensors such as a tri-axial accelerometer, gyroscope and magnetometer into a single unit to be an alternative method for the measurements of time spent, average duration, frequency and speed of movements, with the potential to circumvent some of the shortcomings of notational analyses and minimize others. In this regard, research showed that the combination of an accelerometer, gyroscope, and magnetometer in a GPS device provides accurate results with regard to movement data and the external demands of sport activities irrespective of the environment. Acceptable between-device reliability values were also obtained when Catapult GPS units with integrated accelerometers were used in an indoor sport setting. Similarly, MinimaxX GPS units were efficient to quantify training loads, work-rates and to compare individual players' performances in an indoor hall. However, a comparison in measures of distance and speed between MinimaxX GPS units and a high-resolution motion analysis system revealed that GPS units underestimated distances covered, especially at higher speeds and during repeated movement patterns.

On the other hand, notational analyses seem to be the preferred method for especially badminton match-analysis. Literature pointed out that notational analysis can be categorised into hand-based, video-based, time-motion and computerised notational analysis methods. Most of these notational analysis methods are aimed at determining match duration, rally time, rest time, stroke frequency, strokes per rally, types of strokes played, and work density, amongst others. In this regard, studies that made use of notational analysis to analyse last-mentioned variables of male singles badminton matches have indicated the following: average match durations vary between 1047 s and 2754.6 s; average rally time between 4.62 s and 10.4 s; average in-between points rest time between 9.71 s and 25.2 s. Results of average match stroke frequency varied between 0.92 s^{-1} and 1.09 s^{-1} whereas strokes per rally varied between 4.74 and 11.1. Work density values of between 0.36 and 0.63 were reported in general for badminton matches. The percentage distribution of the mentioned strokes during badminton matches was reported to be as follows: the smash (13 - 29.1%), the clear (12.1 - 16%), the drop (2.31 - 16.0%), the net stroke (13.32 - 20.7%), and the drive (6.3 - 15%). Literature further pointed out that the clear, drop and net strokes were among the most popular performed strokes in men singles match-play. In addition, male singles players preferred to use the low serve as an offensive strategy, and most of their strokes were returned to the forecourt area. The most effective strokes were returns to the fore-

court, and the most ineffective strokes were returns from the rear-court. Returns from the left rear court scored the most 'ineffective' rate compared to the other areas of the playing court, which is an indication that the backhand performed in the rear court tends to be the weakest stroke among high-level badminton players.

To date, only two studies have compared the effects of the old and new scoring systems on male singles badminton match characteristics by using notational analysis. The following results were found for the mentioned variables by each of the research groups: average match durations of 2754 ± 178.9 s vs. 1949.7 ± 147.6 s and 1443.6 ± 142.8 s vs. 1036.2 ± 160.2 ; average rest time of 10.29 ± 1.42 s vs. 9.71 ± 1.32 s; shot frequency of 0.98 ± 0.01 s⁻¹ vs. 1.05 ± 0.02 s⁻¹ and 1.03 ± 0.47 s⁻¹ vs. 1.03 ± 0.22 s⁻¹ for the old and new scoring systems respectively. Some of the variables obtained significantly higher values for the old compared to the new scoring system. However, researchers postulated that the shorter playing time under the new scoring system would lead to changes in tactical strategies applied during match-play. This, in turn, would result in higher physiological demands (i.e., exercise intensity) of singles matches.

Unfortunately, video-based systems analysis holds certain limitations that need to be considered when interpreting match-analysis results. Numerous cameras have to be fixed, positioned and also calibrated according to the width, height and length of the screened area. Furthermore, video-tape noise, imperfect camera calibration and quantization errors as well as operator mistakes can negatively influence analysis results. Some systems also require extra information such as players' jersey colours and numbers as well as a prediction of players' running patterns. Most systems also do not provide real-time match data as results usually takes about 24 hours to process. One of the major limitations of semi-automated and manual video analysis systems is that it only focuses on the external match-loads of players. Furthermore, notational match-analysis data may not be reliable enough to draw conclusions regarding match-play characteristics and profiles. Researchers also regard this method to be moderate to poorly reliable for determining total time spent, average duration, and frequency of individual players' movements and the types of strokes executed. Another limitation is that only one player can be analysed at a time, which does not allow for the determination of relationships between work-rates of partners or opposing players. Hence researchers will only obtain reliable and accurate information with regard to the match-loads of players if external match-load-determining-methods are combined with methods that are used to measure the internal match-loads of players, such as the heart rate (HR) monitoring method.

Player load is categorised as being internal when measurements are taken to establish the physiological responses players experience when they perform different activities during match-play. HR monitoring is one of the most common and efficient methods researchers use to determine the internal load of sport participants during match-play. Research suggests that the average maximal heart rate (HR_{max}) values that are reached during badminton matches range between 186 and 201 bpm and the average HR values between 162 and 187 bpm. According to literature, HR can be categorized into low- (60 – 69%), medium- (70 – 79%) and high- ($\geq 80\%$) intensity zones based on each player's HR_{max} . However, despite the acceptance and use of HR as an internal load-determining parameter, certain limitations to using this parameter need to be considered. For example, factors such as court and weather conditions as well as hydration status and stress may lead to HR changes that are not related to external match demands alone. Furthermore, HR may sometimes show a delayed response when players perform movements or cease to perform movements, which may lead to an under- or overestimation of internal match-loads. Based on these limitations, with regard to the use of HR as an internal load-determining method, and the need for more comprehensive load profiles, it is essential to quantify both internal and external match-load measures and assess relationships between these two aspects.

The overall literature suggests that significant relationships do exist between session rating of perceived exertion (sRPE) and HR-based training-load models in indoor-related sports such as basketball. Similarly, researchers found moderately significant relationships between basketball players' external accelerometer-determined training load, sRPE and TRIMP (Duration (minute) $\times (HR_{exercise} - HR_{rest}) / (HR_{exercise} - HR_{rest}) \times (0.64 \times 2.712^{192} \times (HR_{exercise} - HR_{rest}) / (HR_{exercise} - HR_{rest}))$). A large significant correlation was also established between external training load and the SHRZ model ((duration in HR zone 1 $\times$ 1) + (duration in HR zone 2 $\times$ 2) + (duration in HR zone 3 $\times$ 3) + (duration in HR zone 4 $\times$ 4) + (duration in HR zone 5 $\times$ 5)) in the same group of basketball players. Significant correlations were also observed between accelerometer-determined physical measures, HR- and sRPE-based values among soccer players. Although these findings indicate that measures of external and internal match-loads are related in team sport participants, no studies have investigated the possible relationship between the external and internal measures in racket sport participants such as badminton players.

The above-mentioned findings suggest that practitioners should incorporate different methods that allow them to simultaneously obtain both internal and external match-loads of badminton players in order to compile a more accurate and reliable match-play profile. On the other hand, a match profile alone will not give researchers an indication of the match profile characteristics

related to badminton performance. The need therefore exists to identify match-analysis characteristics that distinguish between different levels (successful and less successful) of badminton players. The identification of distinguishing match-analysis characteristics may enable coaches and sport scientists to identify and develop these characteristics to enable players to perform successfully. Another aspect that researchers do not focus on is the possible relationships between specific notational singles match-analysis components. Relationships between match-analysis components such as strokes and foot movements may provide researchers and practitioners with important information regarding the influence of different strokes on players' foot movements or *vice versa*. Researchers and practitioners will then be able to focus their attention directly on the most important and influencing components that need to be addressed during physical and skills training. It is against this background that the following articles were compiled.

Chapter 3 contained the research article titled "Notational singles match-analysis of male badminton players who participated in the African Badminton Championships", which was published by the *International Journal of Performance Analysis in Sport*. The article was compiled in accordance with the guidelines of the last-mentioned journal. The purposes of this article were firstly, to determine the notational singles match-analysis results of male badminton players that participated in the African Badminton Championships and secondly, to determine the relationships between notational singles match-analysis-determined strokes and foot movements in male badminton players that participated in the African Badminton Championships. Computerised-notational analysis showed that the percentage of real time played was 29.8% which in absolute terms worked out to 432.9 s on average out of a total match duration of 1470.4 s. Players spent 17.3 s on average resting in-between rallies and performed 68.4 rallies on average per match for an average duration of 5.6 s. Furthermore, on average, 444.3 shots were played per match with a shot frequency of 1.03 shots per second, which caused the average work density to be 0.43 during match-play. Analyses with regard to different strokes played during matches revealed that the drive (122.1 times) and clear (118.0 times), followed by the serve (68.5 times), smash (56.2 times) and net strokes (54.3 times) were performed most often. However, the drop shot was only performed 24.2 times on average during matches, whereas the round-the-head strokes were rarely (1.2 ± 1.3) performed. A further analysis showed that chasse-steps (174.6 times), followed by shuffles (161.7 times) were the foot movements that were performed the most, compared to split-steps (61.6 times), half-lunges (52.2 times), forward-lunges (46.1 times) and scissors-kicks (38.3 times) that were performed less. Lunges to the right (15.5) and lunges backward (12.2) were rarely performed.

Relationships between different badminton shot- and foot movement-related variables revealed that split steps were significantly correlated to three badminton shots, namely the clear, drive and drop shots whereas chasse steps (clear and smash), backward lunges (net and smash) and lunges to the right (net and smash) were all significantly correlated to two shots. All other foot movement-related variables, except for half lunges, were significantly correlated with one badminton shot. The round-the-head and serve shots did not deliver any significant correlations with foot movement-related variables.

Chapter 4 contained the research article titled “The global positioning system (GPS)-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players’ group classification” which was submitted to the *International Journal of Sports Science and Coaching* for possible publication. The article was compiled in accordance with the guidelines of the last-mentioned journal. The purpose of this article was to establish the GPS-determined singles match characteristics that act as predictors of successful and less successful male singles badminton players’ group classification. Only high-intensity accelerations per sec and low-intensity efforts per sec were identified as significant predictors of group allocation with 76.88% of players that could be classified into their original groups by making use of the GPS based logistic regression formula. Furthermore, the Receiver Operating Characteristic Curve (ROC) (0.87) revealed that the classification model is a valid model to classify players into successful and less successful player groups. The independent t-test showed that high-intensity accelerations per sec was the only GPS-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 sec than the less successful player group.

Chapter 5 consisted of the last research article titled “Relationships between results of an internal and external match load-determining method in male singles badminton players” which was compiled and submitted to the *Journal of Strength and Conditioning Research* for possible publication. This article has been accepted by the last-mentioned journal for publication later during 2017. The purpose of this article was to determine relationships between results of an internal and external match load-determining method in male singles badminton players. Moderate significant correlations were found between absolute distance ($r = 0.42$, $p < 0.05$) covered, time spent ($r = 0.44$, $p < 0.05$), player load (PL) ($r = 0.44$, $p < 0.05$) and HR in the HI zone. Furthermore, absolute ($r = 0.43$, $p < 0.05$) and relative match duration ($r = 0.38$, $p < 0.05$) correlated significantly with HR in the low-intensity (LI) zone. Non-significantly trivial to

moderate correlations were evident for absolute and relative distance covered as well as PL and HR in the medium intensity (MI) zone. In addition, only non-significantly trivial correlations were observed between relative distances covered, match duration, PL and HR in the high intensity (HI) zone.

2. CONCLUSIONS

Conclusions drawn from this research are presented in accordance with the set hypotheses in Chapter 1.

Hypothesis 1:

The notational singles match-analysis results of male badminton players that participated in the African Badminton Championships will compare well to that of previously investigated players that also played according to the new 21-point scoring system: an average match duration of 24.06 ± 2.38 min; an average game duration of 8.64 ± 1.33 min; an average rally duration of 4.62 ± 0.86 s; an average real-time played 306.9 ± 46.5 s ($27.7 \pm 2.9\%$); an average rest time of 9.71 ± 1.32 s between rallies; an average work density of 0.48 ± 0.07 ; an average number of shots per match of 331.25 ± 44.74 ; an average number of rallies per match of 70.25 ± 1.26 and 4.74 ± 0.78 for the average shots per rally. Hypothesis 1 is rejected based on the findings that the majority (10 out of a possible 11) of notational singles match-analysis results of male badminton players that participated in the African Badminton Championships showed very different values than those of players from other countries. The results from this study revealed that the average match duration for African male badminton players was 1470.4 ± 341.9 s (i.e. an average match duration of 24.5 min compared to 24.06 min), and the real time and percentage of real time played were 432.9 ± 91.6 s and $29.8 \pm 4.5\%$, compared to 306.9 ± 46.5 s and $27.7 \pm 2.9\%$, respectively. The average duration for rallies was 5.6 ± 5.8 s (compared to 4.62 ± 0.86 s), players performed an average of 6.5 ± 1.3 (compared to 4.74 ± 0.78) shots per rally during each match that worked out to an average number of shots per match of 444.3 ± 101.1 (compared to 331.25 ± 44.74). The work density was determined to be 0.4 ± 0.1 (compared to 0.48 ± 0.07) on average during matches. On average players rested for 17.3 ± 4.6 s (compared to 9.71 ± 1.32 s) in-between rallies during each match.

Hypothesis 2:

Significant relationships will exist between the majority of notational singles match-analysis-determined strokes and foot movements in male badminton players. Due to the fact that the majority of notational singles match-analysis determined strokes and foot movements did not

reveal significant relationships, hypothesis 2 is rejected. However, the study revealed moderate significant relationships between players' chasse steps and clearing shots, split steps and drive, and also lunges-to-right direction and smash shots. Very large relationships were observed between the chasse step foot movements and smash shots, and between backward lunges and net shots. A large significant relationship also existed between scissors kick foot movements and smash shots, shuffle-steps and clear shots, and between split-steps and clear shots. Similarly, large significant relationships were observed between forward lunges and net shots, lunges to the left direction and net shots, backward lunges and smash shots, and between lunges to the right direction and net shots. Similarly, a trivially significant relationship was detected between split steps and drop shots.

Hypothesis 3:

GPS measurements (characteristics) such as player load, time spent in different acceleration zones and efforts performed at different intensities will serve as significant predictors of successful and less successful male singles badminton players' group classification. Hypothesis 3 is partially accepted based on findings that forward stepwise logistic regression results of the cluster analysis' reduced GPS variables showed that only high-intensity accelerations per sec and low-intensity efforts per sec were identified as significant predictors ($p < 0.05$) of group allocation with 76.88% of players that could be classified into their original groups by making use of the GPS based logistic regression formula. Furthermore, the Receiver Operating Characteristic Curve (ROC) (0.87) revealed that the classification model is a valid model to classify players into successful and less successful player groups.

Hypothesis 4:

Significant relationships will exist between the results of an internal and external match load-determining method in male singles badminton players. In view that only a few significant correlations were found (5 out of a possible 18), hypothesis 4 is only partially accepted. Only absolute distance covered, time spent and PL in the HI zone as well as absolute and relative match duration in the LI zone revealed significant relationships with HR in the mentioned zones.

To the researcher's knowledge, this is the first study to provide sport practitioners (sport scientist and coaches) with information concerning the computerised-notational analysis-related badminton singles match characteristics of African players as well as possible relationships between several of these characteristics. It is also the first study to investigate the predictive value of GPS determined match characteristics to classify badminton players into successful and

less successful groups according to championship results. Furthermore, no studies have up until now investigated the possible relationships between the external and internal match-load measures in racket sport participants such as badminton players.

The computerised-notational analysis results showed that the majority of notational singles match-analysis results displayed very different values than those of players from other countries. Therefore, comparative results confirm that African badminton players' match profiles are different from those of other international players. However, current team rankings of the Badminton World Federation indicate that none of the African countries are ranked higher than thirty-first on the world rankings (Badminton World Federation, 2017). Furthermore, the highest ranked African player is ranked hundred-and-fifteenth on the most current list (Badminton World Federation, 2017). Consequently, African players' would need to increase their standard of match-play to successfully compete against higher ranked teams and players of other countries. In this regard, especially real time (306.9 s versus 432.9 s) and percentage of time played (27.7% versus 29.8%), average duration for rallies (4.62 s versus 5.60 s), shots per rally during matches (4.74 versus 6.50) and number of shots per match (331.25 versus 444.30) of African players delivered much lower values than those of other international players. Values were lower despite the average match duration that was more or less similar for African (24.50 min) compared to non-African badminton players (24.06 min). Therefore, comparatively international players maintain a much higher work rate for the same amount of match-playing time than African players. With this in mind, badminton coaches and sport scientist that work with African players will have to focus more on increasing player's ability to enforce and sustain a high work rate while playing matches.

Nevertheless, notational analysis results also suggest that a typical badminton conditioning programme for African players should focus more on drills and activities that take place for durations of 5.57 s at a time, at a work:rest ratio of 1:3 for a total duration of 3-5 min after which a break of 2 min must be allowed. This set can then be followed by another set of activities that lasts more or less 3-5 min. Activities that are executed during each set must be of a high-intensity and incorporate foot movements such as chasse-steps, shuffle-steps, split-steps, half and forward lunges as well as strokes such as the drive, clear, serve, smash and net strokes. The reason for highlighting these foot movements and strokes is that they were identified as the most executed strokes and foot movements during competitive match-play. Furthermore, significant correlations between split steps and three badminton shots (clear, drive and drop), chasse steps and two shots (clear and smash), backward lunges and two shots (net and smash) as well as

lunges to the right and two shots (net and smash) indicate that coaches must compel players to combine these foot movements and shots during badminton practices and drills.

Despite the value of the above-mentioned notational analysis determined singles match results, shortcomings of notational analysis such as time-inefficiency, poor to moderate reliability of results and an inability to do real-time analyses as well as analyse more than one player at a time have accentuated the need for other match-analysis methods. Hence, GPS wearable tracking devices that integrate multiple sensors such as a tri-axial accelerometer, gyroscope and magnetometer into a single unit are seen as an alternative method for the measurements of time spent, average duration, frequency and speed of movements, with the potential to circumvent some of the shortcomings of notational analyses and minimize others. Notwithstanding the potential of these tracking devices to analyse indoor badminton matches, this is the first study to explore the predictive value of GPS determined match characteristics to classify badminton players into groups (successful and less successful) based on championship results. Although study results revealed that only high-intensity accelerations per sec and low-intensity efforts per sec served as significant predictors of group allocation, descriptive statistics also suggested that successful players performed more high-intensity accelerations per sec and low-intensity efforts per sec when compared to less successful players. Similarly, successful players were the group of players that performed more overall efforts and efforts in LI, MI and HI zones than their less successful counterparts. These results indicate that the level and quality of play increase as players progress and that more successful players have to exert themselves more in order to obtain top performances.

Therefore, the above-mentioned findings indicate that badminton coaches should spend more time in their conditioning programs on speed training which is focused on developing acceleration and top speed sprinting. This is especially important in view of the fact that the majority of badminton coaches do not frequently use training techniques that are aimed at improving players' abilities to accelerate at high intensities. On the other hand, the identification of low-intensity efforts per sec as a predictor of group classification suggests that aerobic based training that is aimed at developing aerobic endurance should not be neglected. Although not measured directly in this study, researchers are of the opinion that successful players' visual search strategies allow them to perceive and anticipate their opponents' movements more accurately. This may suggest that more successful players in this study had a better ability to anticipate opponents' tactics and the trajectory of the shuttle than less successful players, which may have benefited them in terms of the intensity of efforts that they had to perform.

Even though the GPS derived findings are definitely of value to describe the match profiles of badminton players, information with regard to relationships between match-analysis results of external and internal match load-determining methods will provide researchers and sport scientists with more clarity concerning the body's physiological responses due to the external loads that are experienced during match-play. Relationships between results of an internal and external match load-determining method in male singles badminton players revealed that measures of internal badminton match-loads are more related to measures of external match-loads at a LI and HI than at a MI. Furthermore, the duration of activities, which can be used as an external match-load measure, was more related to measures of internal match-loads than any of the other external match-load-related parameters (distance covered or PL). What this suggests, amongst other things, is that external and internal match load-related measures are especially related to each other, if the duration of an activity in a certain zone is of a sufficiently long duration in order that HR can respond to that activity. Another unique finding of this study was that external match-load-related relative values increased as internal match-load-related relative values decreased. This is a unique finding as we expected both internal and external loads to increase or decrease in a similar fashion. The overall results also showed that match situations may lead to more pronounced cardiovascular responses to activities and movements that take place at lower movement speeds. However, researchers do regard individual physiological responses to different exercises and activities (internal load) to be a more accurate acute marker of load than external load-determining measures. In addition, the study results suggest that practitioners should incorporate different methods that will allow them to simultaneously obtain both internal and external match-loads of badminton players in order to compile a more accurate and reliable match-play profile.

In addition to dissimilarities between these results and other studies, the study suggests that practitioners should rather make use of actual competitive matches to evaluate and analyse loads instead of simulated matches or training activities. This is an important point since load monitoring may enable practitioners to acquire more accurate profiles of match responses, which will assist them in designing suitable training programs for improved match performances.

3. LIMITATIONS AND RECOMMENDATIONS

Although this current study is the first to provide sport practitioners (sport scientist and coaches) with information concerning the notational singles match analyses results of African badminton players, as well as findings with regard to relationships between notational singles match

analysis-determined strokes and foot movements of this group of players; the GPS-determined singles match characteristics that act as significant predictors of successful and less successful male singles badminton players' group classification and the comparison between methods to determine the internal and external match-loads of male singles badminton players; future researchers that wish to focus on this study area should consider the following study limitations as well as recommendations that will allow researchers to overcome each of the limitations:

1. **Limitation:** The study only focussed on between twelve and twenty-one African, male singles badminton players that either participated in one (1) championship or five (5) championships during the 2014 and 2015 season. The current sample size may have caused the high individual variability in values to have negatively influenced the Spearman's rank correlation coefficients and binary, forward stepwise logistic regression analysis results, causing non-significant results. Furthermore, the relatively small sample size of this study makes it difficult to generalize these results to all African and International Badminton Players.

Recommendation: Future studies should therefore include larger samples of badminton players to verify and expand on the current study results.

2. **Limitation:** The prediction model (binary forward stepwise regression logistic) in this study was developed particularly for male singles African Badminton Players.

Recommendation: Therefore it is of paramount importance to test the logistic model of classified GPS 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.

3. **Limitation:** Technical and tactical components, which have also been recognized as important determinants of badminton performance, were not measured in this study.

Recommendation: As such, further studies may focus on a more elaborate range of variables, which also include the last-named components as part of the testing protocol.

4. **Limitation:** Although the internal and external match load-determining protocols that were used in this study create a platform for other researchers that want to evaluate the match-loads of badminton players, the possible effects of factors such as match outcomes, the level of competition, the strength of opposition players, hydration and recovery status, etc. may influence results.

Recommendation: Researchers that wish to investigate the internal and external match-loads of badminton players should also measure and correct the above-mentioned factors when collecting and analysing data.

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APPENDICES

APPENDIX A: Author Guidelines and Published Article Samples

- The International Journal of Performance Analysis in Sport
Journal sample
Proof of submission
Proof of acceptance
- International Journal of Sports Science and Coaching
Journal sample
Proof of submission
- The Journal of Strength and Conditioning Research
Journal sample
Proof of submission
Proof of acceptance

APPENDIX B: Ethical Approval for Umbrella Project

APPENDIX C: Ethical Approval for Sub-Study

APPENDIX D: Permission Letter from Badminton Confederation of Africa

APPENDIX E: Permission Letter from Badminton South-Africa

APPENDIX F: Permission Letter from Badminton World Federation

APPENDIX G: Permission Letter from Botswana Badminton Association

APPENDIX H: Invitation Letter from Botswana Badminton Association

APPENDIX I: Participation Leaflet and Consent Form for Badminton Players

APPENDIX J: General Information and Data Collection Form

APPENDIX K: Letter from Language Editor

APPENDIX A

AUTHOR GUIDELINES AND PUBLISHED ARTICLE SAMPLES

The International Journal of Performance Analysis in Sport

Instructions for Authors

1. Scope

The International Journal of Performance Analysis in Sport is published on behalf of the Centre for Performance Analysis, Cardiff School of Sport at Cardiff Metropolitan University and in association with the International Society of Performance Analysis in Sport. The emphasis is on the analysis of actual performance in sport and exercise. Studies using observational methods, biomechanical analysis, self-report emanating from actual sports performance, qualitative observation and measurements such as heart rate response during actual sports performance are all within the scope of the journal. Laboratory studies of key techniques within sports are also of interest where such techniques are clearly important and cannot be analysed in detail during actual competition. Such techniques include tennis serves and golf swings. There may be other contributions that do not analyse sports performance at all that are within the scope of the journal. For example, interview studies or meta-analyses may lead to theoretical contributions explaining the nature of sports performance, tactics used and factors influencing performance. Review articles relevant to sports performance are also welcome. Other topics covered include technologies such as design of analysis systems, sports equipment, research into training, and modeling and predicting performance. Contributors wishing to clarify whether papers they are writing are within the scope of the journal are welcome to contact the general editor.

The volume of papers published by the journal has increased from 40 in 2008 to 68 in 2013 and as a consequence the quality of accepted papers has also increased. Authors should use the most recent issues of the journal to understand the required quality. Authors should ask themselves the following questions when preparing a paper.

- a) Does the paper report on a substantive research exercise? If the data could be gathered and analysed over a single weekend, the authors should consider submitting the work for poster presentation at a conference.
- b) Is the research sufficiently original? Will the paper have impact? Does the paper make a contribution to our knowledge of something important about sports performance?

- c) Does the research warrant the number of authors listed on the paper? This has become a problem with a lot of recent submissions where the nature and volume of the work certainly does not warrant the number of authors included. In cases like this, the paper has not been sent for review and has been rejected by the editor.
- d) Is the analysis sufficiently rigorous? Authors should consider the reliability of methods used, the units of analysis used, the choice of independent and dependent variables and the assumptions of any statistical tests used. In saying this, there is nothing wrong with original descriptive research and authors should avoid complex predictive modeling designs where these are not appropriate.
- e) Does the paper fit within the scope of the journal? Sports performance analysis does involve a more expanded array of methods and types of study these days. However, there have been papers submitted to the journal that are clearly not performance analysis papers. Some of these papers are of a very high quality in all other respects, but they are simply not within the scope of the journal.

2. Submission

Authors must submit an original article in electronic form, (preferably by e-mail) in Microsoft Word, to the General Editor (podonoghue@cardiffmet.ac.uk). Papers submitted to the Journal will be refereed blind by acknowledged experts in the subject. The General Editor has the final decision on publication. No word limits are specified for papers, but discursive treatments of the subject matter are discouraged. The Journal does not normally publish letters to the editor.

Due to the volume of papers submitted, we now require authors to provide the names of three potential expert independent reviewers for their paper.

3. Originality

All material submitted for publication in the journal must be accompanied by a statement by the lead author, with the authority of all of the authors, that: the material submitted is original and unpublished, and is not under consideration for publication elsewhere and that the material will not be submitted for publication elsewhere while it is under consideration by the journal.

4. Format

Papers consist of a title page, blind title page and the main text of the paper. Figures and tables should be included in the text rather than following the text. Typical sections of the text are

Introduction, Methods, Results, Discussion, Conclusions, any acknowledgements, References and author correspondence details. However, it is acceptable to have a conclusions paragraph at the end of the discussion. Further variation is possible for review articles or where papers report on a series of studies that are best reported in a study-by-study order.

Page Layout

Pages must be A4 using margins of 3cm at the top, bottom, left and right. Portrait orientation is used except where landscaped orientation clearly assists the presentation of tables and / or figures. Paragraph text should be single spaced.

Title Page

The title page should contain the title (Times Roman, size 18, bold), author names using first names, other initials and surnames and affiliations of authors, the abstract and key words. All text other than the abstract should use Times Roman size 12 font. The abstract should be bold and in italics not exceeding 200 words. It should be inserted in the article after the authors' affiliations and indented by 1 cm at the left and right. The abstract should not contain figures or tables.

Blind Title Page

This should include all of the information on the title page except the author names and affiliations. Where acknowledgements or information in the methods about ethical clearance may compromise the blind reviewing process, the General Editor will temporarily remove this information while the paper is being reviewed.

Headings

Headings and subheadings should all be in Times Roman font, bold and size 12. Headings should be numbered 1., 2., 3., etc. with any subheadings being 1.1., 1.2., for example.

Tables

Tables should normally only include horizontal lines to mark the top and bottom and separate column headings from the main body of tables. Tables must be created in word to facilitate any necessary editing by the journal. There are occasions, where correlation tables, for example, require vertical lines and this is acceptable. Table captions should appear above the table.

Figures

Illustrations, photographs, screen dumps, charts, plates and any other artwork should be included in the electronic submission. Authors must have permission to use any photographs within the paper and copyrighted material from published sources must not be included as Figures in the paper. Figure headings should be placed below figures.

Symbols, units and abbreviations

Symbols, units and abbreviations in papers must conform to the *Système International d'Unités* (SI Units). Authors are advised to consult the National Physical Laboratory publication (R.J. Bell (ed.), 1993, *SI: The International System of Units*. London: HMSO). For all abbreviations other than units, write the word or words to be abbreviated in full on the first mention followed by the abbreviation in parentheses. If at all possible, group these definitions together near the beginning of the article. As indicated earlier, avoid use of nonstandard abbreviations, especially fabricated ones, within the text; words are much easier to read and follow than abbreviations.

References

References in the text are cited as follows: Smith (1985) ... or (Brown and Green, 1996) ... or, if there are more than two authors, as Jones *et al.* (1993) ... or (Jones *et al.*, 1993). Citations of different publications by the same author(s) in the same year are differentiated as Green (1993a) ... (Brown *et al.*, 1995b); the a, b, c, etc., are normally in order of citation in the text. Multiple citations are listed in ascending chronological order. Multiple publications by the same authors are treated in lists: Smith (1991, 1995), Brown and Green (1992, 1993), Jones *et al.* (1993, 1996a,b); or (Smith, 1991, 1995; Brown and Green, 1992, 1993; Jones *et al.*, 1993, 1996a,b). A list of all cited references should be collected at the end of the paper in alphabetical order by, in the first instant, the first author's surname. Where the name of the first author appears more than once, the order is determined by: first, the number of co-authors (zero, one, or more than one); secondly, for one co-author, the first co-author's surname then the year; for two or more co-authors, year then order as dictated by the use of 1990a,b,c (for example) in the citations. The following is an example of how references would be ordered in the reference list: Brown (1980), Brown (1990), Brown and Jones (1977), Brown and Smith (1973), Brown and Smith (1975), Brown *et al.* (1990a), Brown *et al.* (1990b), Brown *et al.* (1990c). Note that the last three examples would all have been cited as Brown *et al.* in the text, with the a, b and c relating to the order of citation. The names and initials of all authors should be given in the list of references. The style should follow the examples below:

Journal Papers

Newton, P.K. and Keller, J.B. (2005), The probability of winning at tennis, Theory and Data, **Studies in Applied Mathematics**, 114, 214-269.

Books

Ashe, A. (1981), **Arthur Ashe's Tennis Clinic**. London: Heinemann.

Chapters of Edited Books (including conference proceedings published as books)

Hughes, M. and Clarke, S. (1995), Surface effect on elite tennis strategy. In Reilly, T., Hughes, M. and Lees, A. (Eds.) **Science and Racket Sports** (pp. 272-277). London: E & FN Spon.

Conference abstracts published in journals

O'Donoghue, P.G. (2003), The effect of scoreline on elite tennis strategy: a cluster analysis. **Journal of Sports Sciences**, 21, 284-285.

5. Proofs

Once accepted papers have been edited, the PDF versions will be sent to the authors for final checking and final editing.

6. Copyright

Submission of a paper to the International Journal of Performance Analysis in Sport is taken to imply that it represents original, unpublished research and that authors agree that the International Journal of Performance Analysis will have copyright to the material.

Notational comparison of men's singles badminton matches between Olympic Games in Beijing and London

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Abstract

The purpose of the study was to compare the notational structure in men's singles games between the Olympic Games in Beijing and London to observe how badminton evolved from 2008 to 2012. Twenty games of each event (n=40), were analyzed using the official videos of the Beijing 2008 and London 2012 Olympic Games. Game duration (Beijing:1124.6±229.9 s vs. London:1260.3±267.1 s; $P<0.05$), real time played (Beijing:306.9±45.7 s vs. London:354.7±86.5 s; $P<0.05$), rally time, shots per rally, rest time at point 11, rest time between games and shots per rally were significantly higher in London than in Beijing. Rally time intervals between 0-2.9 s were more frequent in Beijing ($P<0.05$) than in London and rest time between rallies of 27-29.9 s were more frequent in London ($P<0.05$); this distribution of time intervals suggests that badminton is evolving towards longer rallies with greater rest intervals pushing the limits of the badminton regulations. No differences were found between Beijing and London in the distribution of the last shot in each rally. In conclusion the timing factors of the badminton game was different in London 2012 from Beijing 2008, badminton is evolving towards longer rallies with greater rest intervals resulting in longer matches.

Key Words: Badminton, notational analysis, elite performers, Olympic Games.

1. Introduction

Badminton is a sport characterized by intermittent efforts of moderate to high intensity, caused by short and repetitive actions (Abian-Vicen et al., 2012; Cabello and Gonzalez, 2003; Lees, 2003). In badminton it is necessary to highlight a timing structure with the sequence of action and pause intervals, as is the case with other sports with similar characteristics like tennis (Christmass et al., 1998; Fernández-Fernández et al., 2007; König et al., 2000), squash (Alvero et al., 2006; Sanchis et al., 1998) or paddle (Sañudo et al., 2008). Badminton also involves a high level of perceptual-motor performance

(Munzert et al., 2008), as well as its tactical component (Hastie et al., 2009) and a psychological burden in competition (Faude et al., 2007).

In the field of high level sport performance, evaluation of game actions that occur during a competition is a matter of great interest and importance and a frequent object of study in most racquet sports (Abian-Vicen et al., 2013; Cabello and Gonzalez, 2003; O'Donoghue and Ingram, 2001). Notational analysis using video recordings of the matches is a method that will provide important real conclusions about what matches are like, the characteristics of each event, each player and each competition, and be of use for coaches and players to plan more efficient training and competitions (Abian-Vicen et al., 2013; Fernandez-Fernandez et al., 2008; Hong and Tong, 2000; Hughes et al., 2007; O'Donoghue and Ingram, 2001; Pearce, 2002)

Many studies have examined the importance of different variables such as the timing factors, the motor actions or the technical and tactical patterns of play in different racquet sports like squash (Girard et al., 2007), badminton (Abian-Vicen et al., 2013; Cabello and Gonzalez, 2003; Fernandez-Fernandez et al., 2013) or tennis (Fernandez-Fernandez et al., 2008; O'Donoghue and Ingram, 2001). A large number of technical actions, a reduced decision time between an action and the next one, exceeding the frequency of a shot per second (Abian-Vicen et al., 2013) can currently be observed in every badminton game.

The new "rally-point scoring" system introduced by the Badminton World Federation (BWF) in 2006 has also added a further dimension to the game. Under this new format, a match consists of the best of three games and the player who scores 21 points first wins the game with a difference of two points up to a maximum of 30 points. Several studies have analyzed the notational badminton structure comparing the old scoring system (the best of three games of 15 points for doubles and men's singles and 11 points for women's singles) with the new "rally-point scoring" system (Chen and Chen, 2008; Chen et al., 2011) and also comparing men with women (Abian-Vicen et al., 2013; Cabello et al., 2004; Fernandez-Fernandez et al., 2013). These studies have found differences in the notational structure between both scoring systems and greater total game time, rally time and rest time between rallies in men compared to women. (Abian-Vicen et al., 2013; Cabello et al., 2004; Chen and Chen, 2008; Chen et al., 2011; Fernandez-Fernandez et al., 2013; Ming et al., 2008).

We have not found any study that analyzes the evolution of badminton in notational structure with the current scoring system. Some of the differences between the two scoring systems found in other studies (Cabello and Gonzalez, 2003; Chen and Chen, 2008; Chen et al., 2011) could be due to the evolution of the sport and the changes in the training systems designed to prepare the players. It is possible that these differences between both scoring systems remain when comparing two different moments with the same, "rally point scoring" system, due to badminton players having improved physically, technically, tactically and psychologically during the last few years. The purpose of the study was to compare the timing factors and the notational structure of top world level badminton in men's singles games between the Olympic Games in Beijing and London to observe the evolution of this sport between 2008 and 2012.

of the court, 4) Net: a precise shot from near the net (including net drop, push, kill and brush), 5) Drive: a hard shot made at middle body height and in the middle of the court with a flat trajectory, 6) Lob: a high and deep shot, made from the end up towards the front of the court, and 7) unforced error: an error of a player during the rally in a situation where it was not expected: there was no excessive pressure from the opponent and there were possibilities to make effective shots to place the shuttlecock on the other court.

It should be noted that the variables listed above are generally recognized to comprise an effective evaluation index for analyzing the timing factors and the notational structure of badminton matches (Cabello and Gonzalez, 2003; Faude et al., 2007). The reliability coefficient was calculated in order to ensure that the observation results of the analyst were consistent. The reliability of the timing factors was assessed with the intraclass correlation coefficient (ICC) and the typical error expressed as a coefficient of variation, from three measurements of each variable (Hopkins, 2000). In a previous study, carried out using video-recorded games of badminton from eleven different men's single matches containing a total of 727 points, the ICCs were high for all the variables (from 0.995 to 1). Typical errors expressed as a coefficient of variation were from 0 to 0.9 %.

2.4. Statistical Analysis

The following software programs were used: *Microsoft Excel spreadsheet* (Microsoft, Spain) to store the results and *SPSS v. 17.0* (SPSS Inc., USA) to perform the statistical calculations using descriptive and inferential statistical tests and to calculate means, standard deviations and ranges. Initially, normality was tested in all variables with the Shapiro-Wilk test. After that, Student's t test for independent samples was used to establish the differences in the variables normally distributed between the two Olympic Games (Beijing vs London). Levene's test was used to assess the homogeneity of variance, and it was seen that variances were homogeneous in all variables except in real time played, shots per rally, rest time at point 11 and shots per game. For the non-parametric variables (percentage of the last shot of the rally and frequency of time intervals), differences between the Beijing and London Olympic Games were established with the Wilcoxon signed-rank test. The criterion for statistical significance was set at $P < 0.05$. All the data are presented as mean $\pm$ standard deviation.

3. Results

A comparison of the timing factors of games played in the London Olympics versus the Beijing Olympics is presented in Table 1, all of them showed a normal distribution. Higher values in game duration ($t = 2.12$, $P < 0.05$, the difference was 135.6 s; 95% confidence interval 2.7 to 268.5 s) and real time played ($t = 2.16$, $P < 0.05$, the difference was 47.7 s; 95% confidence interval 3.1 to 92.4 s) were found in the games played in London compared to the games played in Beijing. No differences were found in percentage of time played and total points played in each game.

Table 1. Mean $\pm$ Standard deviation obtained in each timing factor.

	Beijing	London	<i>P</i> value
Game duration (s)	1124.6 $\pm$ 229.9	1260.3 $\pm$ 267.1	.046
Real time played (s)	306.9 $\pm$ 45.7	354.7 $\pm$ 87.5	.039
% time played	27.7 $\pm$ 2.9	28.0 $\pm$ 2.7	.669
Total of played points	34.0 $\pm$ 4.1	34.9 $\pm$ 4.4	.487
Rally time (s)	9.0 $\pm$ 1.1	10.4 $\pm$ 2.1	.016
Shots per rally	9.8 $\pm$ 1.1	11.1 $\pm$ 2.2	.024
Rest time (s)	24.7 $\pm$ 4.3	26.7 $\pm$ 4.6	.162
Rest time at point 11 (s)	69.8 $\pm$ 5.8	79.6 $\pm$ 11.6	.002
Work density	0.37 $\pm$ 0.05	0.39 $\pm$ 0.05	.389
Shot frequency (shots s⁻¹)	1.09 $\pm$ 0.03	1.07 $\pm$ 0.04	.330
Rest time between games (s)	128.7 $\pm$ 5.9	145.2 $\pm$ 8.8	.000
Shots per game	333.4 $\pm$ 50.4	384.9 $\pm$ 94.2	.039

The rally time and the number of shots per rally were 14.6 % ($t = 2.51$ s, $P < 0.05$, the difference was 1.3 s; 95% confidence interval 0.3 to 2.4 s) and 13.1 % ($t = 2.35$, $P < 0.05$, the difference was 1.3 shots per rally; 95% confidence interval 0.2 to 2.4 shots per rally) respectively higher in London than Beijing, no differences were found in rest time between rallies. Rest time at point 11 was significantly higher ($t = 3.36$, $P < 0.05$, the difference was 9.8 s; 95% confidence interval 3.9 to 15.6 s) in games played in London. It is worthy of note that in London on average 51.5 more shots per game were performed than in Beijing ($t = 2.14$, $P < 0.05$, 95% confidence interval 2.84 to 100.2 shots per game) but shot frequency was not different between the two Olympics. The players rested between games 16.5 s more in London than in Beijing ($t = 4.92$, $P < 0.05$, 95% confidence interval 9.5 to 23.6 s).

A comparison in time intervals between London and Beijing in the duration of rallies and breaks in the games of the match is shown in Figures 1 and 2. The rallies were significantly more frequent ($P < 0.05$) between 0 and 2.9 s for Beijing. A tendency was found in the rallies between 6 and 8.9 s to be more frequent ($P = 0.08$) for Beijing and in the rallies between 12 and 14.9 s to be more frequent ($P = 0.06$) for London. In relation to the rest periods between rallies, intervals between 27 and 29.9 s were more frequent ($P < 0.05$) in London. A tendency was found in the rest periods between 21 and 23.9 s to be more frequent ($P = 0.06$) for London and in the rest periods between 15 and 17.9 s to be more frequent ($P = 0.06$) for Beijing.

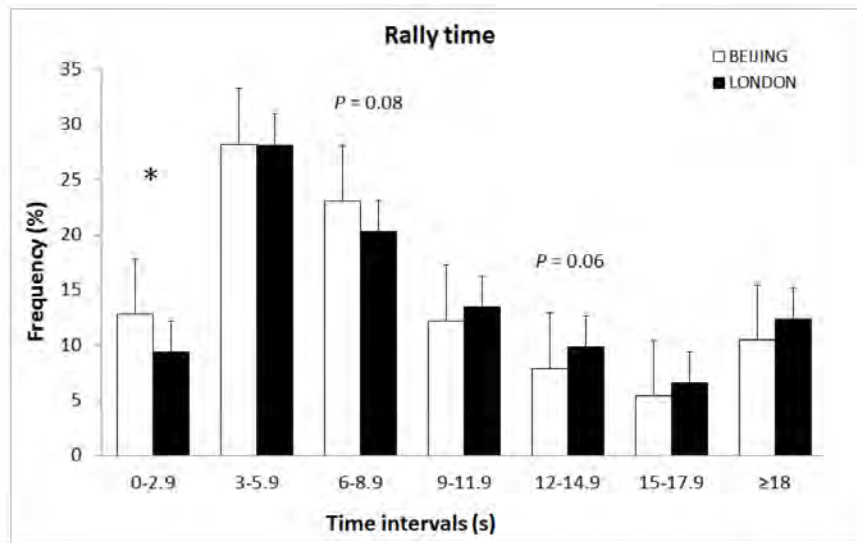


Figure 1. Comparison between Beijing and London in rally time distributed by intervals. (* = Significant differences ($P < 0.05$) between Beijing and London).

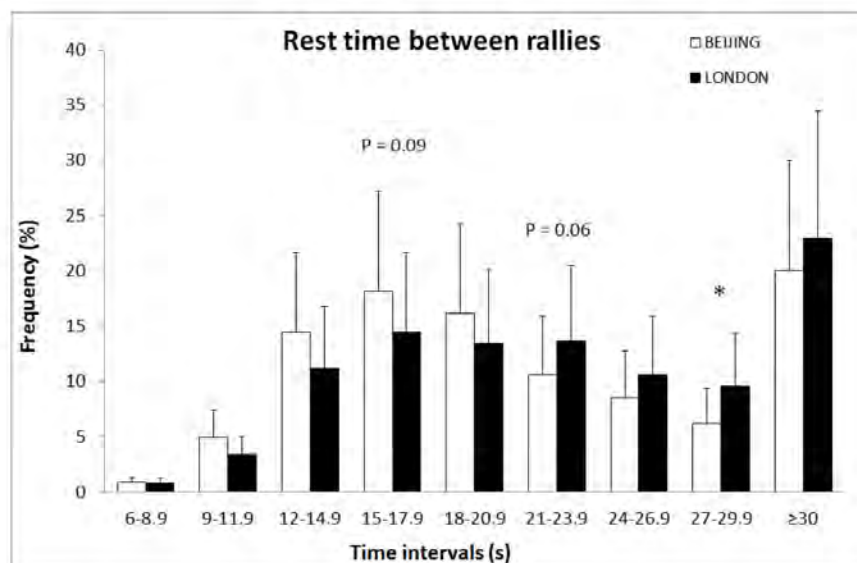


Figure 2. Comparison between Beijing and London rest time between rallies distributed by intervals. (* = Significant differences ($P < 0.05$) between Beijing and London).

The frequency distribution of the last shot of each rally during the game is shown in Figure 3. The unforced error (Beijing: 41.01 ± 9.46 %; London: 42.64 ± 8.89 %; $P = 0.548$) and the smash (29.09 ± 8.43 %; London: 27.84 ± 8.14 %; $P = 0.317$) were the most frequent last shot of the rally. No significant differences were found in any of the shots between Beijing and London, but a tendency was found in the lob (Beijing: 2.31 ± 1.74 %; London: 3.92 ± 4.31 %; $P = 0.06$) to be higher in London and in the net (Beijing: 16.03 ± 6.6 %; 13.32 ± 5.38 %; $P = 0.08$) to be higher in Beijing.

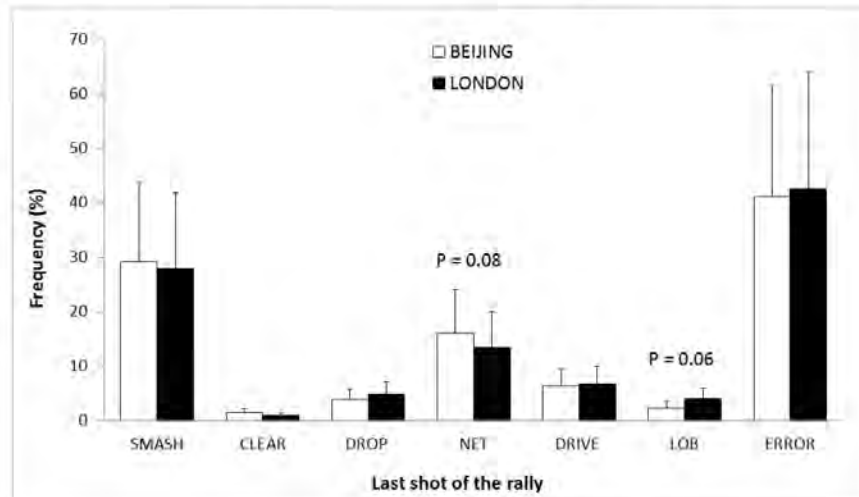


Figure 3. Type of the last shot of each point in the game

4. Discussion

The main findings of this study showed a significant difference in timing structure between the matches played in Beijing and London. Total game duration, real time played, rally time, rest time at point 11, shots per rally and shots per game were higher in London than in Beijing. These findings support our hypothesis that the badminton timing structure has evolved in the four years between the Olympic Games of Beijing held in 2008, the first to be played with the rally point scoring system, and the Olympic Games held in London in 2012. The significant differences observed in a variety of the variables analyzed should be taken into account by the coaches and players to prepare their training and competitions.

When we compared the timing factors of the games played in Beijing and London significant differences were found in most of the variables analyzed. Game duration was 12.1 % higher in London than Beijing (London: 1124.6 ± 229.9 s vs Beijing: 1260.3 ± 267.1 s; $P < 0.05$) and the same was true of the real time played that was 15.6 % higher in London. Total game time and real time registered in our study were greater than those obtained by Cabello and Gonzalez (2003) with the old scoring system (Total game time:

844.5 $\pm$ 156.4 s and real time: 274.4 $\pm$ 49.31 s) and by Chen and Chen (2008) with the new scoring system (Total game time 803.4 $\pm$ 34.7 s and real time: 275.6 $\pm$ 11.5 s). Our values registered with the rally point scoring system are similar to the values obtained by other authors with the old scoring system (Cabello et al., 2004; Chen and Chen, 2008). These are details that create controversy when, according to other studies, the matches were shorter with the new scoring system (Chen and Chen, 2008; Chen et al., 2011; Faude et al., 2007; Ming et al., 2008; Ooi et al., 2009). These differences are probably due to the fact that in this study we analyzed matches of the best players in the world and the current rally time and especially the rest time between points were much higher in our study than in other studies (Cabello et al., 2004; Chen and Chen, 2008), even more so when Cabello et al. (2004) registered that in the old scoring system many more rallies were played per game than with the current scoring system (98 $\pm$ 32 vs 68 $\pm$ 6 rallies per game).

Data registered from the present study suggest that the top players have adapted to the current scoring system. Although it was initially thought that the games would be shorter with the "rally point scoring system" the present data show us that players have increased the intensity of the games with longer rallies (15.5 % greater in London than Beijing) and with more shots per rally. In London we registered 1.3 shots per rally more than Beijing; moreover the shots per rally registered in London were greater than those recorded by other authors in both the new and the old scoring systems in studies performed in the years before 2012 (Chen and Chen, 2008; Chen et al., 2011; Fernandez-Fernandez et al., 2013; Ming et al., 2008). Rest time at point 11 and rest time between games were 14.04 % and 12.8 % respectively greater in London. We deduce from these data that the physical demands required for playing longer rallies and games in London implied the need for a better recovery so that players tried to rest as much as possible during the breaks in the match. The official regulations of the badminton World Federation state that the break in point 11 should be of 60 seconds and between games should be of 120 seconds. The rest time at point 11 and between games in Beijing (at point 11: 69.8 $\pm$ 5.8 s and between games: 128.7 $\pm$ 5.9 s) and mainly in London (at point 11: 79.6 $\pm$ 11.6 s and between games: 145.2 $\pm$ 8.8 s) were higher than those established in the regulations. It is up to the Badminton World Federation to decide the criteria of whether these differences are important or not.

Rally time and rest time registered in badminton have been higher than other racquet sports like tennis, paddle or squash. Sañudo et al. (2008) registered a rally time and rest time of 7.24 s and 9.11 s respectively with 12 national level male paddle players. Smekal et al. (2001) registered a rally time of 6.4 $\pm$ 4.1 s in tennis players and in another study performed with the top 50 professional players in the year 2000 the authors found differences in the timing factors depending on the court surface (Registro Profesional de Tenis, 2002): they registered a mean in the rally time and the shots per rally of 2.3 s and 2.1 shots on grass courts, 5.7 s and 5.1 shots on hard courts and 7.2 s and 6.8 shots on clay courts. All values were lower than those recorded in badminton matches, which makes badminton the racket sport included in the Olympic schedule with the longest points.

It is well established that a winning strategy under the old scoring system is based around patience, control, stamina, and using a succession of shots to open up an area of

the opponent's court for attack (Hong and Tong, 2000). After the change in the regulation of the scoring system players began to play more aggressive badminton adopting different skills and tactics (Pearce, 2002; Tu, 2007). The differences observed in the frequency distribution by intervals of rally time and rest time between rallies (Figure 1 and 2), suggest that current men's singles top level badminton is evolving towards longer rallies in which players have to work each point very well to win, and establish strategies for taking full advantage of the rest time between points to delay the onset of fatigue and maintain a higher performance as long as possible. Longer rallies, a shortened stroke time combined with the increased number of shots per rally seem to make the games played in London more competitive than four years ago, a fact which in addition could be partly related to improved racquet technology, an improvement in the physical and mental health of the players, and improved training methods (Chen and Chen, 2008; Tu, 2007).

No differences were found between Beijing and London in the distribution of the last shot in each rally. The unforced error, the smash, the net and the drive were the most frequent ways points were finished in both Olympic Games, and these shots were those most prevalent in male badminton players in all previous studies both with the new scoring system and with the old one (Abian-Vicen et al., 2013; Cabello and Gonzalez, 2003; Chen et al., 2011). During a men's singles badminton match the lob, the clear and the drop are the preferred tactical shots against repeated smashing (Hong and Tong, 2000; Pearce, 2002) but male badminton players preferred the smash as the last shot to win the points (Abian-Vicen et al., 2013; Chen et al., 2011). The frequency of unforced errors, with an average of $\sim 42\%$, in men's singles in the Beijing and London Olympic Games was lower than the percentage of unforced errors registered in women's singles in the Beijing Olympic Games ($48.6 \pm 9.0\%$) by Abian-Vicen et al. (2013) and in simulated matches with the current scoring system in the study by Chen et al. (2011) with male Taiwanese players, who registered an average of 61.5% of unforced errors. This difference may be due to the fact that in the present study participants were the best male players in the world and their quality was reflected in a lower percentage of unforced errors per game.

5. Conclusions

From these results, we can conclude that total game duration, real time, rest time at point 11, rally time, shots per rally and shots per game were greater in London 2012 than in Beijing 2008. Rally time intervals between 0-3 s were more frequent in Beijing ($P < 0.05$) than London and rest times between rallies of 27-30 s were more frequent in London ($P < 0.05$), this distribution of time intervals suggests that badminton is evolving towards longer rallies with greater rest intervals pushing the limits of the badminton regulations. At the end of each rally, the unforced error, the smash and the net were the most frequent last shot of the rally, both in Beijing and London. The significant differences observed in the timing factors of badminton games between Beijing and London can help players, coaches and federations to manage types of workouts or competition schedules more specifically adapted to the characteristics of current badminton.

6. Practical applications

This paper increases knowledge about badminton match analysis and gives normative values to establish practice and match goals. This research could help to show what the evolution has been like from 2008 to 2012 with regard to the notational structure in men's singles badminton matches with the new "rally-point" scoring system introduced in 2006 by the Badminton World Federation.

The differences registered in timing factors between Beijing and London, based on the analysis of the top world badminton players' matches in the most important championships in the years 2008 and 2012 (Olympic Games), suggest that coaches need to be constantly updating their coaching knowledge to adapt to the evolution of the badminton game in the top world badminton players' training. Data also suggest that further notational studies should be conducted regularly because badminton is a sport that is in a period of full development.

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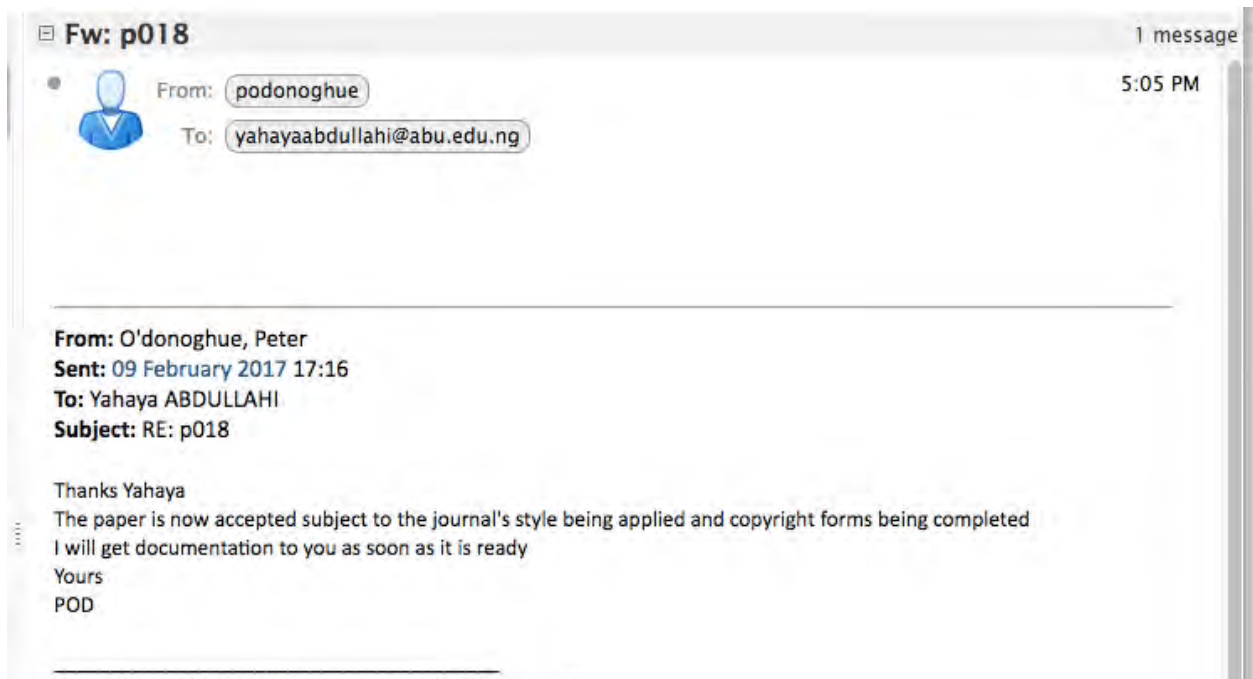
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Dear Sir,
Attached here is the corrected article (p018) for your kind action.

kind regards

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Yahaya ABDULLAHI
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The Science of Speed: Determinants of Performance in the 100 m Sprint

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ABSTRACT

Performance in the 100 m sprint is influenced by a multitude of factors including starting strategy, stride length, stride frequency, physiological demands, biomechanics, neural influences, muscle composition, anthropometrics, and track and environmental conditions. The sprint start, the accelerative phase of the race, depends greatly on muscular power. Three considerations of the sprint start are reaction time (time to initiate response to the sound of the starting gun), movement time (onset of response until end of movement) and response time. Maximal velocity running is a result of stride length and stride frequency. While stride length can be greatly limited by an individual's size and joint flexibility, stride frequency can be affected by muscle composition, neuromuscular development, and training. Although 100 m sprint world record times have progressed drastically, there is limited evidence for how technology has contributed to such improvement. As such, human physiology and physique combine to be the most influential determinants of improved sprint performance.

Key words: Acceleration, Biomechanics, History of Track-and-Field Athletics, Reaction Time, Running Velocity, Sprinting

INTRODUCTION

The shortest existing competition in outdoor track and field running events is the 100 m sprint. As in any sprint race, the primary objective of the 100 m sprint is to cover the designated distance in the shortest time possible. Historically, the race has been recognized as a focal component of track and field, as the man and woman who owns the gender-specific world record in the 100 m sprint also traditionally carries the prominent title of "world's fastest athlete".

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Yannis Pitsiladis (University of Glasgow, UK)

As compared to other sprinting events, the relative simplicity of the 100 m sprint makes it ideal for studying the elements of sprint running. Unlike other track-and-field sprints, such as the 200 m or 400 m event, the 100 m sprint does not involve a curve of the track. Thus, running technique involves purely linear movement, and no centrifugal or centripetal (outward and inward radial) forces.

Given recent world record accomplishments in the male 100 m sprint event, we thought that a review of this event, and the multiple determinants to 100 m sprint performance would be a timely addition to the scientific and coaching literature within athletics. Consequently, the purpose of this review is to identify the features of the 100 m sprint that make it such an iconic event, and summarize the multi-faceted determinants to sprint running performance so that understanding and commentary on performance can be based on science rather than speculation or personal bias.

A SHORT HISTORY OF THE 100 m SPRINT

The 100 m sprint first officially appeared in the Modern Olympics in 1896, in Athens, Greece. In the inaugural race, Thomas Burke, of the United States, claimed victory at 12.00 seconds, and was the lone sprinter who followed a squat starting stance.¹ During the initial decades of the Olympics, the track used in Olympic and World athletic events was predominantly made of crushed cinder, clay, or dirt. In contrast, today's tracks are made of synthetic material designed to offer enhanced cushioning and elastic recoil, or at least this is the theory as we explain later in this review.

Since the late 1900's, the sprint event has remained relatively unchanged, except for the improvements in track conditions and footwear worn by the athletes. Tables 1 and 2 present the top-10 100 m sprint times for males and females, respectively, and reveals that all occurred since 1988. Figures 1a and b presents a chart of the world record times for the 100 m sprint for both men and women, spanning 1912 to the most recent world record. There are certain features of the trend for world record improvement that are interesting. First of all, the improved times do not reveal a smooth trend. There are periods of relative stability in world record performance, spanning as long as 1936 to 1956 for men, and 1935 to 1952 for women. Another period of stability occurred from 1968 to 1988 for men.

The current female world record 100 m sprint time of Florence-Griffith Joyner of the USA in 1988 clearly deviates from the prior world record trend from 1948 to 1984 which was remarkably consistent over this time period. The stark difference between the two slopes of Figure 1a reflect interesting changes in the progression of the 100 m sprint pre- to the post World War II era.

Interestingly, the male world record times for the 100 m sprint revealed consistent improvement pre- and post World War II. Like for the women, the improvement in record times for men slowed down (1983 and 1999), yet then surprisingly improved again, and its greatest rate in the history of the event occurred between 1999 and 2008. The current world record of 9.58 s, belonging to Usain Bolt of Jamaica (set August 16, 2009 at the IAAF World Athletics Championships in Berlin, Germany)¹ beat his own previous standing world record of 9.69 s at the 1998 Olympic Games in China, by 0.11 seconds, and demolished other previous world records in the 100 m dash, including the world record of 9.74 seconds set on September 9, 2007 by fellow Jamaican, Asafa Powell (Table 1). Like the current world record for the women, the current male record is a major deviation from the recent trend.

Table 1. Top 10 Men's All-Time 100-Meter Sprint Times¹

Rank	Time (s)	Athlete	Country	Date
1	9.58	Usain Bolt	JAM	2009
2	9.69	Usain Bolt	JAM	2008
3	9.72	Usain Bolt	JAM	2009
		Asafa Powell	JAM	2009
4	9.74	Asafa Powell	JAM	2008
5	9.76	Usain Bolt	JAM	2008
6	9.77	Asafa Powell	JAM	2007
		Tyson Gay	USA	2008
		Usain Bolt	JAM	2005
7	9.78	Asafa Powell	JAM	2008
8	9.79	Maurice Green	USA	2008
9	9.80	Maurice Green	USA	2007
10	9.82	Maurice Green	USA	1999

Table 2. Top 10 Women's All-Time 100-Meter Sprint Times¹

Rank	Time (s)	Athlete	Country	Date
1	10.49	Florence Griffith-Joyner	USA	1988
2	10.61	Florence Griffith-Joyner	USA	1988
3	10.62	Florence Griffith-Joyner	USA	1988
	10.64	Carmelita Jeter	USA	2009
4	10.65	Marion Jones	USA	1998
5	10.67	Carmelita Jeter	USA	2009
6	10.70	Florence Griffith-Joyner	USA	1988
		Marion Jones	USA	1999
	10.71	Marion Jones	USA	1998
7	10.72	Marion Jones	USA	1998
8	10.73	Christine Aaron	FRA	1998
9		Shelley-Ann Fraser	JAM	2009
10	10.74	Merlene Ottey	USA	1996

DETERMINANTS TO 100 m SPRINT PERFORMANCE

100 m sprint performance is dependent on multiple factors and we have categorized them based on environmental, mechanical/equipment, biomechanical and psycho-physiological labels. Explanations for all items are provided below.

TIMING THE 100 m SPRINT

Clearly, today's use of electronic technology in timing athletic performance is unique to the electronic age, and was not available in the early 20th century athletic events. In fact, coordination of the timing to the starter's gun became electronically automated in 1912, and current standards are that such electronic integration must not add a delay of more than 1/1000th (0.001) of a second to total time. Prior to 1912, hand-timing via use of stopwatches was used to determine winning times, and shortly after, chronographs and photoelectric recording technology became compulsory for timing accuracy. In 1965, the International Association of Athletics Federations (IAAF) began accepting automatic electronically timed

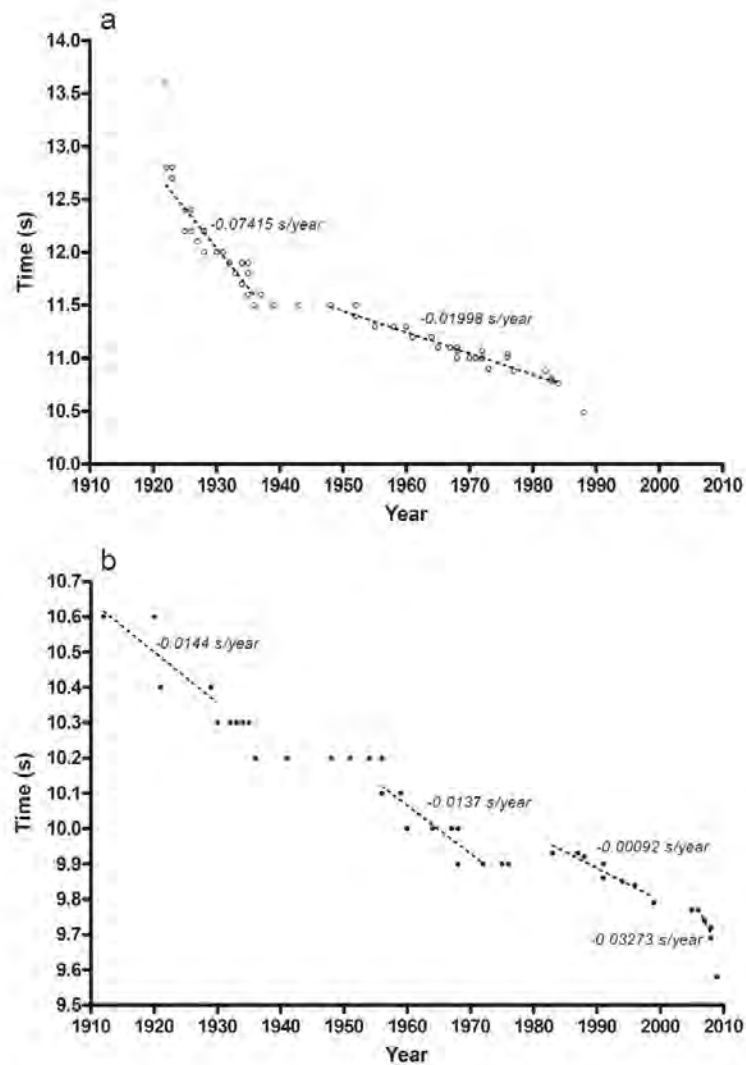


Figure 1. Timelines of 100 m Sprint World Records for a) Females, and b) Males. Regression lines for specific segments show the slopes for the rate of improvement

records for up to the 400 m event. Automatic timing to the hundredth of a second became mandatory on January 1, 1977.

The start of the race is prompted by an official who follows the standard IAAF mandated three-command start that involves two verbal cues and a final, loud gunshot from a starting pistol. The timing of the race begins at the firing of the starting pistol and concludes as the movement of the athletes across the plane of the finish line is electronically monitored. Some technological limitations of timing systems include sensitivity to light, wind, temperature and pressure. However, the most successful and commonly relied on optical systems oscillate at high frequencies, such that they operate optimally despite fluctuations in environmental conditions.²

ENVIRONMENTAL CONDITIONS

Under adequate race conditions, wind is the only environmental factor that may impact the official, documented result of the race. Generally, in the presence of wind, the competitors will race with the wind at their backs. However, the direction in which the competitors will run is officially determined by race officials at the meet. A wind headed the same direction of the race is known as a tailwind. A tailwind exceeding 2.0 mph is sufficient to eliminate a record breaking time.¹

THE SPRINT START

The modern 100 m dash race is held on a straight stretch of the standard 400 m surfaced, oval track. According to the International Association of Athletics Federations (IAAF)¹, the governing organization of track and field, a crouch start is mandatory for the 100 m dash and all other sprint races up to and including the 400 m dash.

The traditional starting position for sprint racing was a standing start. However, as early as 1884, athletes were increasingly adopting a crouched position, and the use of divots in the ground to better support the feet soon followed. The use of a starting block was accepted in 1937, and today we refer to the use of a starting block and related starting position as the crouch start.³

Starting blocks assist in overall acceleration during the sprint start, as the feet can exert large backwards forces and create a stretch of the calf muscles that consequentially load the muscles. When starting blocks first became mandatory in all sprint races, little scientific research supported the use of starting blocks. Recently, Salo and Bezodis³ compared the two starting stances, standing and crouched, to determine if starting blocks should remain a mandatory implement of sprint races. Salo and Bezodis³ found that in using a staggered, standing start, the sprinter is able to increase acceleration in the initial phase of the race, compared to the crouch start. In a standing start, the distance between the front and rear foot is naturally long, causing the individual to exert a greater push on the front foot once the rear foot has cleared the ground. Although there is an initial delay in movement, a longer push produces a higher force, and thus, a greater velocity.^{3,4}

In the crouch start, elongated spacing between the front and rear block plates correlate to an increase in the duration of front foot impulse, but also starting velocity. In a study conducted by Henry⁵, a distance of approximately 26 inches, between the feet in a crouched position, produced greater starting velocity than any other distance. Salo and Bezodis³ determined, however, that the greater horizontal velocity advantage of the standing start was inconsequential to the remainder of the race.

The sprint start is best characterized as the period of time between the moment the sound of the starting gun has been received and the moment both feet have cleared the starting

blocks. According to Harland and Steele⁶, the start can account for approximately 5% of total race time in the 100 m dash.

The sprint start involves near maximal activation and complex, functional movements of an athlete's gross musculature.⁷ A powerful start is crucial to attaining an optimal standard of performance in a sprint race⁴. Three key contributors to the sprint start are reaction time, movement time, and response time. Minimizing the duration of each of these components can contribute to a faster start time, and ultimately a better sprint performance.⁷

Reaction time is the time it takes to initiate the response to a given stimulus. In the sprint start, the stimulus is the sound of the start gun and reaction time is measured by the first change in force after the gun. Movement time is the onset of the response until the end of the movement.⁸ In the sprint start, movement time is monitored from the end of reaction time, when the force by the rear foot on starting block is 0 Newtons, to when the same foot has completed its first successful strike on the ground. Total response time in the sprint start is the time interval that begins at the onset of the "go" signal and halts at the completion of the movement, the first foot strike. Response time is therefore a resultant of the reaction time and movement time combined.

Both legs are equally important in the overall task of the sprint start, but the movement itself is inherently asymmetrical. While both limbs engage in the reactive movement, the trail leg, or the leg in the rear position, is the first to respond.⁴ It remains controversial which leg the sprinter should adopt as the trail leg (the leg placed in the rear position during a staggered stance), as there has been little consistency in theories. Most often, sprinters are encouraged to select a specific leg based on preference, rather than performance.⁸

In the human body, each limb is controlled by the opposite cerebral hemisphere. Because of this unique relationship between each limb and its contralateral hemisphere, Eikenberry et al.⁸ hypothesized that a particular limb may have special access to the specific capabilities of the corresponding cerebral hemisphere, with potential to gateway neurological advantages to improve overall sprint performance. While the right hemisphere has been identified for its role in spatial and attention processing, such as the detection of a signal⁹, the left hemisphere has been identified for its specialization in the execution of muscle forces. The study demonstrated a left-footed start to be consistent with a reaction time advantage, and a right-footed start to be consistent with movement time advantage. A left-foot rear reaction time advantage (26 ms) compared to a right foot rear movement time advantage (104 ms), gave an overall response time advantage of nearly 80 ms. This result was obtained despite varying rear foot preferences among subjects, confirming that asymmetries in the sprint start, a complex, gross motor movement, are due to cerebral organization rather than preferred or practiced stance. In considering the typical sub-10 second outcome of the modern, elite level 100 m dash, a 80 ms advantage can be truly influential in the outcome of the race, suggesting that sprint coaches should emphasize a right foot rear stance in the sprint start.

In regulation with the IAAF¹, the starter verbally initiates the track-and-field sprint start with an "on your marks" command. This command cues the sprinters to assume a crouched position in the starting blocks, such that both feet are in contact with the blocks, hands are placed on the ground behind the starting line, and the knee in rear is relaxed against the surface of the track.

Mero et al.⁴ found sprinters to have greatest velocities out of starting blocks with block angles for both feet set at 40°. Presumably, a 40° block angle offers desirable muscle-tendon lengthening of the gastrocnemius and soleus muscles. Longer initial muscle tendon lengths contribute to greater peak ankle joint moment and power. Decreasing front block obliquity, such that the block angles of 65° and greater demonstrated significantly slower starting

velocities and are not recommended. Decreasing front block obliquity (more of a vertical angle) induces neural and mechanical modifications due to stretch of both muscle and tendons of the gastrocnemius and soleus. Such stretch induces elastic recoil that further supports the velocity of muscle contraction during the explosive pushing phase.

The starter next initiates a "set" command, cuing the athlete to prepare to sprint.¹ The idea is to shift the body center of mass, such that it is forward and upward. Hips will be high, the rear knee will be lifted off the ground, and shoulders will be over the starting line. The athlete will remain in this position until he hears the starting gun fire.

The set position is potentially the most critical position of the sprint start, as optimal body position will translate towards a more consistent, and explosive start. In the set position, the angles of the joints are key towards producing an accelerative position. An angle of 90° between the upper and low parts of the front leg is desirable. Initial velocity is increased with a reduction of the front block angle, as this consequently changes the angles of the knee and ankle, producing a favorable muscle length of the calf that is more powerful. An angle of approximately 120°, between the upper and lower part of the rear leg is desirable, as well. The greater angle allows the rear leg to have a stronger push off the block. The intention is for the rear foot to effectively rotate under the body, to produce a dynamic first step.⁶

Some coaches believe that while the athlete is in the set position, they should actively press hard against the blocks while waiting for the "go" signal. The pressing motion of the feet against the blocks pre-tenses the extensor muscles of the legs. It is expected that in pre-tensing the muscles, the athlete will have an increased ability to generate force in the accelerative phase of the race. However, in a study conducted by Gutierrez-Davila et al.¹⁰, no significant sprint performance differences were observed of muscle pre-tensing in the starting blocks compared with relaxed, or more moderately activated muscles in the starting blocks. On the contrary, Mero and Komi² found the sprint start to be enhanced with activation of the important muscles used in sprint acceleration prior to force development on the starting blocks.

The "go" signal is the sound of a gunshot from the starting gun, fired by the starter. The movement triggered by the "go" signal should be explosive and dynamic. The starter is always positioned closest to lane 1.¹ Research has indicated differences in reaction time of athletes at the starting line, based on the distance between the starting gun and the athlete. Those competitors who are assigned to lanes closest to the starter, have the advantage of hearing the loudest "go" signal, and therefore, will have a faster reaction than the rest of the field.⁷ Loud auditory stimuli have the potential to significantly increase peak force prior to the maximal execution of a simple task. Adopting this theory, it seems probable that the same concept may apply to a complex task, such as sprinting, and increased peak force at the start would facilitate greater horizontal velocity. According to Brown et al.⁷, in an analysis of the 2004 Olympic Games track sprint events, competitors in the inner lanes, the lanes closest to the starter, had significantly lower reaction times than the competitors in the outer lanes. In a study analyzing the sprint start at varying auditory "go" signals, the same researchers discovered the louder the stimulus the shorter the reaction time, and the shorter the time necessary to attain maximal horizontal velocity from the starting blocks. The intensity of the auditory stimulus did not affect the magnitude of maximal horizontal force. However, although Brown et al.⁷ were able to provide evidence to suggest modifications be made to current starting procedures, no current accepted alternatives exist to combat the problem.

A false start occurs when the athlete initiates movement prematurely, and not in response to the starting gun. In recent years, engineers have experimented with technologically advanced starting blocks that contain movement detection devices sensitive to forces on the

blocks, to help identify false starts. However, the majority of force plates have been more unreliable, as they are hypersensitive to movement changes. Therefore, false starts are visually monitored by officials at the starting line.¹¹

ACCELERATION PHASE

The sprint start is purely accelerative, in that the greatest acceleration during the 100 meter dash is achieved during the first 15 m of the race. The sprint start is relatively unconstrained in both spatial and temporal dimensions.⁸ The only constraining objective is that the athlete accelerates from the starting blocks in a relatively straightforward direction in as little time as possible. The movement triggered by the start gun should be explosive and dynamic. Although high propulsive forces may be desirable for forward acceleration, in order to achieve optimal stride frequencies, vertical emphasis should be minimized. Faster individuals typically exhibit longer ground contact time.

In the event that the first step is too long, the hips will lead the movement, compromising the drive phase inherent to effective acceleration.¹² From a mechanical perspective, it is important to orient the body so that the mean location of the body mass (body's center of mass) and the center of gravity is as forward as possible to allow continued forward acceleration.

MAXIMAL RUNNING VELOCITY

During sprint running there are two parameters that affect running velocity: stride length and stride frequency. Speed training should therefore target the improvement of these two components, keeping in mind not to compromise biomechanical efficiency (energy input required to run at a certain velocity). An individual's body mass and body height greatly influence both stride length and stride frequency, independent of the athlete's physical fitness level.¹³ Muscle mass is important to the accelerative phase of the race, where it is essential to overcome inertia and increase the length of the stride.⁷ Body height has a greater impact on maintaining speed and stride length. Faster men are, in general, taller than slower men.¹⁴

An extensive study conducted by Paruzel-Dyja et al.¹⁴ on a large number of elite 100 m dash sprinters, found stride length, not stride frequency, to have the most dominant impact on success in the 100 m dash for the male gender. Interestingly, the opposite was true for top female sprinters, whose excellence in sprint performance was based on high stride frequency rather than long strides. This analysis suggests a distinction for gender-specific technical training, as different parameters of the 100 m dash are characteristic to each gender.

According to Swanson and Caldwell¹⁵, high intensity incline treadmill training is a useful method to trigger adaptations in stride frequency by amplifying lower extremity muscle activation and joint power. However, some researchers argue that high-speed incline treadmill training may not translate to ground-based sprint performance, because total body kinematics differ in the two activities. Other research finds ground-based resistive techniques to decrease both stride frequency and length.¹⁶

While muscle power from the lower body is an important determinant of optimal sprint performance, Chelly and Denis¹⁷ found leg stiffness to significantly correlate with maximal velocity running. Muscle power is a greater contributor during the accelerative phase of the race, while muscular resilience, the efficiency of the muscles to rebound, is inherent to top speed running. The estimated theoretical limit of power output of an Olympic level sprinter is approximately 4400 W. When considering the typical individual who has a body mass of 70 kg, the relative power output is approximately 60 W per kg of body weight. This value is massive, explaining the property of great anaerobic capacity in world-class sprinters.

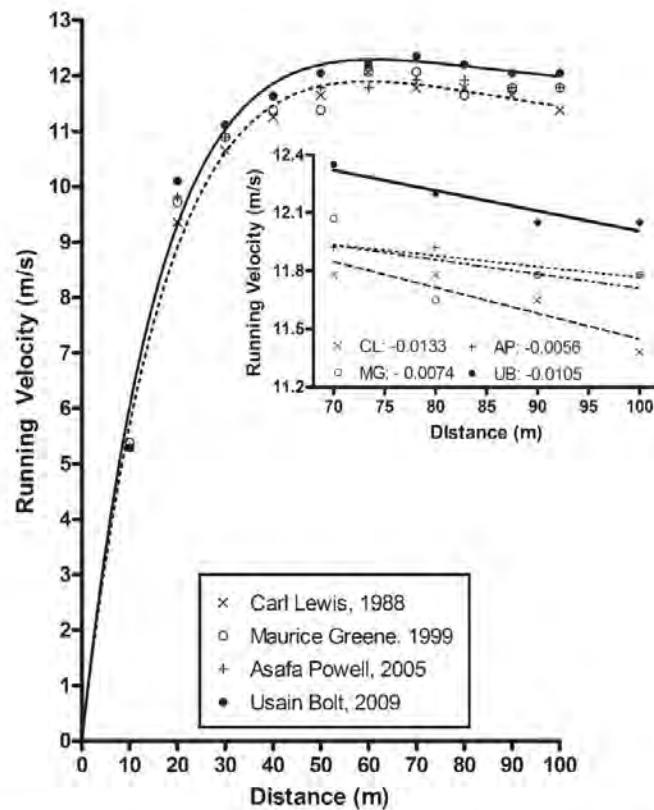


Figure 2. Running Velocity Data for Each 10 m Interval for the Prominent World Men's 100 m Records in Recent History

The two fitted curves are for Usain Bolt (solid line) and Carl Lewis (dashed line) representing the fastest and slowest times of the data set. The in-set graph reveals the differences and similarities in the decrement in running velocity (fatigue) over the final 40 m. The numbers next to the athletes name initials are slopes ($\text{m/s}\cdot\text{s}^{-1}$).

At the elite level, there still exists a great variance of sprinting methods. Figure 2 illustrates the progression of four world-class sprint athletes through their individual, world-record setting 100 m dash races. Despite differing running techniques and physiques, Carl Lewis (1988), Maurice Greene (1999), Asafa Powell (2005) and Usain Bolt (2008) all display a very similar velocity curves in the 100 m sprint. Usain Bolt remains unique in his greater rate of acceleration (increased velocity over time) and peak velocity (Figures 2 and 3). All athletes began to slow down between the 60 – 70 m distances of the race.

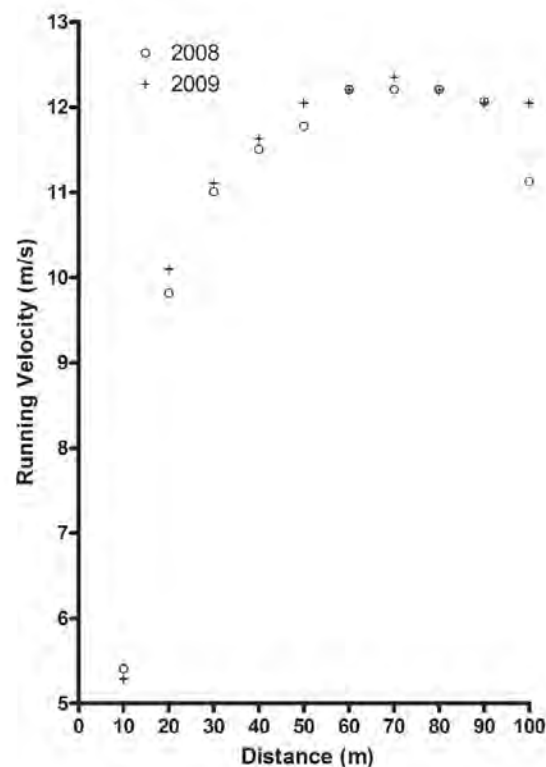


Figure 3. Usain Bolt 10 m Interval Running Velocity for His 2008 vs. 2009 World Record Performances

PHYSIOLOGICAL ELEMENTS

Metabolic factors are important determinants of sprint performance and maximal anaerobic performance.¹⁸ It is believed that genetic factors contribute to about 50% of the variance in short-term anaerobic performance phenotype, although it remains unclear the actual influence of environmental development and genetic factors to differences that are observed in the phenotype.¹⁹

The 100 m dash is a predominantly anaerobic race, meaning physiologically, mitochondrial respiration (involving the consumption of oxygen) has a minimal contribution to the energy generated. The term 'anaerobic power' describes the maximal adenosine triphosphate (ATP) turnover rate by the body, during a short, maximal exercise.¹⁸ As there is always at least a basal rate of oxygen consumption, no exercise performed by the body is totally anaerobic. Nevertheless, the shorter the event, the smaller the 'aerobic' contribution. We know from research of intense exercise for 30 s, that there is about a 30% contribution to ATP turnover from mitochondrial respiration. For the 10 s 100 m sprint, this contribution is probably less than 5%.

The dominant metabolic energy system is the phosphagen system that relies heavily on the muscle store of creatine phosphate (PCr). In the phosphagen system, creatine kinase breaks down creatine phosphate into a creatine molecule and transfers inorganic phosphate (Pi) from PCr to ADP to form ATP. Thus, while the phosphagen system is at work (as long as creatine phosphate remains available) ATP is regenerated at a very high rate and muscle ATP is maintained at a moderately constant level. Interestingly, the phosphagen system can only meet the energy demands of intensely contracting muscle for up to approximately 10 seconds, the time frame encompassing elite 100 m sprint performance.²⁰

While the phosphagen system can efficiently meet energy demands for maximally contracting muscle in an instantaneous manner, its contributions are balanced by the rapid stimulation of the glycolytic metabolic pathway. Glycolytic metabolism, which functions fundamentally on glucose as a fuel source, is an added contributor to ATP turnover during explosive muscle action such as sprint running. Glycolytic metabolism can account for greater than 55% of the energy production during a sprint exercise lasting approximately 10 seconds.²¹ Like the phosphagen system, the glycolytic system's capacity is dependent on its specific fuel reserves (mostly muscle glycogen, with a small supply from blood glucose).

Research has demonstrated sprint training to be effective in enhancing the enzyme activity of creatine kinase (catalysis of PCr) and myokinase (also known as adenylate kinase) (resynthesis of ATP from ADP) in the phosphagen system. According to Hirvonen et al²², maximal sprint performance depends on an individual's ability to catalyze high-energy phosphates, as elite sprinters have an augmented ability to breakdown CrP. In a study assessing maximal sprint performances at 40, 60, 80 and 100 m distances, Hirvonen et al²² established that a decrease in running speed occurs when the body is near depleted of PCr and must rely predominantly on glycolytic metabolism for energy.

Similarly, a higher rate of glycolytic enzymatic activity has been observed in response to sprint training, including enzymes phosphofructokinase, lactate dehydrogenase, pyruvate kinase and glycogen phosphorylase. Most interesting would be the increased expression of lactate dehydrogenase, the enzyme responsible for catalyzing the conversion of pyruvate to lactate, as it solidifies the necessity of lactate conversion. Lactate, commonly thought to hamper performance with accumulation in the body, is actually beneficial to muscle metabolism during sprint running. Lactate production helps offset the effects of metabolic acidosis by buffering, not producing, a proton. In addition, lactate production is an effective and fast mechanism for muscle to regenerate cytosolic NAD⁺, which is essential for glycolysis to continue and regenerate ATP.²³

NEUROMUSCULAR EFFECTS

During sprint running, the entire body engages in movement. Efficient interactions between agonist, antagonist, and synergist muscles in joint kinematics are key characteristics to optimal sprint performance. The agonist muscle, the active muscle, must have the ability to effectively generate great force. At the same time, to get the greatest output from the agonist muscle, the antagonist muscle must relax. In running motion, when one knee extends, the other knee flexes. During knee extension, the agonist muscle group is the quadriceps (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius) and the antagonist group is the hamstring muscles.

According to Daley et al.²⁴, all terrestrial animals adhere to a common joint kinematics during steady movement, despite natural variability, including number of legs, size and shape of legs, and body mass. Sprint running is characteristically a complex and multi-joint exercise. Improved movement coordination will have a greater impact on muscle force gains

in more complex, multi-joint exercises.²⁴

Although the lower body receives considerably more attention in sprint running research, the upper body has an important role of counterbalancing the actions of the lower body. The shoulder region is the origin of the arm swing, while the hip region is the origin of the leg swing. The arms act contralaterally to each leg, which is inherent to running.¹³ Stride frequency, which is an important contributor to maximum speed running, will be best accommodated by strong shoulders and hips, as they will be essential to generating a faster swing.

During maximal sprinting, it is both biomechanically and aerodynamically favorable for a sprinter to have a slight forward lean in the body. A forward lean of the body optimizes the striking angle of the foot. The athlete is better positioned to strike on the forefoot during ground contact, a region of the foot that is commonly termed the ball of the foot.²⁵ A forefoot strike can more easily translate to a quicker toe-off in initiation of the next stride, than an alternative foot strike. A flat-footed strike or a heel-to-toe strike, would both be detrimental to purpose of a sprint stride, which is to generate a fast and explosive turnover for a faster time. Heel contact with the ground would prolong the stride initiation phase.¹³

To improve speed, muscles and movements inherent to sprinting action should be specifically targeted. Research demonstrates that exercises that emphasize the speed and full range of movement have a greater effect on sprint performance than exercises that emphasize only absolute strength.¹⁹ Sprint running, like most athletic activities, requires strength at fast velocities (power). Studies demonstrate strength increases to be specific to the velocity at which they are trained. Thus, it is optimal to target both force production and velocity of muscles in resistance training to maximize power performance, which cannot be achieved by traditional heavy resistance strength training that follows a high force and low velocity format. To increase power and sprint performance, resistance training must be conducted at high speed.

Every gross and fine motor movement impacts the nervous system in a positive or negative manner, thus it is important to train neural pathways to behave accurately with the desired movement pattern. With increased complexity of movement, the greater the number pathways trafficking in the brain and neuromuscular system. In sprint training, the nervous system must be stimulated to act specifically to fast movement. Cardiovascular fitness is an important component of high-speed performance sports, but training involving slow movements will counteract the goal of sprint performance, which is to be dynamic and explosive. Nevertheless, the only condition where this may not apply is for the use of resistance training with high loads for the development of increased muscular strength.

MUSCLE COMPOSITION

Human variations in skeletal muscle properties affect maximum speed potentials. For example, individuals who have a genetic expression of fast-twitch muscle will be better suited to events that involve rapid and forceful muscle contractions such as sprinting. Researchers believe that muscle fiber composition is genetically determined and minimally affected by training.²⁶ Type I, oxidative muscle fibers, are rich in mitochondria, red in appearance and carry great endurance capacity. Type II muscles fibers, also known as fast-twitch muscle fibers, possess few mitochondria, are white in appearance, and have a high capacity to contract forcefully and rapidly, due to having different structures of key proteins involved in muscle contraction that allow faster ATP breakdown and contractile protein movement during contraction.²⁷ Fast-twitch fibers are commonly additionally classified as fast-twitch type a (IIa), (moderate fatigue resistance) and fast-twitch type b/x (IIb/x) (low

fatigue resistance). While training does not affect the distribution and amount of slow-twitch and fast-twitch muscle fibers, type IIa and type IIb/x fiber types may interconvert with training.²⁷

Muscle fiber size is greatly affected by age and training. Muscle fiber area increases by 15-20 fold (hypertrophy) from birth through young adulthood. While increases in muscular strength are often accompanied by muscle hypertrophy, an increased ability to generate force does not always occur with simultaneous increases in muscle cross-sectional area.²⁵ This phenomenon is a result of an improvement in the capacity of the neuromuscular system to recruit and activate a greater number of muscle motor units.

TECHNOLOGY

The introduction of technology to the sport of track and field makes it difficult to ascertain whether the decline in men's 100 m dash world record times should be attributed to more technology, raw physical ability of the athlete, knowledge of proper technique, or other variables. However, it is clear that world records have significantly changed over the decades (Figure 1), and while female world-record times have not improved since 1988, the recent trend for continued improvement in male sprint world-record times raises the possibility for equipment-centered technological contributions to sprint performance.

Since the 18th Olympiad held in Japan, the last venue to host an Olympics with a track made of cinders, all running and approach surfaces have been made with synthetic materials. Percy Beard pioneered the first synthetic hard surface track in the 1940s. Since then, synthetic track surfaces have dramatically advanced to provide greater recoil for improved running times. The first spiked shoes were used in 1868 in a track meet hosted in London, and according to historians the shoes were helpful in winning a prize in every event in which they were used. Stefanyshyn and Fusco²⁸ determined that increasing shoe stiffness increases sprint performance by modifying tension in the calf muscles.

Research surrounding synthetic tracks has been contradictory. According to Stafilidis and Arampatzis²⁹, although changes in track stiffness may cause differences in joint displacement, the center of mass movement, ground contact times and lower limb mechanics remain unaffected. Whereas in the study by McMahon and Greene³⁰, very compliant surfaces contributed to an increase in ground contact time and decreases in step length, leading to slower running speeds.

Despite advances in technology, modern-day sprinters have limited control over technology. Essentially, each competitor has equal access to racing technology. Therefore, the recent acute differentiations between sprint times, may suggest that human ability is a much greater contributor to sprint performance in the modern-day 100 m sprint than technology itself.

CONCLUSION

Adaptations in sprint performance are gauged through improvements in sprint times. Training modality and intensity will dictate the body's neurological and muscular adaptations. Although not discussed in this article, sprint performance greatly depends on the health and motivation of the athlete. Injuries can considerably hamper performance, as can poor mental focus. It is also important to recognize frequent ergogenic aid and supplement use amongst athletes for performance enhancement. While such conduct is not encouraged or accepted by the greater athletics community, supplementation may be as much a factor in modern sprint performances as training programs that enhance technique.

When considering whether sprinting speed can be improved through training,

constructive proof lies in the fact that personal records are constantly being broken by individuals. In the year of 2008, Usain Bolt posted a total of ten sub-10-second 100 m dash times, all career best times and none associated with drug abuse.

Optimal sprint performance depends on many controllable and non-controllable factors. Aspects that are fixed are an athlete's anthropometric measurements (height, body cross-sectional area, limb lengths) and to a large extent muscle composition. To combat these limitations, sprint coaches seek training programs that augment an athlete's strength, power, and neuromuscular system, for an overall positive effect on sprint performance. As described in this article, sprint training programs must aim towards increasing the recruitment and activation of an athlete's gross musculature, such that elements characteristic of top short-sprint performance come naturally for the athlete. These key attributes include an explosive start, a smooth transition to maximal running speed without compromise in the accelerative phase and maintenance of top speed throughout the remainder of the race. Sport-specific training and resistance training at high velocities will gateway the greatest adaptations in musculature and kinematic control.

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The basic and derived units most commonly used in reporting research in this Journal include the following:

Mass - gram (g) or kilogram (kg); force - newton (N); distance - meter (m), kilometer (km); temperature - degree Celsius (°C); energy, heat, work - joule (J) or kilojoule (kJ); power - watt (W); torque - newton-meter (N·m); frequency - hertz (Hz); pressure - pascal (Pa); time - second (s), minute (min), hour (h); volume - liter (L), milliliter (mL); and amount of a particular substance - mole (mol), millimole (mmol).

Selected conversion factors:

$$1 \text{ N} = 0.102 \text{ kg (force);}$$

$$1 \text{ J} = 1 \text{ N} \cdot \text{m} = 0.000239 \text{ kcal} = 0.102 \text{ kg} \cdot \text{m};$$

$$1 \text{ kJ} = 1000 \text{ N} \cdot \text{m} = 0.239 \text{ kcal} = 102 \text{ kg} \cdot \text{m};$$

$$1 \text{ W} = 1 \text{ J} \cdot \text{s}^{-1} = 6.118 \text{ kg} \cdot \text{m} \cdot \text{min}^{-1}.$$

When using nomenclature for muscle fiber types please use the following terms. Muscle fiber types can be identified using histochemical or gel electrophoresis methods of classification. Histochemical staining of the ATPases is used to separate fibers into type I (slow twitch), type IIa (fast twitch) and type IIb (fast twitch) forms. The work of Smerdu et. al (AJP 267: C1723, 1994) indicates that type IIb fibers contain type IIx myosin heavy chain (gel electrophoresis fiber typing). For the sake of continuity and to decrease confusion on this point it is recommended that authors use IIx to designate IIb fibers in their manuscripts.

Smerdu, V., Karsch-Mizrachi I., Campione M., Leinwand L., Schiaffino S. Type IIx myosin heavy chain transcripts are expressed in type IIb fibers of human skeletal muscle. Am J. Physiol. 267 (6 Pt 1):C1723-1728, 1994.

THE RELATIONSHIPS BETWEEN INTERNAL AND EXTERNAL TRAINING LOAD MODELS DURING BASKETBALL TRAINING

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ABSTRACT

Scanlan, AT, Wen, N, Tucker, PS, and Dalbo, VJ. The relationships between internal and external training load models during basketball training. *J Strength Cond Res* 28(9): 2397–2405, 2014—The present investigation described and compared the internal and external training loads during basketball training. Eight semiprofessional male basketball players (mean $\pm$ SD, age: 26.3 $\pm$ 6.7 years; stature: 188.1 $\pm$ 6.2 cm; body mass: 92.0 $\pm$ 13.8 kg) were monitored across a 7-week period during the preparatory phase of the annual training plan. A total of 44 total sessions were monitored. Player session ratings of perceived exertion (sRPE), heart rate, and accelerometer data were collected across each training session. Internal training load was determined using the sRPE, training impulse (TRIMP), and summated-heart-rate-zones (SHRZ) training load models. External training load was calculated using an established accelerometer algorithm. Pearson product-moment correlations with 95% confidence intervals (CIs) were used to determine the relationships between internal and external training load models. Significant moderate relationships were observed between external training load and the sRPE ($r_{42} = 0.49$, 95% CI = 0.23–0.69, $p < 0.001$) and TRIMP models ($r_{42} = 0.38$, 95% CI = 0.09–0.61, $p = 0.011$). A significant large correlation was evident between external training load and the SHRZ model ($r_{42} = 0.61$, 95% CI = 0.38–0.77, $p < 0.001$). Although significant relationships were found between internal and external training load models, the magnitude of the correlations and low commonality suggest that internal training load models measure different constructs of the training process than the accelerometer training load model in basketball settings. Basketball coaching and conditioning professionals should not assume a linear dose-response between acceler-

ometer and internal training load models during training and are recommended to combine internal and external approaches when monitoring training load in players.

KEY WORDS team sport, court-based sport, exercise, heart rate, accelerometer

INTRODUCTION

The implementation of techniques to monitor athlete responses to training stimuli is pertinent to the team-sport coach and conditioning professional. Measurement of athlete training loads provides objective evidence for the management of training variation, which might allow greater precision and control of periodized conditioning plans along with a reduced incidence of overtraining (23). Accordingly, various methods of monitoring internal (5,16,18) and external (9,15) training load in team-sport athletes have emerged.

The internal training load represents the physiological stress imposed on the athlete in response to the training stimulus (e.g., perceptual rating of intensity, heart rate [HR], hematological measures) (33,34). Meanwhile, quantification of the physical training stimulus detached from the internal response of athletes indicates the external training load (e.g., training duration, distance traveled, running speed, and body accelerations) (33,34). To date, internal training load models incorporating perceptual (3,18,22) and physiological (3,5,16) parameters have been the most widely used in team sports. Specifically, Foster et al. (18) developed a training load model incorporating perceptual indicators of exercise intensity through the session rating of perceived exertion (sRPE) and exercise duration. Moreover, Bannister (5) proposed a physiological training load model based on resting, mean, and maximum HR responses and exercise duration, identified as the training impulse (TRIMP). Similarly, Edwards (16) put forward the summated-heart-rate-zones (SHRZ) model that determines training load based on the duration spent working in predetermined HR ranges. These models have been applied in field-based team sports, including Australian rules football (34), rugby league (19), and soccer

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(23,22). However, limited internal training load data exist for court-based team sports, such as basketball (25).

Training load approaches need to be determined for each sport and should address the specific demands encountered by players in that sport. Recent time-motion data indicate that the high-intensity intermittent nature of basketball game play, combined with the requirement to perform sport-specific activities such as dribbling, shuffling, positioning, and cutting maneuvers, impose a unique set of demands on basketball players (7,29,30). Consequently, it is important that the efficacies of established training load models are assessed during basketball training so that appropriate workload monitoring practices can be adopted in the sport. To date, internal training load responses have largely been reported during isolated training sessions (18) or game play (27) in basketball players. Only one investigation could be identified reporting on training load responses across repeated training sessions in basketball players (25). Manzi et al. (25) observed significant relationships ($r = 0.69\text{--}0.85$, $p < 0.001$) between the sRPE and HR-based training load models in professional male basketball players during in-season training. Although Manzi et al. (25) provide novel findings regarding the use of internal training load models, comparisons with these models and external training load are yet to be reported in basketball. Measurement of the external training load in basketball is warranted given both internal (e.g., sRPE, HR, and hematological measures) and external responses (e.g., movement distances, speeds, and accelerations) have been suggested to comprise the complete training process (33,34). More specifically, the internal and external training loads have been likened to the training response and dose, respectively (33,34). As such, assessing the commonality of popularized internal training load models with externally derived measures of the training stimulus provides insight into the construct validity of internal models (34), which has been examined in various other team sports (11,33,34).

Currently, a paucity of research has examined external training load models in basketball, possibly because of the limitations associated with popular approaches used in other team sports. For instance, the labor-intensive nature of time-motion video analyses (15), and the signal interference (26) and inaccuracies (14) associated with global positioning system (GPS) use during indoor court-based sports, limit the applicability of these methods to basketball. Alternatively, accelerometry overcomes many of the aforementioned limitations of other approaches to monitor external training load and has received increased interest as a practical approach to measure external training load in team sports (11,33,34). A triaxial accelerometer training load model has been developed that involves vector magnitude calculations of the instantaneous rate of change in acceleration in the 3 movement planes (8,26). Given that basketball-specific activity typically involves whole-body displacement in forward, backward, lateral, and vertical directions, the accelerometer

training load model is suited to monitor external training load during basketball training (26). However, to date, the accelerometer training load model has only been used to differentiate the physical demands experienced by elite junior male basketball players during different individual drills (26). Subsequently, the accelerometer training loads experienced by basketball players during repeated complete training sessions typically performed across the annual training plan are yet to be elucidated. Furthermore, this approach might provide a practical approach in basketball settings against which comparisons with common internal training load models can be made.

The provision of these data will provide important practical insight regarding the construct validity of various internal training load models through comparisons with external training load in basketball settings. The aim of this study was to describe and compare the internal (sRPE model, TRIMP, and SHRZ models) and external training loads (accelerometer model) encountered during basketball training. Given previous team-sport studies have shown player response to significantly ($p \leq 0.05$) correlate with concomitant training stimuli ($r = 0.72\text{--}0.84$) (11,33,34), it was hypothesized that internal and external training load models would be strongly related and possess high shared variance ($R^2 > 50\%$) during basketball training.

METHODS

Experimental Approach to the Problem

Players were monitored during the general and specific preparatory phases of the annual training plan. The activities performed during each of the training phases are detailed in Table 1. Player sRPE and HR were collected across all training sessions to calculate internal training load responses. In addition, player accelerometer outputs were obtained across all training sessions to calculate external training load. All outdoor and indoor training sessions were conducted in similar ambient conditions (temperature: $26.4 \pm 1.8^\circ\text{C}$; relative humidity: $73.4 \pm 10.8\%$).

Subjects

Eight semiprofessional male basketball players (mean $\pm$ SD, age: 26.3 ± 6.7 years (range: 19–37 years); stature: 188.1 ± 6.2 cm; body mass: 92.0 ± 13.8 kg) volunteered for this study. Players were competing in the Queensland Basketball League, which forms part of a state-level, second tier Australian basketball competition. Before commencement of the study, all participants were screened for health conditions and injuries that contraindicated participation. The aims, procedures, risks, and benefits of the study were explained to all participants before they voluntarily gave informed consent. All research procedures were granted prior approval by an Institutional Human Research Ethics Committee in accordance with the Helsinki declaration.

Training load data were collected across a mean ($\pm$ SD) of 5.5 ± 2.8 sessions for each player (range of 2–9 sessions).

TABLE 1. The training activities performed during the general and specific preparatory phases of the annual training plan.

Training phase	Training activities	Training goals
General preparatory	Repeated linear running	Stress a combination of energy systems for metabolic adaptation
	Repeated linear sprinting	Increase emphasis on high-intensity work with training progression
Specific preparatory	Intermittent linear running drills	Improve running and sprint technique
	Speed and footwork drills using cones and ladders	Develop physical and cognitive agility qualities
	Visual opponent-based reaction drills	Develop on-court speed in multiple directions
	Upper-body power drills using medicine balls	Improve lower- and upper-body power qualities
	Lower-body power drills using jumps and hurdles	Improve anaerobic metabolic conditioning
	Repeated multidirectional running and sprinting	Develop intermittent endurance
	Multidirectional shuffling drills	Develop skills in key areas
	Intermittent running drills (with and without ball)	
	Offensive and defensive skill-based drills	

resulting in 44 total sessions being examined. Data for each player were included in the analyses if (a) the player completed the entire training session and (b) useable sRPE, HR, and accelerometer responses were gathered in combination for the player.

Procedures

Demographic information was initially collected for each player, including body mass (digital medical scales, model BWB-600; Tanita Corporation, Tokyo, Japan) and stature

(digital stadiometer, model 274; Seca, Hamburg, Germany). Polar Team2 Pro HR monitors (Polar Electro Oy, Kempele, Finland) were affixed to each player before all testing and training sessions. Player HR responses were sampled at 1-second intervals, recorded onto the monitors of each player, and externally downloaded to a personal computer after each session for analysis using Polar Team2 software (Polar Electro Oy). Before training load assessment, players completed a Yo-Yo intermittent recovery test (level 1) to determine individual maximum HR response (HR_{max}) as

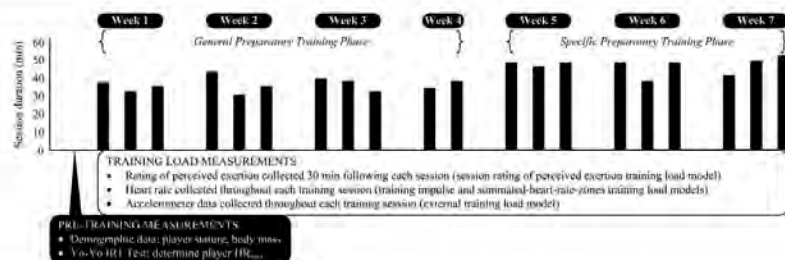


Figure 1. A schematic representation of the testing and training schedule followed in this study. Yo-Yo IR1 = Yo-Yo intermittent recovery test (level 1); HR_{max} = maximum heart rate; session warm-up and cool-down not included in session duration.

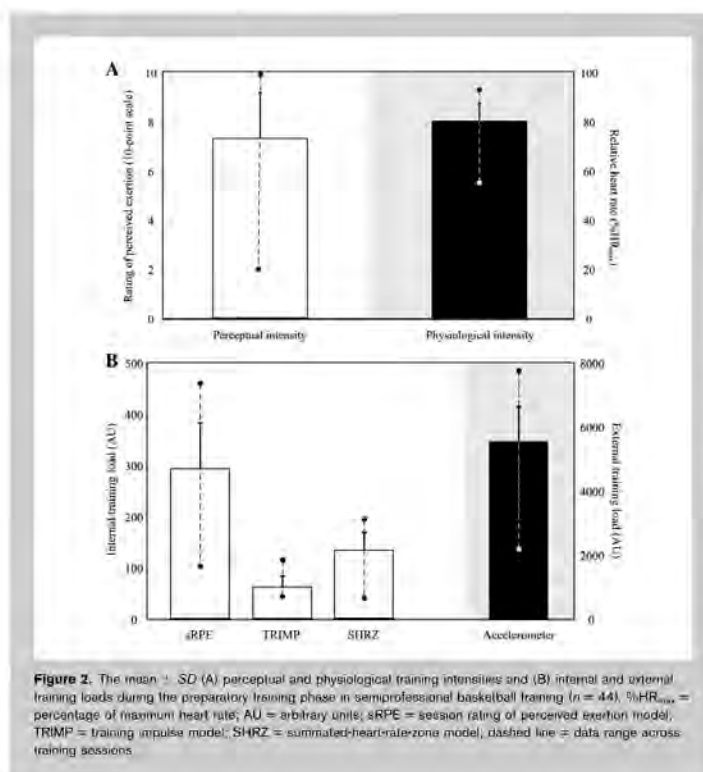


Figure 2. The mean $\pm$ SD (A) perceptual and physiological training intensities and (B) internal and external training loads during the preparatory training phase in semiprofessional basketball training ($n = 44$). %HR_{max} = percentage of maximum heart rate; AU = arbitrary units; sRPE = session rating of perceived exertion model; TRIMP = training impulse model; SHRZ = summated-heart-rate-zone model; dashed line = data range across training sessions.

previously used in training load studies (25,33). The reliability of the Yo-Yo intermittent recovery test (level 1) has been previously supported (coefficient of variation [CV] = 4.9%) (24). In addition, HR was measured across a 2-minute period in a rested condition for each player to determine individual resting HR (HR_{rest}) (5,25,33). Before each team training session, players performed a 15-minute standardized warm-up, involving low-intensity jogging,

and activity intensity, which is weighted according to 5 discrete HR zones relative to HR_{max}. A multiplier accompanies each HR zone that places greater weighting on higher relative HR responses (22). Previously, the TRIMP (2,3) and SHRZ (25,34) models have been used to determine internal training load in team-sport athletes. The following formulae were applied to determine internal training load using the (a) TRIMP (5) and (b) SHRZ (22) models:

$$\text{TRIMP training load (AU)} = (\text{Duration [minute]}) \times (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) / (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}) \times 0.64e^{1.92x},$$

whole-body dynamic stretches, and brief bouts of high-intensity running. A schematic overview of the training and testing design of this study is shown in Figure 1.

where HR_{ex} = average HR during exercise; HR_{rest} = HR at rest; HR_{max} = maximal HR; $e = 2.712$; and $x = (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) / (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}})$.

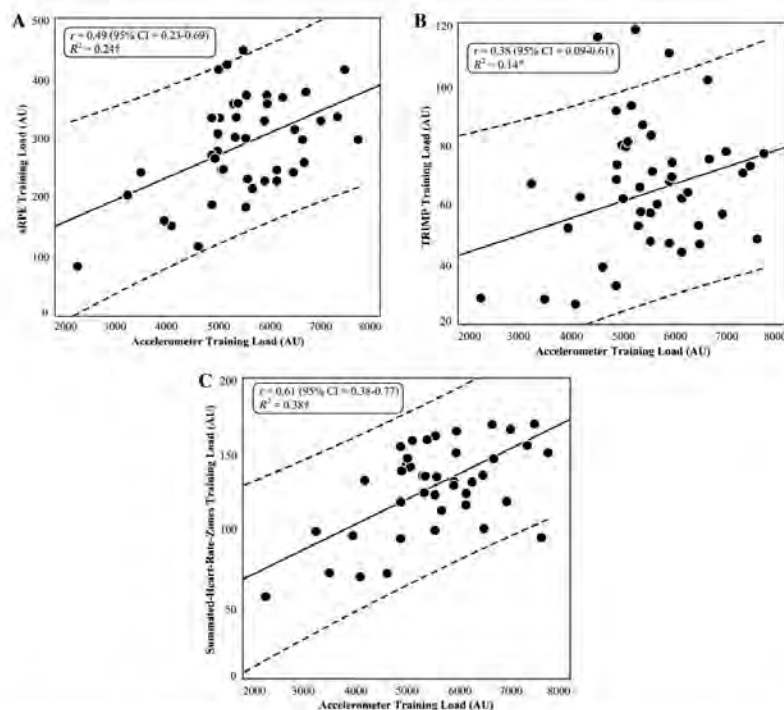


Figure 3. Correlations between external training load (accelerometer model) and (A) session rating of perceived exertion (sRPE) model, (B) training impulse (TRIMP) model, and (C) summated-heart-rate-zones model during semiprofessional basketball training ($n = 44$). AU = arbitrary unit; 95% CI = 95% confidence intervals; * denotes $p \leq 0.05$; † denotes $p \leq 0.001$.

$$\begin{aligned} \text{SHRZ training load (AU)} = & (\text{duration in zone 1} \times 1) \\ & + (\text{duration in zone 2} \times 2) \\ & + (\text{duration in zone 3} \times 3) \\ & + (\text{duration in zone 4} \times 4) \\ & + (\text{duration in zone 5} \times 5), \end{aligned}$$

where zone 1 = 50–60% HR_{max} ; zone 2 = 60–70% HR_{max} ; zone 3 = 70–80% HR_{max} ; zone 4 = 80–90% HR_{max} ; zone 5 = 90–100% HR_{max} .

External training load was determined using 4 triaxial accelerometers (model MMA7361L; Freescale Semiconductor, Inc., Austin, TX, USA) positioned on the posterior surface of the torso at the level of the inferior angle of the scapulae. Each accelerometer was affixed to a breakout board with a Logomatic data logger (version 2; SparkFun

Electronics, Boulder, CO, USA), which transferred the data to a SD memory card. Accelerometers were secured to each player through customized pouches attached to the HR monitor chest bands. Accelerometer placement at this location minimized the risk of player contact injuries and infrastructure damage. Our accelerometer placement positioned the device closer to the body's center of mass compared with placement locations typically seen with the use of vests (9), which proved advantageous given positioning the accelerometer closer to a player's center of mass has been demonstrated to better represent whole-body movement (26). Each accelerometer had a full-scale output range of $\pm 6g$ and sampled at a rate of 100 Hz. Whole-body movements were determined as the accumulated instantaneous rate of change in acceleration in the 3 movement planes (anteroposterior, mediolateral, and craniocaudal) (9). External training load was then calculated using an established

algorithm developed by Catapult Innovations (Scoresby, Australia). Previously, this model has been frequently used to determine external training load in team-sport athletes (9,33). LabVIEW software (v2013; National Instruments, Austin, TX, USA) was used to calculate external training load by the following formula (8,11):

$$\text{External training load} = v \left[(a_{y1} - a_{y1-1})^2 + (a_{x1} - a_{x1-1})^2 + (a_{z1} - a_{z1-1})^2 \right] / 100,$$

where a_y = anteroposterior acceleration; a_x = mediolateral acceleration; and a_z = craniocaudal acceleration.

Pilot data supported the reliability (intraclass correlation coefficient [ICC] = 0.92; standard error of the mean [SEM] = 256.3 AU) of the accelerometer training load model in semi-professional basketball players ($n = 6$) during volume-matched, field-based repeated running and sprinting activities across varied distances. Furthermore, the validity of the accelerometers was also supported during pilot testing in the same participants, with an almost perfect correlation ($r = 0.98$) observed between accelerometer training load and running speed during treadmill-based incremental running ($8\text{--}16 \text{ km} \cdot \text{h}^{-1}$).

Statistical Analyses

An a priori analysis using G*Power software (version 3.1.7; Heinrich Heine University Düsseldorf, Düsseldorf, Germany) for bivariate correlation models (using a 2-tailed alpha value of 0.05, an effect size of 0.5, and power of 0.80) recommended a sample size of 29, supporting the present analyses ($n = 44$) (6,17). Shapiro-Wilk tests indicated that the present data were suitable for parametric analyses. Relationships between internal and external training load models were determined using Pearson's product-moment correlation with 95% confidence intervals. Correlation magnitudes were evaluated according the following criteria: trivial: 0–0.10; small: 0.11–0.3; moderate: 0.31–0.50; large: 0.51–0.70; very large: 0.71–0.90; and almost perfect: 0.91–1.00 (21). The coefficient of determination (R^2) was determined to identify the commonality between each comparison made for the included internal and external training load models. Means ($\pm SD$) were calculated for all descriptive and outcome measures. All statistical analyses were performed using IBM SPSS Statistics (v20.0; IBM Corporation, Armonk, NY, USA). Statistical significance was accepted at $p \leq 0.05$.

RESULTS

The mean $\pm SD$ intensity (sRPE attained after each training session and %HR_{max}) of the basketball training monitored in this study is shown in Figure 2A. The mean $\pm SD$ internal (sRPE, TRIMP, and SHRZ models) and external training loads of the basketball training monitored in this study are displayed in Figure 2B.

The correlations and coefficients of determination between internal and external training load models during basketball

training in this investigation are shown in Figure 3. Although all relationships were statistically significant ($p \leq 0.001\text{--}0.011$), correlation magnitudes varied between models. Moderate relationships were found between external training load and the sRPE and TRIMP models, whereas a large relationship was evident between external training load and the SHRZ model.

DISCUSSION

This study provides the first analysis of internal and external training load models in basketball. Significant ($p \leq 0.05$) correlations were observed between internal and external training load models. Contrary to our working hypothesis and providing limited support for commonality between internal and external training load approaches in basketball, the magnitude of the relationships between internal and external models were moderate to large ($r = 0.38\text{--}0.61$) with shared variances of 14–38%. Consequently, these data indicate that common internal training load models measure largely different constructs than the accelerometer training load model.

It has been theorized that internal training load models are important for monitoring the training response in athletes and external training load models are useful for prescribing and planning training (33,34). This notion indicates that internal and external training loads are 2 separate constructs that provide unique information to team-sport coaching and conditioning professionals. Indeed, our findings ($r = 0.38\text{--}0.61$, $R^2 = 0.14\text{--}0.38$) support this viewpoint given it has been suggested that outcome measures should yield shared variances greater than 50% if they represent general constructs (4). In contrast, existing research has demonstrated internal and external training load models to possess very large relationships (11,33,34), supporting the commonality of sRPE and HR-based training load models with the accelerometer training load model in field-based team sports. Consequently, internal training load (response) has been suggested to be a product of the external training load (dose) (34). However, our findings indicate that this dose-response relationship is not as strong during basketball training compared with field-based team sports. This discrepancy might be explained by the unique sport-specific training activities undertaken by basketball players compared with other team sports. Consequently, basketball coaching and conditioning professionals should be cognizant of the type of activities used during specific training sessions when applying different training load models.

Previously, significantly ($p \leq 0.05$) very large relationships between sRPE and accelerometer training loads have been observed during soccer and Australian Rules football ($r = 0.74\text{--}0.84$) (11,33,34). The authors of these studies concluded that training stimuli measured by accelerometry were strongly related to the internal responses of the athletes (11,33,34). However, we observed only a moderate relationship ($r = 0.49$) with low commonality ($R^2 = 0.24$) between

sRPE and accelerometer training load during basketball training. Differences between our observations and those made previously (11,33,34) might be attributable to variations in the activity modes and movement directions between basketball and field-based team sports. Basketball players are likely to experience greater intermittent and lateral movement requirements during sport-specific training activities than field-based athletes (29,31). This notion is supported by recent time-motion studies that highlight the extensive changes in movement intensity and execution of lateral shuffling during basketball activity compared with field-based team sports (10,12,29). Greater intermittent and lateral activity have been shown to exacerbate player sRPE by 13–25% when total external load is controlled (13,20,35). Accordingly, the drills typically performed during basketball training may disproportionately increase player perceptual demands relative to whole-body movements. Similarly, the distinctive movement requirements incorporated into basketball training might also account for the weaker relationships between HR-based and accelerometer training loads observed in our work compared with past findings.

To date, comparisons between HR-based and accelerometer training load models have only been provided during soccer training (11,33). Significantly ($p \leq 0.05$) very large relationships have been reported between both the TRIMP and SHRZ training load models and accelerometer training load in professional Australian ($r = 0.73$ – 0.80) (33) and semi-professional Spanish ($r = 0.72$) (11) soccer players. In opposition, we observed the TRIMP and SHRZ training load models to possess moderate ($r = 0.38$, $R^2 = 0.14$) and large ($r = 0.61$, $R^2 = 0.38$) relationships with accelerometer training load, respectively. Differences between our observations and those made previously might be because of the frequent execution of isometric actions commonly performed during basketball training drills. Previously, isometric muscular contractions have been shown to elevate HR response more so than dynamic muscular contractions (28). Given basketball players frequently perform isometric actions during training activities, such as screening, blocking, defending, and positioning (26), HR responses are likely to increase disproportionately compared with the relatively low whole-body displacement that occurs in these instances. Furthermore, limitations associated with the use of HR measurement during basketball-specific activities might also have contributed to the strength of the relationships we observed between the HR-based internal training load models and accelerometer training load. Specifically, HR responses underestimate workload at supramaximal intensities and lag behind rapid changes in exercise intensity, both of which are frequently performed during basketball training (1).

Further to the intermittent activity, lateral movements, and isometric actions performed during basketball training, the quantity of directional changes is also a likely influential factor in the relationships we observed between internal and external training load models. The higher intermittent

requirements combined with the smaller playing area of basketball (28×15 m) compared with soccer (90 – 120×45 – 90 m) and Australian Rules football (135 – 185×110 – 155 m) (10,12,29) suggest that basketball activity is likely to place a greater demand on changing direction and multidirectional running than field-based team sports (31). Such activity has been demonstrated to impose greater HR and oxygen uptake responses than linear running patterns (35). Consequently, many basketball-specific drills attempt to replicate rapid directional changes in the training environment, including those monitored in this study. The inclusion of directional changes during intermittent drills has been shown to increase the perceptual and cardiovascular responses of team-sport athletes (13). More frequent directional changes introduced to intermittent exercise have been shown to evoke larger increases in player sRPE and HR responses than traditional in-line intermittent exercise (13). Furthermore, accelerometer training load has been suggested to largely depend on accelerations in the craniocaudal movement plane, which are repetitively accentuated during each heel strike in the typical running gait (33). Given the change of direction tasks carry increased contribution of rotational and horizontal accelerations (32), these altered gait dynamics might elicit unconventional accelerometer outputs relative to the internal responses of players, compared with drills that involve large quantities of in-line running commonly performed in other team sports. Further research should examine the contribution of each movement plane to overall accelerometer training load in conjunction with internal measures during basketball training drills to confirm this suggestion.

In the completion of this study, a number of future research directions were identified. First, further research should investigate the relationships between internal and external training load models in national/international-level professional players during multiple training phases as the training schedules, activities, and thus demands are likely to vary between competition levels and across different training modes used across the annual training plan (25,29). Second, future work should examine the intraplayer relationships between internal and external training load models to more precisely monitor longitudinal patterns relative to player fitness and role (3,22). Third, the weaker correlations between internal and external training load models in our study compared with field-based team sports suggest that refinements to the accelerometer training load model in basketball might prove useful. For instance, innovations that identify and account for basketball-specific movements (e.g., multidirectional running, shuffling, isometric exertion) that carry increased cardiovascular demands and oxygen uptake (35) might better reflect the external training stimulus imposed on players. Fourth, the reliability of the sRPE model should be determined during basketball-specific training activities. Finally, although it is auxiliary to our research question, future studies should assess the validity of accelerometry to

measure external training load during basketball training through comparisons with other external techniques (e.g., time-motion video analyses).

Our results demonstrated significant ($p \leq 0.05$) moderate to large ($r = 0.38$ – 0.61 , $R^2 = 0.14$ – 0.38) relationships between internal and external training load models during basketball training. These data reaffirm that internal and external training load are separate constructs and indicate factors (e.g., training status, fatigue stage, and genetics) outside of the whole-body movements detected by accelerometry influence the internal response of players during basketball training.

PRACTICAL APPLICATIONS

Our results suggest that sRPE and HR-based training load models possess less commonality with accelerometer training load during basketball training than field-based team sports. Consequently, based on the present findings, basketball coaching and conditioning professionals are recommended to (a) not implement training load models based solely on the known practices and existing research findings for field-based team sports; (b) understand the unique information that each training load approach provides before implementation; (c) not assume a linear dose-response between the external training load (detected by accelerometry) and the player's internal training load during basketball-specific activities; and (d) combine the use of internal and external approaches when monitoring training load in players.

Because of the limitations associated with other technologies (time-motion video analyses and GPS technologies), the accelerometer training load model is currently the most practical approach available to monitor external training load in court-based team sports. However, if using accelerometry to monitor external training load, basketball coaching and conditioning professionals should concurrently gather sRPE and HR measurements for an indication of individualized training response, coping abilities, and progression in their athletes. Using internal and external training load models together might decrease the appearance of overtraining in athletes, thus resulting in more efficient use of practice time and improved on-court performance.

ACKNOWLEDGMENTS

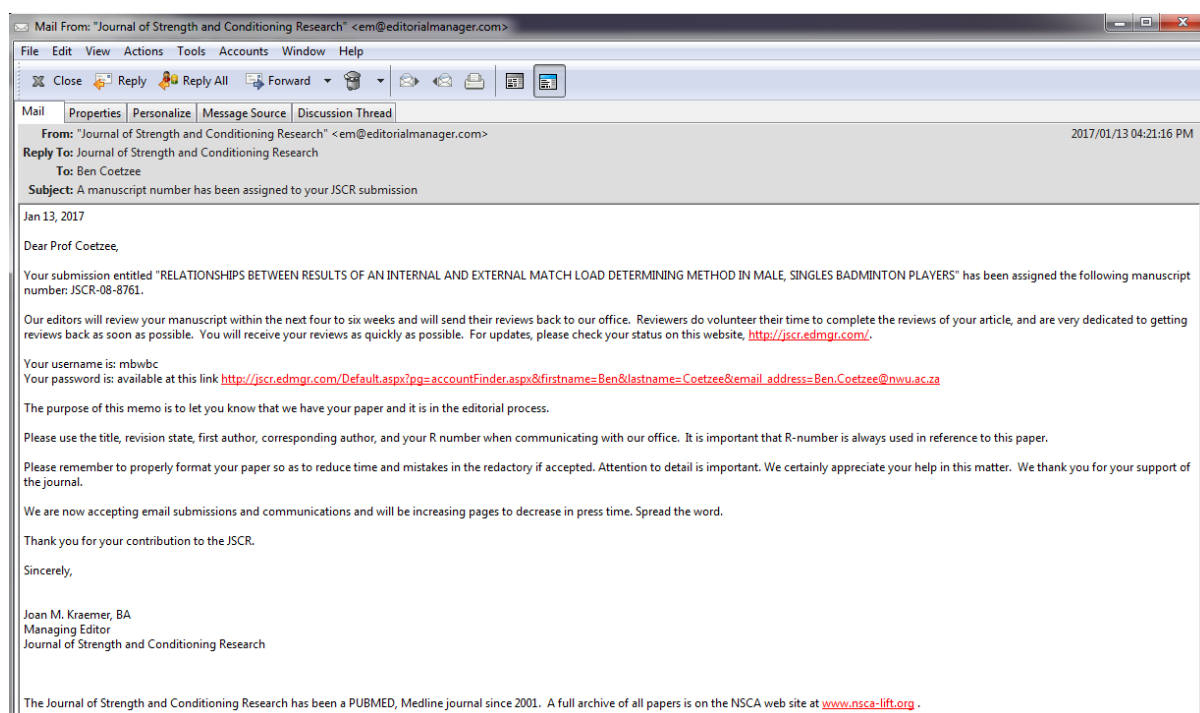
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PROOF OF SUBMISSION TO THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH



PROOF OF ACCEPTANCE TO THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH

From : Ben Coetzee <Ben.Coetzee@nwu.ac.za>
Subject : Fwd: JSCR Decision ACCEPT
To : yahayaabdullahi@abu.edu.ng
Cc : abdulne@gmail.com, vandenbergl1@tut.ac.za

Mon, Jun 26, 2017 04:55 AM

Good news

I received the feedback a while back and rectified everything. They have accepted our publication and it will be published in the next 6-9 months. Congratulations Yahaya.

You can now place this email in the Appendix of your final thesis as proof of acceptance.

Ben

Vrywaringsklousule / Disclaimer: <http://www.nwu.ac.za/it/gov-man/disclaimer.html>

>>> "Journal of Strength and Conditioning Research" <em@editorialmanager.com> 2017/06/26 02:37 AM >>>
Jun 25, 2017

RE: JSCR-08-8761R1, entitled "RELATIONSHIPS BETWEEN RESULTS OF AN INTERNAL AND EXTERNAL MATCH LOAD DETERMINING METHOD IN MALE, SINGLES BADMINTON PLAYERS"

Dear Dr. Coetzee,

I am pleased to inform you of the official acceptance of your manuscript, JSCR-08-8761R1, entitled "RELATIONSHIPS BETWEEN RESULTS OF AN INTERNAL AND EXTERNAL MATCH LOAD DETERMINING METHOD IN MALE, SINGLES BADMINTON PLAYERS" for publication in the Journal of Strength and Conditioning Research. Congratulations to you and your co-authors in meeting the very high standard of quality that is required for publication in this Journal.

The production staff at Lippincott, Williams and Wilkins (LWW) will be sending galley proofs and work with you to put your manuscript into proper format for publication.

I want to take this opportunity to remind you to check the page proofs promptly and carefully for accuracy when you eventually receive them. You will receive them via email so please be attentive to such communications.

OPEN ACCESS

If you indicated in the revision stage that you would like your submission, if accepted, to be made open access, please go directly to step 2. If you have not yet indicated that you would like your accepted article to be open access, please follow the steps below to complete the process:

1. Notify the journal office via email that you would like this article to be available open access. Please send your Email to kraemer.44@osu.edu. Please include your article title and

manuscript number.

2. A License to Publish (LTP) form must be completed for your submission to be made available open access. Please download the form from <http://links.lww.com/LWW-ES/A49>, sign it, and Email the completed form to the journal office.

3. **Within 48 hours of receiving this e-mail:** Go to <http://wolterskluwer.qconnect.com> to pay for open access. If you have not previously used this site to place an order, you will need to register for an account (your login will be different from your Editorial Manager login). When placing your order, you will be asked for the following information. Please enter exactly as shown:

- a. Article Title - RELATIONSHIPS BETWEEN RESULTS OF AN INTERNAL AND EXTERNAL MATCH LOAD DETERMINING METHOD IN MALE, SINGLES BADMINTON PLAYERS
- b. Manuscript Number - JSCR-08-8761R1

Finally, please be aware that there is usually a delay at this point in time of about 6-9 months before the article will appear in print, due to the high demand for space in the Journal. However, your paper will appear in an "ahead of print" format prior to its formal publication.

We look forward to the submission of other manuscripts from your laboratory. Thank you for your contribution to the JSCR.

We wish you all the best in your future research projects.

Kind Regards,

William J. Kraemer, Ph.D., CSCS*D, FNCSA
Editor-In-Chief
Journal of Strength and Conditioning Research

APPENDIX B

ETHICAL APPROVAL FOR UMBRELLA PROJECT



NORTH-WEST UNIVERSITY
YUNIBESITHA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X8001, Potchefstroom
South Africa 2520

Tel: (018) 299-4900
Faks: (018) 299-4910
Web: <http://www.nwu.ac.za>

Ethics Committee
Tel +27 18 299 4849
Email Ethics@nwu.ac.za

ETHICS APPROVAL OF PROJECT

The North-West University Research Ethics Regulatory Committee (NWU-RERC) hereby approves your project as indicated below. This implies that the NWU-RERC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: HEART RATE VARIABILITY AND RECOVERY AS WELL AS GPS MATCH ANALYSIS CHARACTERISTICS IN RELATION TO MATCH RESULTS IN AFRICAN MALE BADMINTON PLAYERS	
Project Leader: Prof B Coetzee	
Ethics number:	N W U - 0 0 1 9 9 - 1 4 - A 1
Approval date: 2015-04-01	Expiry date: 2016-12-16

Special conditions of the approval (if any): (none)

General conditions: While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following: • The project leader (principle investigator) must report in the prescribed format to the NWU-RERC: - annually (or as otherwise requested) on the progress of the project, - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project. • The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-RERC. Would there be deviation from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited. • The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-RERC and new approval received before or on the expiry date. • In the interest of ethical responsibility the NWU-RERC retains the right to: - request access to any information or data at any time during the course or after completion of the project; - withdraw or postpone approval if: - any unethical principles or practices of the project are revealed or suspected, - it becomes apparent that any relevant information was withheld from the NWU-RERC or that information has been false or misrepresented, - the required annual report and reporting of adverse events was not done timely and accurately, - new institutional rules, national legislation or international conventions deem it necessary.
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The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Linda du Plessis

Prof Linda du Plessis
Chair NWU Research Ethics Regulatory Committee (RERC)

Digitally signed by Linda du Plessis
DN: cn=Linda du Plessis, o=NWU,
V=1, serial=1, email=Linda.DuPlessis@nwu.ac.za,
c=ZA
Date: 2015.04.02 09:15:36 +0200

APPENDIX C

ETHICAL APPROVAL FOR SUB-STUDY



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
Web: <http://www.nwu.ac.za>

Faculty of Health Sciences
Tel: 018-299 2092
Fax: 018-299 2088
Email: Minnie.Greeff@nwu.ac.za

24 July 2015

Prof B Coetzee
Human Movement Science

Dear Prof Coetzee

APPROVAL: ETHICS APPLICATION: NWU-00199-14-A1 (B COETZEE-Y ABDULLAHI) "HEART RATE VARIABILITY AND RECOVERY AS WELL AS GLOBAL POSITINAL SYSTEM MATCH ANALYSIS CHARACTERISTIC IN RELATION TO MATCH RESULTS IN AFRICAN MALE BADMINTON PLAYERS"

Thank you for amending your sub-study "Singles match analysis characteristics of male badminton players during participation in the African Badminton Championships" application. All ethical concerns have now been addressed and ethical approval is granted until 16/12/2016.

Please note that any changes to the approved application must be submitted to the Health Research Ethics Committee for approval before implementation.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Minnie Greeff'.

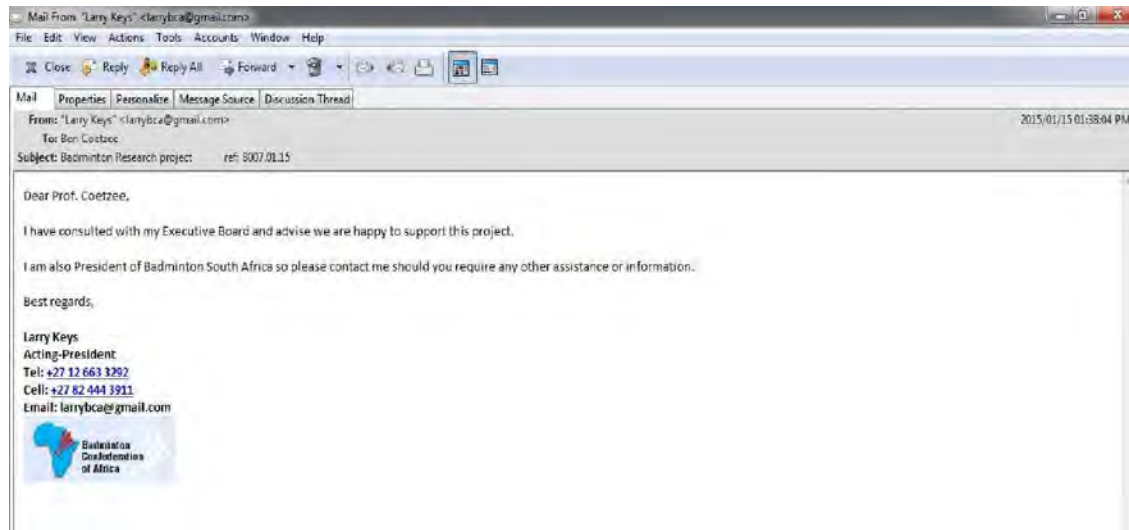
Prof Minnie Greeff
HREC Chairperson

Current details: (13210572) C:\Users\13210572\Documents\HREC\HREC - Applications\2015 Applications\Applications 04 - 14 May 2015\NWU-00199-14-A1 (B Coetzee-Y Abdullahi) (NWU-00199-14-A1 (B Coetzee-Y Abdullahi) - AL\NWU-00199-14-A1 (B Coetzee-Y Abdullahi) - AL.docm)
24 July 2015

File reference: 3.1.5.3

APPENDIX D

PERMISSION LETTER FROM BADMINTON CONFEDERATION OF AFRICA



APPENDIX E

PERMISSION LETTER FROM BADMINTON SOUTH- AFRICA

Page 1 of 1

Ben Coetzee - Research Project Badminton

From: "Klaas Visser" <landas@lando.co.za>
To: "Ben Coetzee NWC" <Ben.Coetzee@nwcw.ac.za>
Date: 2014/04/08 09:06 AM
Subject: Research Project Badminton
CC: <stewartjcarson@gmail.com>, "Badminton SA" <badmintonsa@nwweb.co.za>

Dear Ben

We have discussed your proposal at our recent Board meeting and would like to become involved in your research project. We can clearly see the advantages for Badminton South Africa

How do you suggest we go about it? We are planning a training camp in Benoni from 20 to 22 April (prior to participating in the All Africa Badminton Championships in Lobatse, Botswana). All our National Players will be present. Perhaps it is the ideal situation to discuss this with the players. Or would you rather focus on our top u/19 players? They are currently in Malaysia participating in the World Junior Championships. The SA under 19 tournament is scheduled for Bloemfontein the 1st week of the schools holiday as another option

Our National Head coach Stewart Carson will run the training camp in Benoni

In future please direct all correspondence pertaining to your research to me as the High Performance Manager

Your research will play a vital role in updating our "Badminton for Life" Long Term Participant Development Plan document, I will ask Stewart to give you a copy, otherwise I can send it to you via Dropbox

Kind regards,

Klaas Visser
High Performance Manager
Chair Schools and Junior Section
Vice-President Administration

BADMINTON SOUTH AFRICA

Website: www.badminton.co.za
Email: landas@lando.co.za
admin@stickbond.co.za

Tel: +27 28 271 5321
Fax: +27 28 271 5521
Mobile: +27 82 878 4566

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APPENDIX F

PERMISSION LETTER FROM BADMINTON WORLD FEDERATION

BADMINTON WORLD FEDERATION



12.02.2014

Dear Ben

Thank you for your time during my recent visit to RSA. I was interested to discuss the Badminton research proposal you are currently developing concerning African player characteristics.

Badminton is a sport which is certainly under researched in Africa, with very little specific information available. BWF are therefore happy to confirm its support for this project and I look forward to seeing the outcomes.

If you require further assistance in terms of contacts or recommendations please do not hesitate to contact me.

Kind regards

A handwritten signature in black ink, appearing to read "Ian Wright".

Ian Wright

Director of Development

Badminton World Federation

Unit 17.05, Level 17, Amoda Building
22 Jalan Imbi
55100 Kuala Lumpur
Malaysia

T +603 2141 7155
F +603 2143 7155
E bwf@bwfbadminton.org
W www.bwfbadminton.org

APPENDIX G

PERMISSION LETTER FROM BOTSWANA BADMINTON ASSOCIATION



P O Box 201369
Gaborone
Botswana
Telefax
Email: info@botswanabadminton.com

24th February 2015

Prof. Ben Coetzee
Private Bag X6001
Potchefstroom
South Africa 2520

RE: RESEARCH PROPOSAL SUBMITTED TO BOTSWANA BADMINTON ASSOCIATION

The above subject matter refers.

The Executive Committee of the Botswana Badminton wishes to acknowledge receipt of your research proposal document and a confirmation letter from BWF dated 13th January 2015 and 12th February 2015 respectively.

In light of the above, we wish to confirm our agreement to grant you permission to conduct the research with our players, coaches and managers at your disposal.

Do not hesitate to contact the undersigned for more information.

Thank you.

Yours faithfully

Thuso Mudongo (Mr)

Secretary General

/For President

Mobile: (+267) 72151225 / 71661990 / 73399809

**Email: secretary@botswanabadminton.com
ttndongos@yahoo.co.uk**



APPENDIX H

INVITATION LETTER FROM BOTSWANA BADMINTON ASSOCIATION



P O Box 201369
Gaborone
Botswana
Telefax
Email: info@botswanabadminton.com

9/4/14

YAHAYA ABDULLAH
Human Movement Science, Physical Activity, Sport and Recreation
North-West University, Potchefstroom Campus
Private Bag X6001, Potchefstroom
South Africa 2520

Dear Yahaya,

This letter serves to invite you to the All Africa Badminton championships to be held in Lobatse, Botswana from 22-29 April 2014. We have received communication from the Badminton World Federation about the work you will be assisting them with during the tournament. Clearly, the observations thereof will benefit us and badminton generally.

We look forward to work with you during the tournament.

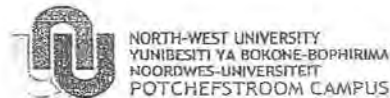
Sincerely,

Moagi Gaborone
President
Botswana Badminton Association
+267 71717549
president@botswanabadminton.com



APPENDIX I

PARTICIPATION LEAFLET AND CONSENT FORM FOR BADMINTON PLAYERS



PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR BADMINTON PLAYERS WHO ARE PARTICIPATING IN THE BADMINTON STUDY.

TITLE OF THE RESEARCH PROJECT:

Heart rate variability and recovery as well as global positioning system (GPS) match analysis characteristics in relation to match results in African male badminton players

REFERENCE NUMBERS: NWU-0199-14-A1

PRINCIPAL INVESTIGATOR:

Prof. Ben Coetzee

ADDRESS:

Physical Activity, Sport and Recreation
Faculty of Health Sciences
Building K21
North-West University
Potchefstroom
2522

CONTACT NUMBER:

0182991803

You are being invited to take part in the **Badminton Analysis Project** that forms part of post graduate, PhD-studies. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively

in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU-0199-14-A1)** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee members or relevant authorities to inspect the research records.

What is this research study all about?

- *This study will be conducted at LC de Villiers indoor training centre at the University of Pretoria and the indoor sport centre of the Show Grounds in Pretoria and will involve the analysis of matches via heart rate, Global Positioning System and video monitoring. Researchers will also determine your mood states and recovery status as well as your habitual dietary intake by making use of questionnaires and an interview, respectively. Experienced sport science researchers trained in human movement and sport science as well as dietetics will conduct the analyses. The aim is to recruit between thirty and forty male players to participate in this study.*
- *The objectives of this research are to determine the meaningful changes in the way that the heart rate varies from one beat to the next (HRV) and the degree in which the heart rate recovers (HRR) during the course of a tournament as well as the relationships between these last-mentioned variables and match results in elite African badminton players. Furthermore, to determine the influence of elite African badminton players' pre-competition dietary preferences, hydration status, sleep quality and quantity as well as mood states on HRV and HRR during the course of a tournament. Lastly, the researchers are also going to determine the singles match characteristics of male badminton players who participated in National and/or International Championships.*

Why have you been invited to participate?

- *You have been invited to participate because you are a male singles badminton player who is participating in a National or International Championship.*
- *You have also complied with the following inclusion criteria: You provided voluntary consent, while your manager and coach gave permission for you to participate in the study.*
- *Furthermore, you are actively involved and competing as a member of your provincial or national team and you are totally free of any injuries as well as illnesses.*
- *You will be excluded if: you become injured or ill at any time or if you are not prepared to play a match while wearing a heart rate and global positioning system (GPS) monitor. Furthermore, you will also be excluded if you do not fill in the questionnaires or undertake a 30 min long interview. Also, players who do not want to be video recorded during match play will also be excluded from the study.*

What will your responsibilities be?

- *You will be expected to undergo body mass and stature measurements in the bath room of the venue where you are participating, fill in a demographic and*

general information as well as a general recovery and hydration status questionnaire and the Stellenbosch Mood Scale. You will also be expected to wear a GPS and heart rate monitor during all matches that you play so that you can be monitored during match play. Lastly, you will also be expected to undertake a 30 minute long interview about you habitual dietary preferences in a secluded room where your privacy will be assured.

Will you benefit from taking part in this research?

- Among the direct benefits are, that you as a player will be able to gain access to your results as well as a personalized report explaining the results. Your data will also be used to explain to you and/or your coach orally during the duration of the different tournaments how your conditioning programmes can be changed in such a way that it prepares you for the demands of match play. Players and coaches will also be afforded the opportunity to talk to the researchers about any conditioning advice that they have a need for. Furthermore, the heart rate, HRV and HRR data will allow the researchers to evaluate players' recovery and fitness levels which may assist you and your coach to identify weak points and to identify factors that are detrimental to your recovery. As part of the research project you will also be afforded the opportunity to do an interview through which your dietary preferences and profile will be determined and evaluated by a dietician. Data with regard to hydration levels, mood states and sleeping quality and quantity will also allow researchers to provide you with feedback concerning these aspects. An indirect benefit of the study is an expansion of existing expert knowledge in the field of Applied Sport Science which can be transferred to the wider sporting community.

Are there risks involved in your taking part in this research?

- Risks will be minimised and the researchers will aim to maximise potential benefits that are likely to have a valuable impact on you, either directly or indirectly. No severe physical, psychological, social stress or other negative consequences beyond the risks encountered in normal match play are foreseen in this study. Each player and coach will be responsible for the warm-up before each match to prepare you physically and physiologically for the demands of match play and to decrease injury risk. The Badminton World Federation requires that medical staff must be available at all times during the tournament, which means that a medical physician and physiotherapist will be available during the course of the tournament, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the study and will be allowed to leave at any time if you feel so. You may experience a bit of discomfort due to the Polar Heart Rate Transmitter Belt that is tied around your chest and the GPS harness that is worn on your back during match play. However, the warm-up period will be used to adjust the heart rate transmitter belt and GPS harness according to your preference and to make you use to the equipment. If you do not feel comfortable to wear the equipment during match play, you will be allowed to play without the equipment.
- For some players it may be uncomfortable to fill in the Stellenbosch Mood Scale questionnaires a few minutes before the match as it may make them feel more anxious.

- Some players may find it uncomfortable to talk about their dietary patterns to the researcher while they are being recorded. However, the interviewer will set the interviewee at ease by providing you with a short introduction of what the interview is going to entail and also by allowing you to ask any questions that are related to concerns about the interview. The interviewer will maintain a demeanour of friendliness, openness and genuineness. Furthermore, the interview will be conducted in a comfortable, good sized, quiet and private meeting room. The interviewer will also make sure that his questions are clear, well-phrased and as jargon-free as possible to help avoid any confusion.

What will happen in the unlikely event of some form of discomfort occurring as a direct result of your taking part in this research study?

- Should you have the need for further discussions after match play an opportunity will be arranged for you to do so. The Badminton World Federation requires that medical staff must be available at all times during matches, which means that first aid personnel will be available for the duration of each match, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the study and will be allowed to leave at any time if you feel so.

Who will have access to the data?

- Anonymity will be partial due to the fact that the coaches and managers also want the feedback of the match analyses but the researchers will respect the decision of each player in order to protect his anonymity. Data will be coded to ensure that no link can be made to a specific player. Confidentiality will be ensured by deleting audio records of interviews after data has been captured. Reporting of findings will be anonymous by only authorising the head researcher to have control over the distribution of these findings. Only the head researcher and research assistants will have access to the data and will also sign a confidentiality agreement to protect players. Data will be kept safe and secure by locking hard copies in locked cupboards in the researcher's office and for electronic data it will be password protected. Data will be stored for 7 years after which the information will be shredded and e-copies deleted.

What will happen with the data/samples?

- This is a once off collection and data will be kept at the North-West University and analysed at the North-West University.

Will you be paid to take part in this study and are there any costs involved?

- No, you will not be paid to take part in the study. There will also be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- You can contact Ben Coetzee at 018 2991803 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 2089; carolien.vanzyl@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher.
- You will receive a copy of this information and consent form for your own records.

How will you know about the findings?

- The findings of the research will be shared with you if you are interested. You are welcome to contact us regarding the findings of the research. We will be sharing the findings with you as soon as it is available

Declaration by participant

By signing below, I agree to take part in a research study titled: **Badminton Analysis Project**

I declare that:

- I have read this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) on (*date*) 20....

.....
Signature of participant

.....
Signature of witness

Declaration by person obtaining consent

I (*name*) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) on (*date*) 20....

.....
Signature of person obtaining consent

.....
Signature of witness

Declaration by researcher

I (name) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (place) on (date) 20.....

.....
Signature of researcher

.....
Signature of witness

APPENDIX J

GENERAL INFORMATION AND DATA COLLECTION

QUESTIONNAIRES



General Information Questionnaire and Test Protocol for the GPS, HRV and HRR badminton match analyses project

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname: **Initials** **First**
Name

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1.2 Age:

<u>Years:</u>	<u>Months:</u>
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1.3 Birth date:

<u>Year:</u>	<u>Month:</u>	<u>Day:</u>
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1.4 Permanent residential address:

1.5 Permanent postal address:

1.6 Phone numbers:

<u>Home:</u>	<u>Work:</u>
<u>Fax:</u>	<u>Cell:</u>
<u>E-mail:</u>	

1.7 Country that you are presenting during this championships

--

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS**2.1 Years you've been playing badminton.**

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more
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2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days
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2.3 Frequency of training - how many days per week do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days
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2.4 Frequency of training - how many days per week do you normally have court sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days
-------	--------	--------	--------	--------	--------	--------

2.5 Frequency of training - how many days per week do you normally do training on the field or road?

1 day	2 days	3 days	4 days	5 days	6 days	7 days
-------	--------	--------	--------	--------	--------	--------

2.6 How many hours per day do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more
--------	---------	---------	---------	---------	---------	-----------

2.7 How many hours per day do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more
--------	---------	---------	---------	---------	---------	-----------

2.8 How many hours per day do you normally spend on training on the court?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more
--------	---------	---------	---------	---------	---------	-----------

2.9 How many hours per day do you normally spend on training on the field or road?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more
--------	---------	---------	---------	---------	---------	-----------

2.10 Do you spend any time on psychological preparation for badminton and competitions?

Never	*Sometimes	*Often	*Always
-------	------------	--------	---------

*** Please specify the type of psychological preparation you do if you marked any of the above-mentioned options:**

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck:
Shoulder/Clavicle:
Arm/Elbow/Wrist/Hand:
Back:
Hip/Pelvis:

Thigh/Knee:
Lower leg/Ankle/Foot:

3.2 Please list any medication being taken currently and/or taken during the last year:

3.3 List any other illness or disorder that a physician has told you of:

4. COMPETITION DATA

4.1 At what level are you competing this year?

4.2 What is the highest level that you competed at last year?

Club:	Provincial:	National:	International:
-------	-------------	-----------	----------------

4.3 How many matches, approximately, have you played?

Club:	Provincial/National:	International:
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4.4 What were the highest achievements you attained during the past two years (2013/14)?

Achievement	Competition	Date

NAME AND SURNAME:

1ST MATCH – DATE AND TIME OF MATCH:	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	
2ND MATCH – DATE AND TIME OF MATCH:	
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

NAME AND SURNAME:

3RD MATCH – DATE AND TIME OF MATCH:	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	
4TH MATCH – DATE AND TIME OF MATCH:	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

NAME AND SURNAME:

5TH MATCH – DATE AND TIME OF MATCH:	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	
6TH MATCH – DATE AND TIME OF MATCH:	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

APPENDIX K

LETTER FROM LANGUAGE EDITOR



17 August 2017

I, Ms Cecilia van der Walt, hereby confirm that I took care of the editing of the thesis of Mr Yahaya Abdullahi titled *Singles Match Analysis Characteristics and Work Loads Associated with Success in Male Badminton Players*

A handwritten signature in cursive script, reading 'C van der Walt'.

MS CECILIA VAN DER WALT

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