Reliability and Discriminative Ability of Badminton Specific Change of Direction Testing

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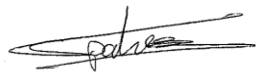
ATTESTATION OF AUTHORSHIP

"I hereby declare that this thesis submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."



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CO-AUTHORED WORKS

The following four manuscripts have been submitted for peer reviewed journal publication as a result of the work presented in this thesis;

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LIST OF ABBREVIATIONS

BSA	Badminton Specific Assessment
CI	Confidence Interval
cm	Centimetre
CMJ	Counter-Movement Jump
COD	Change of Direction
CV	Coefficient of Variation
$deg.sec^{-1}$	Degrees per Second
DL	Dominant Leg
F	Female
H-CMJ	Horizontal Counter-Movement Jump
HRmax	Heart Rate Max
ICC	Intraclass Correlation Coefficient
kg	Kilogram
km/h	Kilometres per Hour
m	Metre
M	Male
MDAT	Multi-Directional Agility Test
MDCT	Multi-Directional Cyclic Change of Direction Test
MDLT	Multi-Directional Lunge Test

MPT	Mean Peak Torque
n	Number
NDL	Non-Dominant Leg
nm	Newton-Metre
$nm.kg^{-1}$	Newton-Metres per Kilogram
s	Second
S-VJ	Sargent Vertical Jump
SEMO	Modified South East Missouri Agility Test
SJ	Squat Jump
SLSS	Straight Line Sprint Speed
SSC	Stretch-Shorten Cycle
TE	Typical Error
V-CMJ	Vertical Counter-Movement Jump
V-DJ	Vertical Depth Jump
W	Watts

ABSTRACT

As one of the fastest sports in the world, the agility component of badminton is crucial in maximising performance. Agility involves two components, the perceptual and decision making component and the physical change of direction (COD) component. COD assessments most often include a single temporal measure, which provides a measure of the COD ability that in most cases inadequately informs programming for COD enhancement in badminton athletes. As an alternative, the multi-faceted badminton specific assessment (BSA) battery has been proposed, which includes the following nine measures: height, body mass, leg length, eight site sum of skinfold, frontal split hip flexibility, sagittal split hip flexibility, vertical counter-movement jump (V-CMJ), multi-directional lunge test (MDLT) and multi-directional cyclic COD test (MDCT). The overall purpose of this thesis was to develop a BSA and to establish which measures best predict overall badminton performance. In study one (Chapter 3), the reliability of two newly designed tests (MDLT and MDCT) was assessed. The MDLT (change in the mean = 0.33-6.78%; TE = 0.03-0.11 s; ICC = 0.55-0.96) and MDCT (change in the mean = 0.12-5.87%; TE = 0.05-0.20 s; ICC = 0.57-0.98) were confirmed to be reliable. In study two (Chapter 4), the purpose was to establish which components of the BSA best predict COD and overall performance in badminton. The best predictors of COD performance were the MDLT (female – r = 0.58; male – r = 0.57), frontal split hip flexibility (F – r = -0.72, M – r = -0.36), eight site sum of skinfold (F – r = 0.65) and V-CMJ (M – r = -0.49). The BSA was most effective in predicting badminton ability in female athletes; specifically the MDLT (r = 0.59), height (r = 0.51) and V-CMJ (r = -0.48). These findings suggest that the following BSA measures may be utilised to effectively assess the following anthropometric characteristics and performance qualities in badminton athletes: height, leg length, eight site sum of skinfold, frontal split hip flexibility, V-CMJ, MDLT and MDCT. The MDLT may also be replaced by a single forward lunge to assess

horizontal neuromuscular capability based on the very large to near perfect correlations ($r > 0.75$, $p < 0.001$) between all MDLT directions. To further enhance the diagnostic potential of the MDCT, four consecutive cycles in a single direction may be implemented to better utilise elastic energy of the stretch shorten cycle and mimic the repetitive COD nature of badminton.

CHAPTER ONE:

PREFACE

Thesis Rationale

As one of the fastest sports in the world, badminton requires athletes to complete rapid whole body movements, as they execute approximately one shot every two seconds. The ability for an athlete to move about the court, is termed agility and can be defined as a whole body change of direction (COD) or velocity in response to a stimulus (1). Agility has been identified as the single best predictor of badminton performance as determined by a qualitative coaching panel (2). Agility involves two components, the perceptual and decision making of when and where the COD is to occur and the physical action of performing the direction change. These two components are interlinked, providing a unique challenge in determining specific methods for agility enhancement. As a result, assessment may benefit from a separation of the two components, thus requiring a perceptual and decision making assessment and a physical assessment. The focus of this thesis is on the assessment of the physical COD component.

The following four badminton specific COD tests were identified in the literature: badminton specific (3), four corners (4), sideways (4) and speed specific (5). Each of these tests assesses an athlete's COD ability in a combination of directions and provides a time to complete the respective test, representing overall COD ability. These tests provide a single temporal measure and are easy to administer, but lack the diagnostic ability to identify specific determinants which may be altered to enhance COD performance. To increase the specificity, COD assessment requires the measurement of numerous factors, including body fat, leg length, hip flexibility and leg strength qualities (1, 6). Straight line sprint speed (SLSS) is also considered a key determinant for COD assessment, however due to the small court dimensions the validity of such a measure to badminton appears questionable.

Badminton athletes have largely been identified to have low levels of body fat (3, 4, 7-15), yet only a single study has attempted to assess the relationship between body fat and COD performance. In a study of junior athletes, Hughes (3) noted that body fat was insignificantly related to COD performance, yet research in comparable sports has found strong relationships between the two variables (16). Additional research into this relationship is required to establish if such findings are replicated in alternate badminton populations.

Cronin, McNair and Marshall (6) established in a non-badminton population that a longer leg length was the second best predictor of absolute lunge performance behind time to peak force. As lunging is the most frequently performed movement in badminton and is used during most horizontal direction changes, it is likely that leg length is an important determinant of COD performance in badminton.

Flexibility is rarely assessed in badminton, however moderate relationships have been noted between the sit and reach test and COD performance (2). A more valid measure of flexibility in badminton athletes may be a frontal split hip flexibility assessment, due to a strong relationship with lunge performance (6). This method of assessing hip flexibility has yet to be utilised in badminton research and will therefore be assessed herein.

A more regularly assessed COD determinant is lower body neuromuscular capability, which is generally assessed via a horizontal (H-CMJ) (2, 3) or vertical (V-CMJ) counter-movement jump (2-4, 17-19). The V-CMJ is considered a valid measure of vertical lower body neuromuscular (ballistic) capability, due to biomechanical similarities between the test and vertical direction changes in badminton. The suitability of V-CMJ as a vertical lower body neuromuscular performance measure is supported by Ooi et al. (4) in which V-CMJ was identified to account for 63 and 49% of the variance in the sideways and four-corners COD tests, respectively. As a measure of horizontal lower body neuromuscular (ballistic) capability, the H-CMJ appears to be of little relevance to badminton specific COD, as direction changes most often utilise a lunge movement. Additionally, the H-CMJ measures neuromuscular (ballistic) capabilities in a single direction, yet recent research has established that lower body neuromuscular performance is directionally specific and therefore may vary accordingly (20). Due to the limitations of the H-CMJ, it is proposed that horizontal neuromuscular performance be assessed through a multi-directional lunge test (MDLT). Such a test should be of greater specificity to badminton and provide a greater insight into an athlete's overall directional specific performance qualities. The multi-directional cyclic COD test (MDCT) is proposed as a measure of cyclic COD ability, as this will allow for the individual assessment of cyclic COD ability in eight directions.

Research Aims

The major aims of this thesis were;

1. To establish a badminton specific assessment for COD.
2. To determine the inter- and intra-session reliability of the MDLT and MDCT.
3. To establish which components of the badminton specific assessment (BSA) best predict COD and overall performance in badminton.

The overall purpose of this thesis was to develop a BSA and to establish which measures best predict overall badminton performance. This was achieved through the inclusion of novel testing procedures along with previously established tests.

Research Design

Three studies were undertaken to test the hypotheses within this thesis. Each study used a cross-sectional analytical design and a range of statistical methods.

1. A review of the current literature pertaining to COD performance in badminton athletes.
2. A cross-sectional study was completed to establish the reliability of two newly designed COD tests: MDLT and MDCT.
3. A second cross-sectional study was completed to determine the best predictors of COD performance. While a secondary aim was to establish relationships between the BSA measures and overall badminton performance.

Thesis Originality

This thesis is novel and original to badminton performance research in the following areas:

1. This is the first known review of COD or agility specific research in badminton.
2. Ballistic and neuromuscular capabilities are generally assessed through a single jump measure, be it a H-CMJ or V-CMJ. The MDLT is proposed as the first multi-directional neuromuscular performance assessment in badminton. Additionally, the MDLT involves lunging as the method of assessment as opposed to traditional jump testing. As a newly designed test, the test-retest reliability of the MDLT was unknown.
3. Cyclic COD ability is frequently assessed through a single test which combines a multitude of directions and provides a single composite time. The MDCT is the first known test to individually assess an athlete’s multi-directional COD ability. As a newly designed test, the test-retest reliability of the MDCT was unknown.

4. Hip flexibility has not previously been assessed in badminton research. The frontal and sagittal split hip flexibility measures have been included to establish which best predicts COD and overall badminton ability.

Thesis Organisation

The thesis consists of five chapters (see Figure 1). Chapter One introduces the thesis, discusses the thesis rationale and outlines the organisation of the thesis. Chapter Two provides a stock take of badminton specific change of direction (COD) research and provides recommendations to practitioners for COD assessment. The review examined the relationships between COD and the following measures: anthropometry, elastic strength, concentric strength, leg muscle imbalances, technique, straight-line sprint speed and flexibility. The BSA battery was proposed, which included the newly designed MDLT and MDCT. The test-retest reliability of the MDLT and MDCT were established in Chapter Three. Following confirmation of reliability, potential diagnosis applications of the MDLT and MDCT is be discussed. The BSA battery also included height, body mass, sum of skinfold, leg length, frontal split hip flexibility, sagittal split hip flexibility and V-CMJ. An acute experimental design (Chapter Four) was adopted for this study to determine the interrelationships between the BSA measures and badminton ability. Each of these measures was assessed during a single session to determine relationships between the BSA measures and badminton ability. The practical applications and future recommendations are discussed in Chapter Four. Chapter Five summarises the thesis and provides practical applications. The limitations of the thesis and future research directions are also discussed to guide badminton specific COD research in the future.

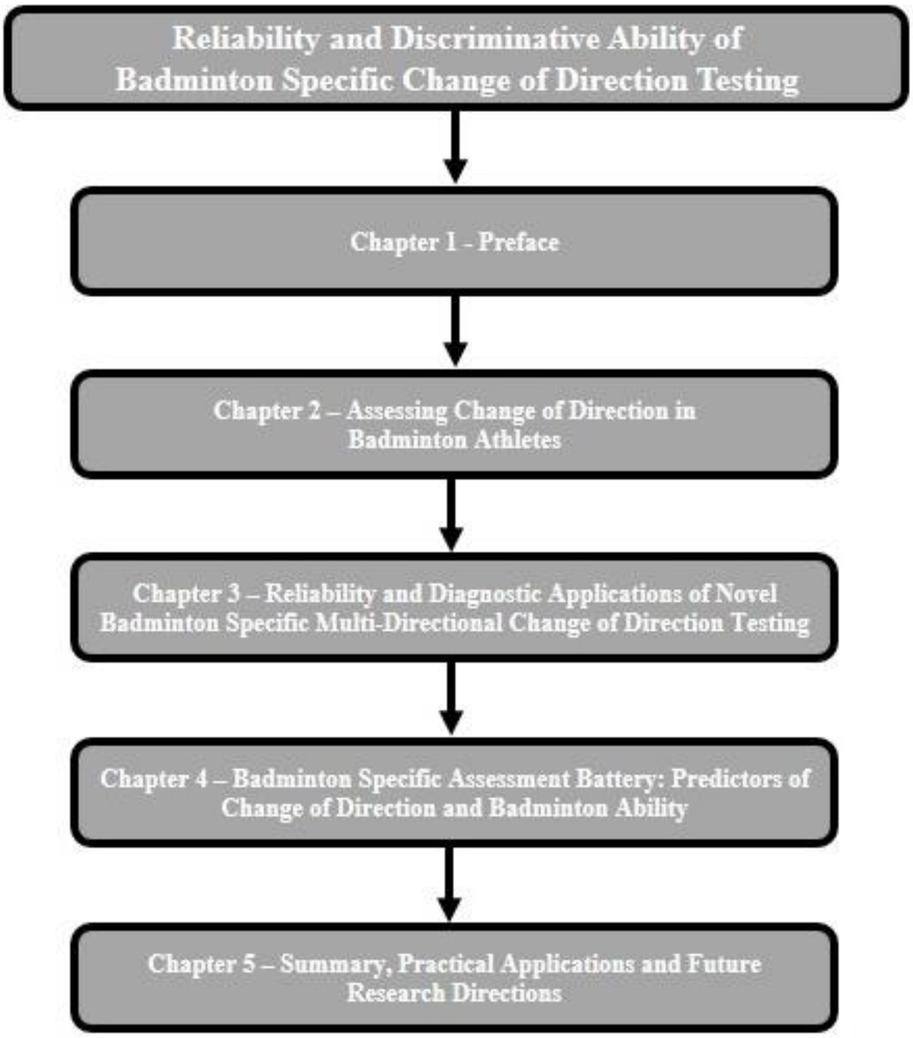

Figure 1. Thesis organisation.

CHAPTER TWO:

ASSESSING CHANGE OF DIRECTION ABILITY IN BADMINTON ATHLETES

Prelude

This review provides a stock take of badminton specific change of direction (COD) research and provides recommendations to practitioners for COD assessment. The review will examine relationships between COD and the following measures: anthropometry, elastic strength, concentric strength, leg muscle imbalances, technique, straight-line sprint speed and flexibility. A badminton specific COD assessment battery is proposed with the inclusion of two new tests: a multi-directional lunge test and a multi-directional cyclic COD test.

Introduction

Played on a 13 x 6 m court, badminton is one of the fastest sports in the world as athletes complete approximately one shot every two seconds (21). Due to the sport's high speeds, athletes are required to excel across a range of physical competencies, including agility, endurance, flexibility, power and acceleration. Badminton involves three events; singles, doubles and mixed doubles, each of which requires distinct physiological demands and tactical strategies. Alcock and Cable (22) found heart rate as a percentage of maximal was greater in singles athletes (88% HRmax) than doubles athletes (76% HRmax), likely a result of an increased work rate. Singles involves a greater quantity of steps per match (singles ~594 vs. doubles ~315) as 90% of shots are either a smash or to the extreme fore and rear court (22). Doubles has a greater diversity and frequency of shots due to the increased court coverage resulting in a fast paced event that encompasses all areas of the court (22). While both events differ in physiological and strategic composition, they each maintain a strong reliance on fast and efficient movements when changing direction.

Agility is defined by Sheppard and Young (1) as "a rapid whole body movement with a change of velocity or direction in response to a stimulus" (p.922). The key to this definition is 'response to a stimulus' which implies agility not only includes the physical COD component, but also a perceptual and decision making component to decide when and where the COD occurs. Due to the high speed nature of badminton, agility is a crucial predictor of performance with fine tuning of both components required for maximal performance (23). These two components are closely interlinked, resulting in a difficulty to diagnose agility weaknesses. However, when COD is assessed separately, assessment offers the potential to identify physical weaknesses, due to reduced interference from the perceptual and decision making component. Jeyaraman and

Kalidasan (2) noted that the best physical predictor of badminton ability as determined via a qualitative coaching panel was COD performance ($r = 0.74$). Across the sub-elite athletes, the next best predictors were elastic leg strength ($r = 0.57$), straight-line sprint speed ($r = 0.55$) and concentric leg strength ($r = 0.35$). It should be noted that these relationships are assessed solely as correlational research, therefore causation cannot be confirmed until intervention research has been completed.

The importance of COD is highlighted by the shot frequency, as each athlete completes approximately one shot every two seconds (21). During the two seconds between shots, athletes change direction towards the centre court and then towards the opponents return. The perceptual and decision making component of agility is equally as important, as during the two seconds athletes process the opponents shot and the shot that they themselves should return with. The perceptual and decision making component further enhances performance, as experienced badminton athletes can predict the direction and speed of their opponents shot up to 0.167 seconds before the shuttle is struck (24). In doing so, athlete's increase the time available to move to the ideal position on the court and increase the quality of their return.

While the perceptual and decision-making components of badminton are important, the focus of this review from this point forward will be on the COD component. Specifically the importance of anthropometry, leg muscle qualities, technique, straight-line sprint speed and flexibility will be discussed. Leg muscle qualities are further separated into elastic strength, concentric strength and leg muscle imbalances for additional critique. A goal of the review is to identify the strengths and weaknesses of existing badminton

COD assessments and make recommendations as to how the diagnostic value of these tests may be improved to provide targeted movement specific feedback to players.

Anthropometry

The first component of the Sheppard and Young (1) model thought to influence COD ability is a player's anthropometry. Anthropometry involves the structure of the human form and how it relates to specific physical movements (25). It includes a range of physical measures, including: body mass, body fat percentage, girths, limb length and standing height. Numerous studies have assessed anthropometrical variables in elite and sub-elite badminton athletes (see Table 1.). However, little research has attempted to establish relationships between these measures and COD performance.

Measures of body fat is a crucial anthropometrical measure, as undesirable levels of body fat hinders power production due to the increased athlete mass, without an increase in force production capabilities (1, 26). A single study assessed relationships between COD performance and body fat percentage with the two characteristics unrelated in both female and male athletes (3). As this study involved junior athletes, further research is required to establish if such findings transfer to senior athletes. Numerous studies have established normative data in terms of body fat percentage for both female (14-19%) and male (8-13%) badminton athletes (see Table 1.). The findings are supported by those of Hume et al. (7), these researchers measured a range of anthropometric variables in 109 athletes across events at the 2007 Proton-Badminton World Federation Championships. Researchers noted that body fat percentage of elite badminton athletes were within the lower limits of the aforementioned ranges (7). It should also be noted that no significant differences between singles (F – 14.2, M –

8.32%) and doubles (F – 14.1, M, 9.91%) athletes were found as both groups had low body fat percentages (7). A strong correlation between badminton ability and body fat percentage was noted in junior male Turkish athletes, as national representatives (13.9%) had a significantly lower body fat percentage ($p = 0.026$) than amateur athletes (17.5%) (10). This finding appears to result from differences ($p = 0.054$) in fat free mass as non-significant differences were found for the fat mass of the athletes.

Standing height and body mass were recorded for athletes across a range of abilities (see Table 1.). These characteristics have been assessed by four studies at the most elite level, 2004 Olympics (27), 2007 World Championships (7), 2008 Olympics (28), and 2012 Olympics (29). Standing height (F – 168 cm, M – 179 cm) and body mass (F – 61 kg, M – 73 kg) were consistent between the studies, allowing for confirmation of normative values for athletes at the most elite level of badminton. When comparing between ability levels, standing height is significantly greater in elite athletes at both junior (elite – 175 cm, sub-elite – 168 cm) (10) and senior (elite – 176 cm, sub-elite 171 cm) (4) levels. Ooi et al. (4) compared Malaysian male athletes between abilities, with elite athletes having significantly greater mass ($p < 0.001$) than the sub-elite athletes. The differences in mass between athletes is primarily due to greater lean muscle mass (p = 0.002) in elite (63.6 kg) compared to sub-elite (56.3 kg) athletes.

Lunging is the most common movement in badminton as it is used during ~90% of movement patterns (6, 30). Cronin et al. (6) established that a longer leg length was the second best predictor of absolute lunge performance, behind time to peak force. However, Jeyaraman and Kalidasan (2) compared leg length to COD performance in badminton athletes, and found a trivial relationship ($r = 0.07$) (2).

Table 1. Anthropometry of badminton athletes

Study	Participants (n)	Height (cm)	Mass (kg)	Body Fat (%)
Male				
Abian et al. (8)	Elite (31)	177.9 ± 6.0	71.7 ± 5.7	8.4 ± 1.4
Alcock et al. (22)	Sub-Elite Singles (8)	184.0 ± 6.0	74.6 ± 11.7	15.5 ± 5.6
	Sub-Elite Doubles (8)	181.3 ± 4.5	84.8 ± 11.3	21.9 ± 4.2
Andersen et al. (9)	Elite (35)	186.0 ± 8.0	79.1 ± 7.2	12.9 ± 0.5
Arslanoglu et al. (28)	Elite (87)	179.0 ± 6.5	73.5 ± 7.6	N/A
Aydogmus et al. (29)	Elite (80)	179.3 ± 6.5	72.8 ± 7.2	N/A
Campos et al. (17)	Junior (10)	172.4 ± 0.5	68.0 ± 7.8	N/A
Faude et al. (21)	Elite (4)	177.0 ± 2.0	70.3 ± 5.5	N/A
Fuchs et al. (18)	Elite (18)	184.0 ± 6.0	79.2 ± 7.7	N/A
Ghosh (31)	Elite (8)	167.9 ± 3.3	63.4 ± 5.5	N/A
Gucluover et al. (10)	Elite (16)	175.2 ± 7.2	67.4 ± 9.8	13.9 ± 4.7
	Sub-Elite (15)	168.0 ± 7.2	63.8 ± 11.1	17.5 ± 3.5
Hughes (3)	Sub-Elite (43)	N/A	70.5 ± 7.3	10.9 ± 3.4
Hughes et al. (32)	Elite (25)	176.0 ± 4.0	75.1 ± 6.2	N/A
Hume et al. (7)	Elite Singles (18)	177.9 ± 6.1	73.4 ± 7.7	8.3 ± 1.6
	Elite Doubles (35)	176.6 ± 7.2	74.6 ± 9.3	9.9 ± 2.2
Hussain (11)	Junior (30)	165.5 ± 5.3	63.5 ± 5.9	11.4 ± 1.3
Jeyaraman et al. (2)	Sub-Elite (84)	175.0 ± 5.7	68.7 ± 20.1	N/A
Kuntze et al. (33)	Sub-Elite (9)	179.0 ± 6.0	70.6 ± 7.4	N/A
Kuntze et al. (34)	Sub-Elite (9)	178.0 ± 5.0	73.2 ± 9.3	N/A
Madsen et al. (35)	Elite (20)	186.7 ± 7.0	77.7 ± 6.0	N/A
	Sub-Elite (21)	182.2 ± 5.1	77.8 ± 7.2	N/A
Maloney et al. (36)	Elite (8)	182.0 ± 5.2	70.9 ± 10.0	N/A
Mathur et al. (12)	Elite (18)	172.4 ± 5.3	67.9 ± 3.6	8.2 ± 1.7
Ooi et al. (4)	Elite (12)	176.0 ± 7.0	73.2 ± 7.6	12.5 ± 4.8
	Sub-Elite (12)	171.0 ± 5.0	62.7 ± 4.2	9.5 ± 3.4
Poliszczuk et al. (13)	Elite (9)	184.6 ± 6.0	80.7 ± 9.1	9.6 ± 3.3
Ramos-Alvarez et al. (15)	Junior (12)	170.8 ± 11.2	61.1 ± 16.7	12.0 ± 2.8
Raschka et al. (14)	Sub-Elite (20)	182.0 ± 4.6	77.5 ± 5.9	10.8 ± 1.9
Revan et al. (37)	Elite (26)	166.4 ± 5.6	59.5 ± 7.7	22.8 ± 3.8
Senel et al. (27)	Elite (86)	179.1	73.7	N/A
van Lieshout (19)	Junior (8)	180.4 ± 8.1	73.4 ± 9.7	9.6 ± 1.6
Female				
Abian et al. (8)	Elite (15)	165.4 ± 5.6	61.1 ± 3.9	16.9 ± 2.4
Arslanoglu et al. (28)	Elite (86)	168.3 ± 6.3	61.7 ± 6.0	N/A
Aydogmus et al. (29)	Elite (90)	169.1 ± 6.1	61.3 ± 5.2	N/A
Campos et al. (17)	Junior (10)	163.8 ± 0.3	61.7 ± 6.9	N/A
Faude et al. (21)	Elite (8)	166.0 ± 5.0	59.8 ± 6.8	N/A
Hughes (3)	Sub-Elite (49)	N/A	61.8 ± 7.8	23.9 ± 3.5
Hughes et al. (32)		167.0 ± 5.0	66.0 ± 6.3	N/A
Hume et al. (7)	Elite Singles (20)	168.0 ± 7.1	61.2 ± 4.9	14.2 ± 2.5
	Elite Doubles (36)	166.5 ± 6.1	61.4 ± 5.5	14.1 ± 2.1
Ramos-Alvarez et al. (15)	Junior (7)	165.4 ± 3.6	59.3 ± 5.2	15.5 ± 3.1
Raschka et al. (14)	Sub-Elite (20)	168.1 ± 5.8	65.5 ± 6.6	18.9 ± 2.1
Revan et al. (37)	Elite (24)	164.2 ± 7.3	60.1 ± 7.3	23.7 ± 3.9
Senel et al. (27)	Elite (76)	168.3	62.2	N/A
van Lieshout (19)	Junior (7)	161.2 ± 4.3	58.1 ± 7.9	19.2 ± 4.5

A running specific Modified Southeast Missouri (SEMO) agility test was adopted as their COD measure; such a test likely differs greatly to badminton movement patterns, which utilise a range of steps when moving across the court (2). Due to an increased specificity, a test which involves lunging in a number of directions may be a better measure of COD in badminton athletes. Such a test would likely have a stronger correlation with leg length than generic COD tests.

Leg Strength Qualities

The following leg strength (ballistic and neuromuscular) qualities have been proposed as significant predictors of COD performance: elastic strength, concentric strength and leg muscle imbalances (1). The effect of these qualities on COD performance in badminton athletes (38) is not well researched and therefore understood. The studies that have measured elastic and concentric strength utilised horizontal and vertical double leg jump (2-4, 17-19, 23, 32), maximal strength (4) and isokinetic dynamometry (9, 19).

Elastic Strength

Elastic strength or movement that involves the stretch shorten cycle (SSC) results in an increased velocity of contraction due to the release of elastic energy (1, 39). Large correlations were noted between badminton ability and elastic strength as tested with vertical (r = 0.57) and horizontal (r = 0.55) counter-movement jumps (CMJ). Badminton movement mechanics efficiently utilise elastic strength through the inclusion of the split step and the lunge when changing direction.

The split step involves the defensive athlete completing a small vertical jump as their opponent is striking the shuttle and landing just following the strike. The ideal timing of this motor task will depend on athlete ability level. Elite athletes have been found to anticipate shuttle trajectory up to 0.167 seconds before the shuttle is struck, whereas sub-elite athletes were only able to predict shuttle trajectory 0.083 seconds before the strike (24). As elite athletes have earlier shuttle anticipation, the split step is landed earlier thus allowing more time to move to the ideal position for the next shot. To the knowledge of the authors no researchers have investigated the effects of the split step on badminton performance, however, perceived benefits are that the split step utilises the SSC to increase the explosiveness of subsequent COD movements.

While the split step begins the initial change of direction, the lunge allows athletes to rapidly decelerate and accelerate when completing a badminton shot (33, 40). The lunge is the most frequent of all movements in badminton (~500 per match), as it is used during ~90% of all shots and thus accounting for 15% of all movements (30, 33). The lunge provides a stable base of support in the anterior-posterior direction due to a wide stance and low centre of gravity, allowing for enhanced COD performance (33). Similar to the split step, the lunge utilises the eccentric deceleration phase to increase the concentric contraction speed during the SSC. Due to a paucity of research, the effect of eccentric strength on COD performance in badminton is unclear. Yet in comparable sports, an increase in eccentric strength reduces the duration of the deceleration phase, resulting in a faster progression to the acceleration phase (16). A faster progression allows for a more efficient utilisation of the SSC by reducing the time for the elastic energy to dissipate prior to the concentric phase. This suggests that an increase in eccentric strength may reduce overall lunge time, thereby enhancing the COD.

While elastic strength appears to be important when changing direction in badminton, relationships between CMJ’s and COD performance are inconclusive (2-4, 32). Hughes

(3) identified elastic strength as a moderate to large predictor of COD performance in junior female athletes, as tested with vertical ($r = 0.49$, $p < 0.01$) and horizontal ($r = 0.60$, $p < 0.01$) CMJ's. Yet both jumps were non-significantly related to COD performance in junior male athletes. In testing elite male athletes, Ooi et al. (4) established that the V-CMJ accounted for 63 and 49% of the variance in the sideways and four corner agility tests, respectively. An independent t-test comparison between elite and sub-elite athletes, revealed no significant differences in V-CMJ and COD performance (4). However, absolute V-CMJ power was significantly greater ($p = 0.001$) in elite athletes (3977 ± 385 W) as compared to sub-elite athletes (3448 ± 304 W). These results can be attributed to the significantly greater body mass of elite athletes (73.2 ± 7.6 kg) compared with sub-elite athletes (62.7 ± 4.2 kg); power outputs did not differ significantly between cohorts following body mass normalisation. Again these results differ to those of Hughes and Bopf (32) in which H-CMJ and V-CMJ accounted for no more than 3% of the variance in the badminton specific speed test for both female and male elite athletes. The inclusion of the vertical depth jump (V-DJ) as a measure of vertical elastic strength, may enhance the specificity of assessment. The depth jump has been identified as a more accurate measure of elastic strength than the CMJ, however a single study has assessed V-DJ performance in badminton athletes (4), yet relationships between V-DJ were not assessed, with researchers instead utilising the CMJ results in the discussion. These results led the researchers to conclude that due to the technical aspects of badminton movement patterns, a more specific measure of elastic strength may be required for valid assessment. These findings suggest that badminton may benefit from additional research into the validity of counter-movement and depth jumps and novel badminton specific elastic strength tests, particularly as predictors of COD performance.

Table 2. Elastic strength tests for badminton athletes.

Study	Participants (n, sex)	Test	Result
Campos et al. (17)	Junior (10, F)	V-CMJ (cm)*	33.4 ± 1.9
		V-CMJ (cm)#	27.2 ± 2.1
	Junior (10, M)	V-CMJ (cm)*	46.0 ± 6.5
		V-CMJ (cm)#	36.7 ± 6.0
Fuchs et al. (18)	Elite (18, M)	V-CMJ (cm)*	48.4 ± 4.0
		V-CMJ (cm)#	43.5 ± 4.3
		V-DJ (cm)[1]	36.7 ± 4.3
		H-CMJ (cm)*	254.0 ± 18.0
Hughes (3)	Junior (49, F)	H-CMJ (cm)*	196.0 ± 18.0
		S-VJ (cm)*	49.0 ± 5.0
	Junior (43, M)	H-CMJ (cm)*	242.0 ± 14.0
		S-VJ (cm)*	63.0 ± 6.0
Jeyaraman et al. (2)	Sub-Elite (84, M)	H-CMJ (cm)	214.4 ± 14.0
		V-CMJ (cm)	46.5 ± 7.9
Ooi et al. (4)	Elite (12, M)	V-CMJ (cm)#	46.3 ± 5.4
		V-DJ (cm)[2,#]	34.4 ± 5.5
	Sub-Elite (12, M)	V-CMJ (cm)#	46.0 ± 3.7
		V-DJ (cm)[2,#]	32.6 ± 4.4
Van Lieshout (19)	Junior (7, F)	S-VJ (cm)#	53.0 ± 4.0
	Junior (8, M)	S-VJ (cm)#	35.0 ± 6.0

Key: H-CMJ – horizontal counter-movement jump, S-VJ – Sargent vertical jump, V-CMJ – vertical counter-movement jump, V-DJ – vertical depth jump, * – arm swing, # – no arm swing, [1] – 35cm, [2] – 42.5cm.

Concentric Strength

No research was identified that assessed relationships between concentric strength and COD performance in badminton athletes. However, due to mechanical differences between concentric-only strength (reduced elastic contribution) and COD performance (high elastic contribution), the two qualities would appear minimally related. When measuring concentric strength, all attempts are made to ensure that the elastic component of elastic strength is minimised, therefore allowing for the effective measurement of the contractile components contribution to force production. As COD in badminton depends a great deal on the elastic contribution of muscles, the use of concentric-only strength tests would appear questionable. However, if the strength and conditioning coach is interested in establishing the quality and quantity of the player's elastic contribution, then there is a place for concentric assessment. For example, the performance of a CMJ over a squat jump (SJ) informs training focus e.g. a minimal increase of jump performance in the elastic assisted CMJ implies more elastic training is required.

Table 3. Concentric strength tests for badminton athletes.

Study	Participants (n, sex)	Test	Result
Andersen et al. (9)	Elite (35, M)	MPT NL Extension ($nm.kg^{-1}$)[1]	3.69 ± 0.08
		MPT DL Flexion ($nm.kg^{-1}$)[1]	1.86 ± 0.04
		MPT DL Extension ($nm.kg^{-1}$)[3]	2.15 ± 0.04
		MPT DL Flexion ($nm.kg^{-1}$)[3]	1.30 ± 0.03
Campos et al. (17)	Elite (10, F)	Squat Jump (cm)	28.1 ± 2.4
	Elite (10, M)	Squat Jump (cm)	39.3 ± 5.7
Ooi et al. (4)	Elite (12, M)	1-RM Squat (kg)	143.2 ± 17.3
		Squat Jump (cm)	42.7 ± 5.2
	Sub-Elite (12, M)	1-RM Squat (kg)	129.9 ± 14.1
		Squat Jump (cm)	41.5 ± 5.2
van Lieshout (19)	Junior (7, F)	MPT DL Extension (nm)[2]	154 ± 35
		MPT NDL Extension (nm)[2]	139 ± 37
		MPT DL Flexion (nm)[2]	93 ± 21
		MPT NDL Flexion (nm)[2]	87 ± 18
	Junior (8, M)	MPT DL Extension (nm)[2]	209 ± 47
		MPT NDL Extension (nm)[2]	213 ± 46
		MPT DL Flexion (nm)[2]	130 ± 20
		MPT NDL Flexion (nm)[2]	132 ± 17

Key – MPT – mean peak torque, DL – dominant leg, NDL – non-dominant leg, [1] – 30 $deg.sec^{-1}$, [2] – 60 $deg.sec^{-1}$, [3] – 240 $deg.sec^{-1}$.

Two badminton specific studies measured concentric strength as the mean peak torque (MPT) of extension and flexion during isokinetic testing (9, 19). While these studies did not compare MPT to badminton ability or COD performance, they do provide baselines for future research to build upon. Anderson (9) measured MPT at slow (30 $deg.sec^{-1}$) and fast (240 $deg.sec^{-1}$) speeds while presenting results relative to body mass ($nm.kg^{-1}$), whereas van Lieshout (19) measured MPT at slow (60 $deg.sec^{-1}$) speeds and presented results as absolute values (nm). Due to the varying methods of data collection, analytic comparisons between studies are difficult, however future research would benefit from establishing the effect of MPT and quadriceps-hamstring ratio’s on badminton and COD performance.

Leg Muscle Imbalances

The third leg strength quality mentioned in the model refers to the degree of muscular asymmetry between legs. This is vital to COD performance in badminton as right leg power determines COD performance when moving to the left; whereas left leg power determines COD performance when moving to the right (41). Leg strength asymmetry is prominent in badminton due to a heavy reliance on dominant leg lunging as a means of changing direction while striking the shuttle (40, 42). During each lunge the dominant leg braces for deceleration with a force equivalent to 50-70% of body mass and then accelerates towards centre court following the completion of the shot (40, 43, 44). As athletes complete ~500 lunges per match, muscle imbalances theoretically occur with significantly greater strength in the dominant leg (30, 44).

Evidence in support of this premise is limited, with a single study (19) identifying the magnitude of muscle asymmetry between legs in badminton athletes. Non-significant differences in absolute leg strength were reported during isokinetic dynamometric leg extension and flexion (see Table 3). Additionally, non-significant differences were observed between the relative strength of the hamstrings, however the relative strength of the quadriceps was greater in the dominant leg (F – 259.6 nm, M – 286.3 nm) than the non-dominant leg (F – 238.4 nm, M – 277.7 nm). As this test was concentric in nature, the assessment most likely lacked the specificity to identify leg muscle imbalances; elastic strength testing involving lunge type movements may be more valid. It may be hypothesised that due to a greater workload, badminton athletes have greater elastic strength resulting in faster direction changes off the dominant leg. Future research into leg strength of badminton athletes, will require multi-directional assessment as Meylan et al. (20) established that muscular performance is directionally specific and therefore, leg asymmetry in one direction may not indicate leg asymmetry in another.

Technique

Technique is the third COD determinant. Athletes should attempt to utilise the SSC, while maintaining a low centre of gravity, a lean in the direction that the COD is occurring and a stable base of support (1). Ideal technique should exploit elastic strength through the use of the split step and the lunge. Prior to the split step an athlete should maintain a base of support that is slightly wider than shoulder width and a low centre of gravity to allow for multi-directional changes of directions. Following the split step, athletes should push off and lean in the direction that the steps are to be taken. While there are multiple ways that COD may occur during and/or following a shot, the most frequent is the lunge as it provides a stable base of support in the direction that the COD is occurring.

Kuntze et al. (33) conducted a COD study in badminton athletes, which compared three lunge techniques: kick, hop and step-in. The kick lunge is the traditional lunge where the dominant leg acts as the primary force producer during the deceleration and acceleration (see Figure 1). The non-dominant leg provides a slight braking force during the drive phase, as the inner toe of the foot slides across the court. The hop lunge differs to the kick lunge in that the drive phase (foot position 4) is slightly shorter to allow for a small forward hop during the deceleration phase of the drive (see Figure 2). Whereas, the step-in lunge differs to the kick lunge in that the non-dominant leg is brought forwards during the drive phase, providing a contribution to the acceleration phase of the direction change (see Figure 3). From the lunge comparison, non-significant differences were noted in the overall time taken to complete each of the three lunges, with the hop lunge producing a slower deceleration phase, but compensating with a faster acceleration phase (33). The increased speed of the acceleration phase is likely due to the increased elastic energy in the Achilles tendon as a result of the hop (33). The acceleration phase of the hop lunge resulted in significantly greater knee and ankle power in comparison to the kick and step-in lunges. As acceleration continues following the lunge the increased speed of the hop lunge may enhance ensuing steps to decrease the total time required to complete the COD.

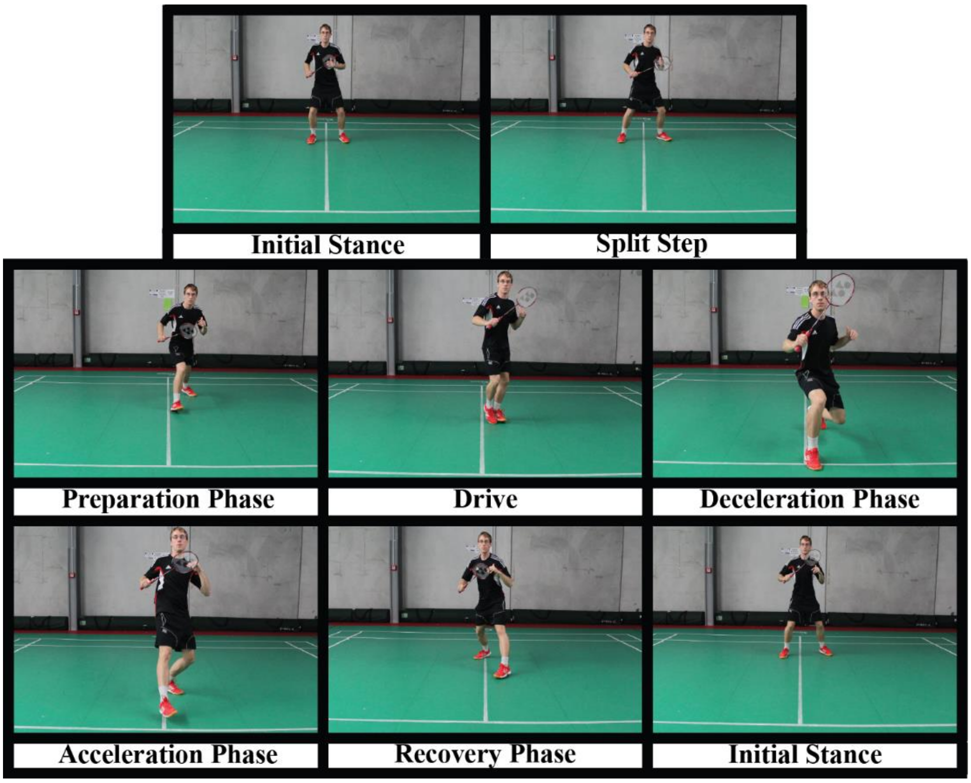

Figure 2. Kick lunge footwork.

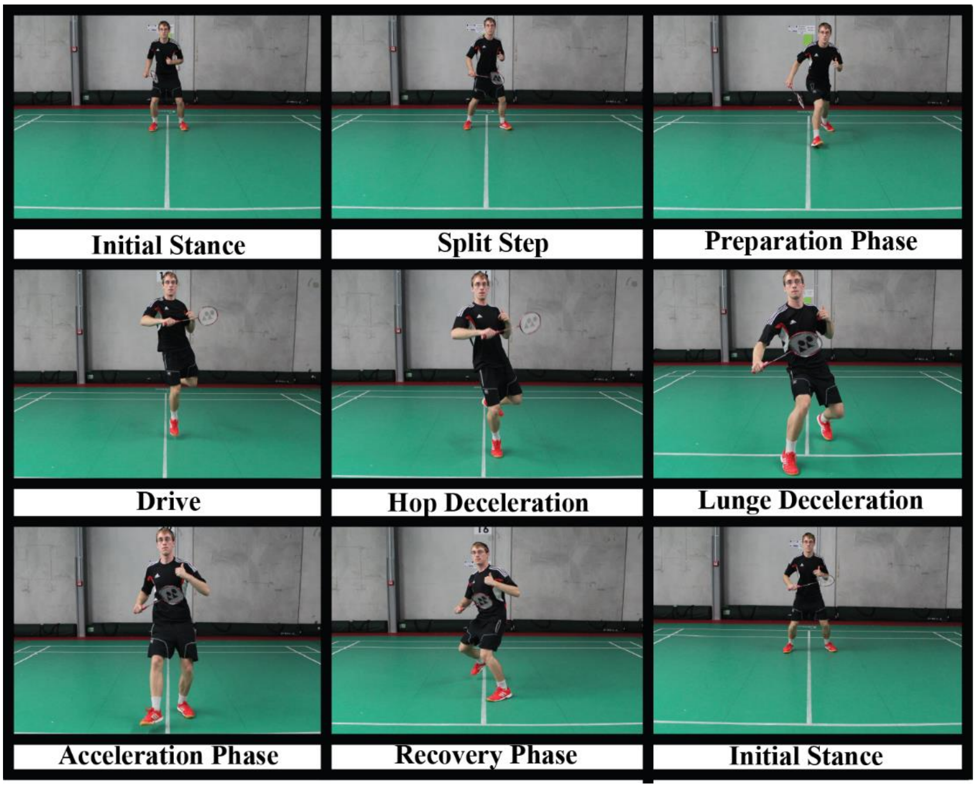

Figure 3. Drive and hop phase of the lunge.

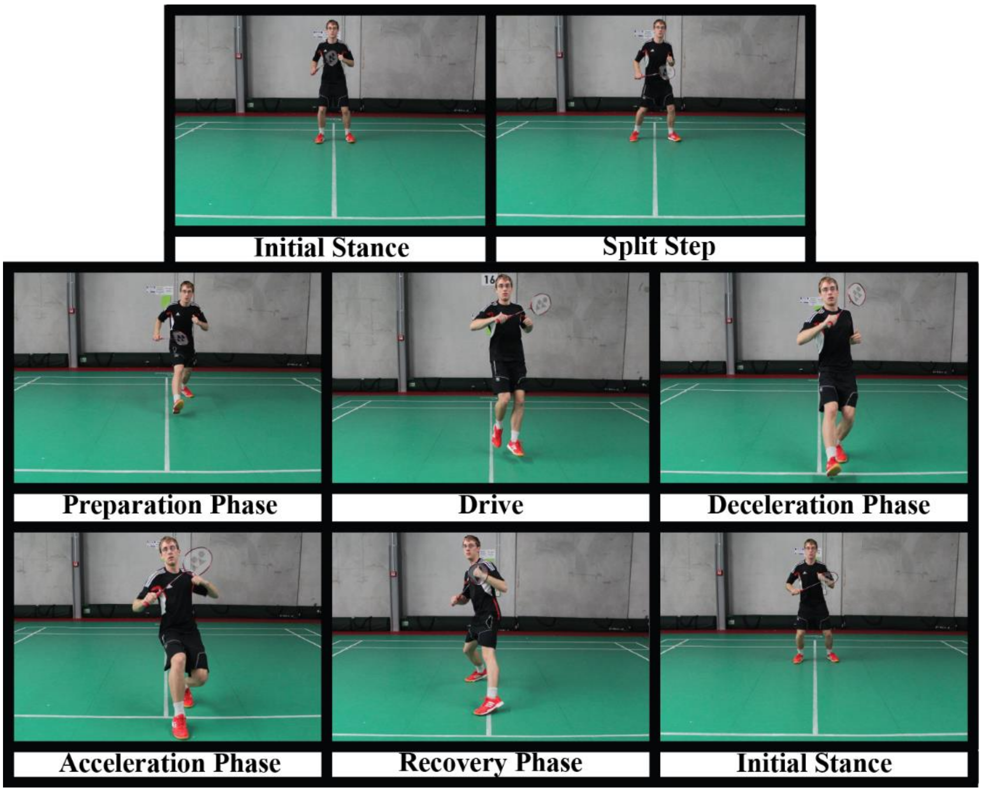

Figure 4. Drive and recovery phase of the step-in lunge.

Coaches currently assess COD technique through either qualitative methods or cyclic COD tests, as a reliable badminton specific COD assessment battery has not been identified. A cyclic test that mimics badminton specific COD could help differentiate poor and high quality movement patterns, when included in an assessment battery. As defined by Sheppard and Young (1), a cyclic COD test is required to be a purely physical test with minimal mental processing. The test would also include badminton specific skills, as sport specific movement has been shown to significantly alter COD performance testing (45, 46). When determining the suitability of a cyclic COD test to be included in an assessment battery, the test should: 1) demonstrate reliability across a series of testing sessions; 2) distinguish between athlete's with strong and weak technical qualities (sensitivity); 3) discriminate between low and high performing direction changes (sensitivity); and, 4) be a purely physical assessment with minimal mental processing.

Table 4. Cyclic change of direction tests for badminton athletes.

Study	Participants (n, sex)	Test	Results (s)
Fuchs et al. (18)	Elite (18, M)	40m T-Test[1]	10.14 ± 0.4
Gucluover et al. (10)	Elite (16, M)	5-0-5[1]	2.5 ± 0.2
	Sub-Elite (15, M)		2.7 ± 0.2
Hughes et al. (3)	Junior (49, F)	Badminton Specific Speed[2]	13.3 ± 1.0
	Junior (49, M)		11.7 ± 0.8
Jeyaraman et al. (2)	Sub-Elite (84, M)	SEMO[1]	12.2 ± 0.2
Ooi et al. (4)	Elite (12, M)	Four Corner[2]	32.4 ± 1.1
		Sideways[2]	15.3 ± 0.7
	Sub-Elite (12, M)	Four Corner[2]	32.9 ± 1.8
		Sideways[2]	15.0 ± 0.6
van Lieshout (19)	Junior (7, F)	SEMO[1]	11.9 ± 0.4
	Junior (8, M)	SEMO[1]	10.7 ± 0.5

Key: SEMO – Modified South East Missouri [1] – generic COD test, [2] – specific COD test.

Current cyclic COD tests used for badminton assessment can be separated into two categories; generic and badminton specific (see Table 4). The generic tests include: 4 x 10 m shuttle run (23, 47), 5-0-5 (10) and SEMO (2, 19). Four badminton specific cyclic COD tests have been identified in the literature: the badminton specific test (3, 48), four corner test (4), sideways test (4) and speed specific test (5), none of which satisfy all of the aforementioned requirements. The badminton specific test requires athletes to complete a mock shot in four areas of the court, with a return to centre court between shots (3, 48). The test does not satisfy all requirements, as it only tests four of the eight directions that an athlete may move on court and it cannot distinguish between individual directions. The specific speed test was adapted from the badminton specific test and involves athletes completing mock shots in each of the four corners and two sideways directions with a sprint through a timing gate in the rear-mid and front-mid (5). While successfully assessing a range of directions, the specific speed test is unable to distinguish between COD ability in each direction. Ooi and colleagues (34) assessed cyclic COD ability with the side-ways test and four-corner agility tests. The side-ways test provides a lateral COD assessment while the four-corner agility test provides a diagonal COD assessment. These two tests combine for the most specific assessment of whole court cyclic COD ability, but lack the potential to distinguish between individual directional weaknesses. A suggested test which satisfies each of the cyclic COD test requirements is detailed in the practical applications.

Straight Line Sprint Speed

The fourth determinant of the Sheppard and Young (1) COD model is SLSS. Minimal evidence supports the inclusion of SLSS as a key determinant of COD performance. Little and Williams (38) concluded that maximal sprint speed, acceleration and COD ability are three independent and relatively unrelated variables. SLSS is likely to have little relevance to badminton performance purely based on the court dimensions and movement pattern differences between badminton and SLSS. This premise is supported by Madsen et al. (35) as 30 m sprint performance did not differ between elite and sub-elite badminton players. However, Jeyaraman and Kalidasan (2) attempted to establish a relationship between COD and SLSS in badminton athletes, with the SEMO agility test found to strongly correlate with 20 m SLSS (*r* = 0.76). As the SEMO agility test is running specific, the application/relevance of findings to in-game badminton specific COD performance appears questionable. Straight line sprinting with a greater focus on short distance acceleration as opposed to speed is likely a greater predictor of COD and badminton performance (19).

Table 5. Straight line sprint tests for badminton athletes.

Study	Participants (n, sex)	Distance (m)	Results (s)
Campos et al. (17)	Junior (10, F)	20	3.50 ± 0.14
	Junior (10, M)	20	3.12 ± 0.08
Fuchs et al. (18)	Elite (18, M)	10	1.73 ± 0.06
Jeyaraman et al. (2)	Sub-Elite (84, M)	50	7.25 ± 0.53
van Lieshout (19)	Junior (7, F)	2	0.49 ± 0.05
		4	0.87 ± 0.08
		6	1.25 ± 0.09
		2 Backwards	0.64 ± 0.06
		4 Backwards	1.20 ± 0.06
		6 Backwards	1.74 ± 0.10
	Junior (8, M)	2	0.44 ± 0.03
		4	0.80 ± 0.04
		6	1.14 ± 0.05
		2 Backwards	0.58 ± 0.03
		4 Backwards	1.08 ± 0.05
		6 Backwards	1.51 ± 0.10

Flexibility

While not included as a COD determinant in the Sheppard and Young (1) model, some research suggests that flexibility is related to COD performance in badminton athletes. Cronin et al. (6) determined that a three variable model of time to peak force, leg length and flexibility accounted for 85% of the explained variance in absolute lunge performance. The flexibility result was recorded as the linear distance between the lateral malleolus of each leg during a frontal split (6). No badminton specific research has adopted this approach as a measure of flexibility; opting instead to primarily measure flexibility through the sit and reach test (2, 5, 10, 47) (see Table 6). Researchers have found the sit and reach test to be moderately correlated with COD performance (*r*

= 0.40) and weakly with playing ability (r = 0.27) (2). In attempting to establish more valid measures of flexibility, van Lieshout (19) assessed flexibility with a Leighton flexometer. The research established that the range of hip extension and flexion was minimally different between dominant and non-dominant legs, with results comparable to ranges for healthy adults (49). As correlations were not established between flexibility and COD, the effect of the hip extension and flexion values on COD performance is unclear. Further research is required to determine which if any flexibility test is best suited to be included in a comprehensive BSA battery.

Table 6. Flexibility tests for badminton athletes.

Study	Participants (n, sex)	Test	Results
Gucluover et al. (10)	Elite (16, M)	Sit and Reach (cm)	35.7 ± 7.8
	Sub-Elite (15, M)	Sit and Reach (cm)	34.5 ± 6.5
Jeyaraman et al. (2)	Sub-Elite (84, M)	Modified Sit and Reach (cm)	11.1 ± 6.5
van Lieshout (19)	Junior (7, F)	Left Hip Extension (°)	42 ± 11
		Right Hip Extension (°)	39 ± 9
		Left Hip Flexion (°)	93 ± 19
		Right Hip Flexion (°)	101 ± 22
		Left Hip Rotation (°)	40 ± 8
		Right Hip Rotation (°)	44 ± 14
	Junior (8, M)	Left Hip Extension (°)	36 ± 9
		Right Hip Extension (°)	35 ± 6
		Left Hip Flexion (°)	85 ± 10
		Right Hip Flexion (°)	87 ± 8
		Left Hip Rotation (°)	36 ± 13
		Right Hip Rotation (°)	39 ± 9

Practical Applications

The findings of this review support the need for improved design and implementation of a BSA battery. The following nine measures have been proposed to comprise the BSA battery: height, body mass, eight site sum of skinfold, leg length, frontal split hip flexibility, sagittal split hip flexibility, V-CMJ, MDLT and MDCT. Relationships between each of these tests and COD performance would provide athletes and coaches with the diagnostic tools and information to enhance COD performance.

Anthropometry

To date, little research has assessed relationships between body fat and COD performance in badminton athletes. It may be expected that COD performance improves as body fat nears the ranges measured by Hume et al. (7). It is proposed that body fat is assessed via an eight site sum of skinfold. The second anthropometric test is a measure of leg length as this has been established as a strong predictor of lunge performance. Relationships between leg length and COD performance have yet to be assessed in badminton. It may be suggested that optimal leg length range is dependent on multiple anthropometric features, such as an increase in muscle mass relative to an increase in leg length.

Flexibility

The inclusion of a flexibility measure appears pertinent; however a badminton specific flexibility test has yet to be established. Of interest may be hip flexibility (e.g. Thomas test, Ober's test), the Y-balance test, frontal split and/or sagittal split due to the relevance of lunging to performance.

Elastic Strength

When measuring elastic strength, it is proposed that the assessment battery includes the MDLT and either a V-CMJ or V-DJ test. The MDLT involves athletes completing a lunge as quickly as possible in each of the eight directions outlined in Figure 5. Each lunge is 1.5 times an athlete's leg length to ensure consistency between athletes (Figure 5 is scaled to an 80 cm leg length). The time taken to complete the lunge is recorded for each direction to provide practitioners with directional specific lunge capabilities to identify weaknesses and enhance training specificity. Research has not assessed the reliability and discriminative ability of this test. It is hypothesised that performance on the MDLT will strongly correlate with COD performance. Both the V-CMJ and V-DJ have been proposed in recognition that direction changes do not solely occur in the horizontal plane, but also the vertical. As it has yet to be confirmed which test is most effective as a badminton specific measure of vertical ballistic capability, an investigation into both measures may be beneficial. The tests have been designed given the information in this area, however the reader needs to be cognisent of the limited literature.

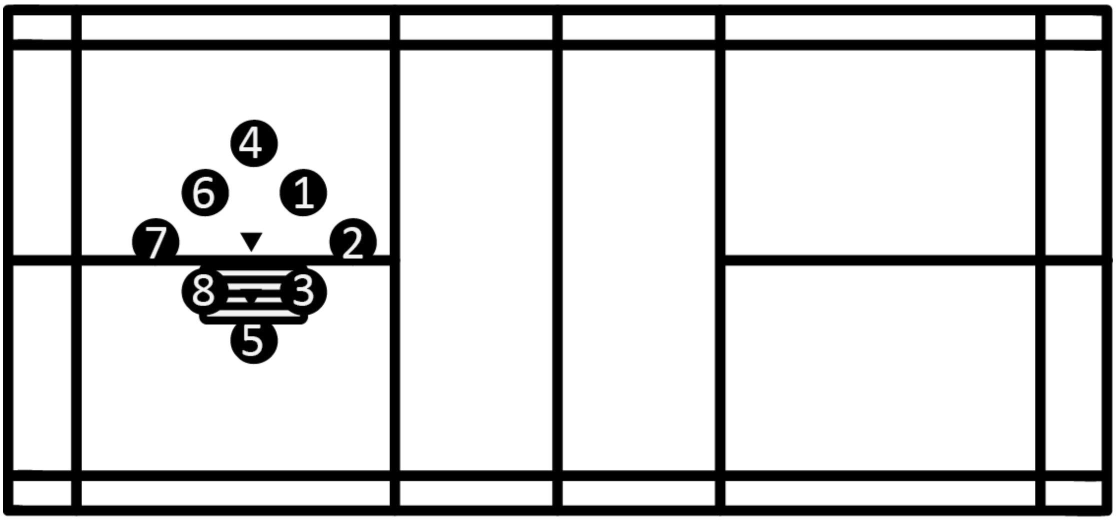

Figure 5. Multi-directional lunge test. ▼ – foot placement, ▤ – contact mat, 1 – front-backhand, 2 – front-mid, 3 – front-forehand, 4 – centre-backhand, 5 – centre-forehand, 6 – rear-backhand, 7 – rear-mid, 8 – rear-forehand.

Cyclic Change of Direction Test

The MDCT is included to assess the athlete's cyclic COD movement ability (see Figure 6). Athletes will use self-selected footwork to move from the centre court to one of the eight perimeter locations and complete a mock shot, before returning to centre court. The time taken to complete the sequence of movements will be recorded for each direction. Results can be compared to the corresponding lunge direction and diagnostics around the player's acyclic and cyclic COD ability can be made. Furthermore, left-right imbalances can be determined and addressed if thought potentially injurious or detrimental to optimal performance.

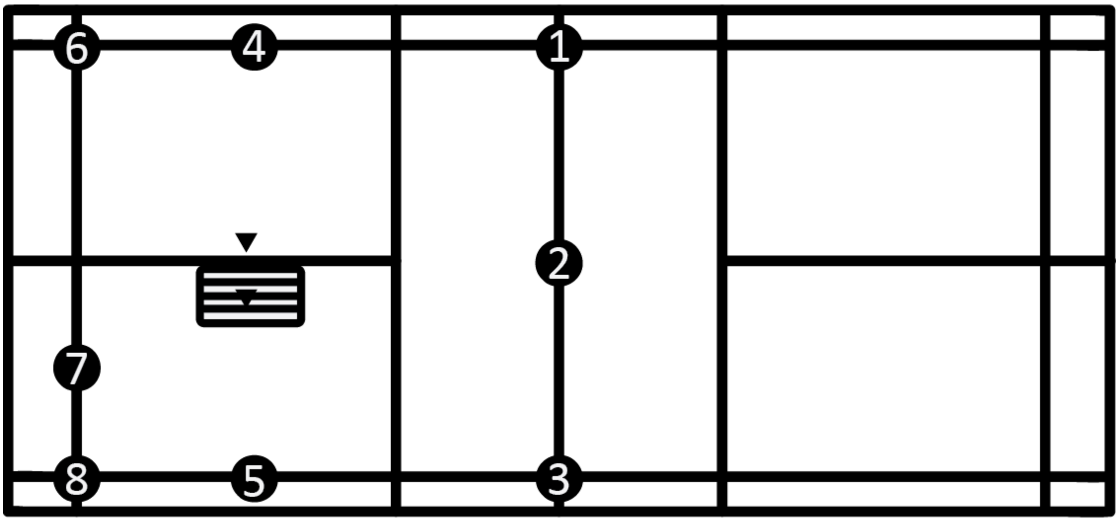

Figure 6. Multi-directional cyclic change of direction test. ▼– foot placement, ▤ – contact mat, 1 – front-backhand, 2 – front-mid, 3 – front-forehand, 4 – centre-backhand, 5 – centre-forehand, 6 – rear-backhand, 7 – rear-mid, 8 – rear-forehand.

Summary

A range of physical qualities appear important for COD performance in badminton athletes. A BSA has been proposed with the inclusion of tests that assess: height, body mass, body fat, leg length, hip flexibility, lunge performance and cyclic COD ability. The reliability, validity and sensitivity of the MDLT and MDCT must be established prior to their inclusion in the BSA. These two tests have been designed to provide a large prescriptive capacity through the inclusion of badminton specific movement patterns. The potential inclusion of videography during these tests may further enhance the diagnostic and prescriptive capacity, as coaches gain greater insight into movement technique.

CHAPTER THREE:

RELIABILITY AND DIAGNOSTIC APPLICATIONS OF NOVEL BADMINTON SPECIFIC MULTI-DIRECTIONAL CHANGE OF DIRECTION TESTS

Prelude

The literature review highlighted a number of limitations in relation to current assessment practices in badminton. It was concluded that a range of physical qualities appeared important for COD performance in badminton athletes. A BSA was therefore proposed that included novel tests of lunge performance and cyclic COD ability. Before the inclusion of any new test in a testing battery, the reliability, validity and sensitivity of the tests should be established. Establishing the reliability of these novel tests provided the focus of this chapter.

Introduction

Shuttle speeds in badminton have been recorded at over 250 km/h at the instance following a smash (50-52). A key aspect of badminton is the high speed nature of the sport which requires athletes to react and move rapidly about the court, this is termed agility. Agility consists of two components, the perceptual and decision making component and the physical COD component. In badminton these two components are closely interlinked as an athlete perceives the required direction change and decides how to respond, before executing the COD. The perceptual and decision making component is crucial to badminton performance as elite athletes process the required direction changes at a faster rate. This occurs as elite athletes more effectively identify key anticipatory cues between shots, for example the timing of a jump between a smash and a drop shot (24). While the perceptual and decision making component is important, the physical capacity to execute the selected COD, is determined by the physical component. Therefore the aim of this research is to assess the reliability of the MDLT (horizontal lower body neuromuscular capabilities) and MDCT (horizontal cyclic COD) which each assess an aspect of the physical COD component.

Lower body neuromuscular assessment in badminton has been limited to the horizontal and vertical CMJ (2-4, 17-19). The V-CMJ with arm swing is an effective measure of vertical lower body neuromuscular (ballistic) capabilities, due to mechanical similarities to vertical jumps performed in badminton. However, the efficacy of the H-CMJ to measure horizontal neuromuscular capabilities in badminton is questionable. Direction changes in badminton rarely utilise a two foot horizontal jump, as the lunge is the primary movement pattern of choice. Therefore, the MDLT, which assesses multi-directional lunge COD performance, should provide greater specificity to badminton, thereby offering the potential to enhance assessment.

Assessment of cyclic COD in badminton occurs most frequently with the following four assessments: badminton specific speed test (3, 48), four corners (4), sideways (4) and speed specific test (5). The badminton specific speed test (3, 48) and speed specific test (5) provide a single time for an athlete to complete mock shots in multiple areas of the court. While the sideways and four corners tests (4) measure the time for athletes to strike a row of shuttles in either the lateral or diagonal directions, respectively. These tests appear effective at assessing overall COD ability, but due to an inability to distinguish between directions, the potential to inform programming is limited. As an alternative, the MDCT is proposed, which individually assesses the cyclic COD ability of an athlete in eight directions.

The purpose of this investigation, was to quantify the reliability of the MDLT and MDCT. If reliable, these assessments should provide a high degree of diagnostic information to guide the individualisation of programming and in turn enhance directional specific COD ability in badminton athletes.

Methods

Experimental Approach to the Problem

The MDLT and MDCT have been developed for badminton athletes, however the reliability of these tests has yet to be established. Fifteen players were assessed over three testing occasions separated by at least seven days. Conventional reliability statistics [percent change in the mean, typical error (TE) and intraclass correlation coefficient (ICC)] were used to quantify the variability of these two COD tests. Diagnostic applications of each test were also discussed.

Participants

A total of 15 participants (3 female, 12 male) took part in the study, including club (7 male) and representative (3 female, 5 male) level athletes. The mean age, height, body mass and playing experience is detailed in Table 1. Additionally, all 15 participants were right hand dominant. Participants were of mixed ethnicity and selected as a population of convenience. The Auckland University of Technology Ethics Committee approved all aspects of the research. All participants were required to sign an informed consent form before participating in the research.

Table 7. Physical characteristics of participants.

Physical Characteristic	Female (3)	Male (12)
Age (years)	19.0 (3.6)	28.8 (10.7)
Height (cm)	169 (1.8)	179 (7.7)
Mass (kg)	62.3 (1.5)	74.8 (6.3)
Experience (years)	7.7 (1.8)	7.4 (8.4)

Testing Protocol

Testing protocols were replicated over three occasions, separated by at least seven days. A warm-up protocol was not required as the testing was completed during the athlete's regular training. The session began with the recording of athlete characteristics – age, height, mass and training experience. The two tests were completed on a contact mat (Kinematic Measurement System, Fitness Technology, Skye, SA, Australia) which measured the time between dominant foot contacts. In preparing for the MDLT the athlete stood facing the net with the dominant foot placed in the centre of the mat and the non-dominant foot placed at a shoulder width distance laterally. Tape markers were then placed at a distance of 1.5 times leg length in each of the eight directions, in-line with the nearest point of the non-dominant shoe (see Figure 5). Athletes were instructed to complete a lunge as quickly as possible by placing their dominant foot over the tape marker and then back to the centre of the contact mat. The non-dominant foot was to remain planted, however it could pivot when necessary. The athlete was provided the opportunity to complete a self-selected quantity of lunges prior to testing, until they felt they were familiar with the protocol. The athlete completed the eight lunges in a randomised order three times, with a 10 second rest between lunges. This was considered adequate as badminton athletes complete approximately 500 lunges (30) in a badminton match, thus a total of 24 lunges for the test was not considered excessive. The total time between dominant foot contacts was recorded to the nearest 0.001 seconds. The final result used for analysis was calculated as the mean of the fastest two trials in each direction.

In setting up the MDCT a shuttle was placed on either the net (number 1-3 on Figure 6) or on a stack of three taped shuttle tubes of 1.26 m height (number 4-8). The location for each shuttle can be observed in Figure 2, with shuttle 7 placed at an arm and racquet length from the centre of the contact mat. The athlete began standing with their feet shoulder width apart and their dominant foot placed on the centre of the contact mat. Instructions were provided for the athlete to use their self-selected technique to move to one of the eight shuttles and with their racquet complete a net kill for shuttles 1-3 and a self-selected shot that moves the shuttle towards the net for shuttles 4-8 before returning to centre court. This sequence of movements in each direction was to be completed as quickly as possible. Prior to testing the athlete was provided a self-selected quantity of trials, until they felt familiar with the protocol. The athlete completed the eight directional changes in a randomised order three times, with a 10 s rest between each directional change to ensure fatigue did not influence the results. The time to complete each directional change was recorded to the nearest 0.001 seconds. The final result for each direction was calculated as the mean of the fastest two trials in each direction.

Statistical Analysis

Means and standard deviations of the two fastest trials were used to represent centrality and spread of data. The sample mean and standard deviation were calculated for each gender and following confirmation of minimal differences between genders all participants were pooled into a single sample for analysis. Box plots, whisker plots and the Shapiro-Wilk statistic were used to identify outliers and data normality. The inter-session reliability was calculated using three statistical methods on a custom-designed Excel spreadsheet (53): percentage change in mean, TE and ICC. The percentage change in mean was used to identify systematic error (i.e. learning effect) between testing occasions. The TE is a measure of absolute consistency and indicates the degree of variability between testing occasions (54, 55); whereas ICC is a measure of relative consistency in that it measures the degree to which athletes maintain their ranking in a sample during repeated trials (54, 55). In interpreting the ICC, thresholds were defined as; 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 high, 0.7 to 0.9 very high and ≥ 0.9 nearly perfect (56). Confidence intervals of 90% (CI) were used for all variables of interest.

Results

A summary of the reliability statistics for the MDLT can be observed in Table 2. The time to complete each MDLT direction ranged from 0.78 s (centre-forehand) to 1.19 s (rear-backhand). The forehand directions were completed in less time in comparison to the backhand directions. Overall, the time to complete each MDLT direction marginally decreased between the first and the third testing occasions. All direction changes in the MDLT were identified to be reliable (change in mean = 0.3 to 6.8%); small changes in the overall TE were noted across all MDLT directions, between both sessions one to two (0.07 s) and sessions two to three (0.06 s). The overall ICC averaged for all eight directions was 0.74 (session 1 to 2) and 0.84 (session 2 to 3).

The reliability statistics for the MDCT are detailed in Table 3. Overall the backhand directions were completed in less time in comparison to the forehand; the fastest direction change occurred in the centre-backhand (1.27 s) direction and the slowest in the front-forehand (2.32) direction. The MDCT was also found to be reliable (change in mean = 0.1 to 5.9%), where the TE and ICC ranged from 0.05 to 0.20 s and from 0.57 to 0.98, respectively.

Table 8. Reliability of the multi-directional lunge test.

Variables	Mean ± SD (s)			Day	% Change in Mean (lower to upper)	Typical Error (s) (lower to Upper)	Intraclass Correlation Coefficient (lower to upper)
	Day 1	Day 2	Day 3				
Front-Back	1.04 ± 0.12	1.02 ± 0.19	1.01 ± 0.18	1-2	-1.53 (-7.18 to 4.12)	0.08 (0.06 to 0.13)	0.75 (0.45 to 0.90)
				2-3	-1.57 (-4.47 to 1.33)	0.04 (0.03 to 0.06)	0.96 (0.89 to 0.98)
Front-Mid	0.87 ± 0.13	0.90 ± 0.11	0.91 ± 0.10	1-2	2.89 (-3.37 to 9.15)	0.08 (0.06 to 0.12)	0.55 (0.14 to 0.80)
				2-3	0.89 (-1.51 to 3.29)	0.03 (0.02 to 0.05)	0.91 (0.79 to 0.97)
Front-Fore	0.87 ± 0.12	0.87 ± 0.17	0.86 ± 0.12	1-2	0.72 (-5.18 to 6.62)	0.07 (0.05 to 0.11)	0.79 (0.51 to 0.91)
				2-3	-0.58 (-4.82 to 3.66)	0.05 (0.04 to 0.05)	0.90 (0.74 to 0.96)
Centre-Back	1.02 ± 0.14	1.02 ± 0.15	0.95 ± 0.12	1-2	-0.44 (-4.71 to 3.83)	0.07 (0.05 to 0.10)	0.82 (0.59 to 0.92)
				2-3	-6.78 (-10.60 to -2.97)	0.06 (0.04 to 0.09)	0.84 (0.63 to 0.93)
Centre-Fore	0.78 ± 0.15	0.82 ± 0.17	0.83 ± 0.15	1-2	3.98 (-1.39 to 9.35)	0.06 (0.05 to 0.09)	0.87 (0.69 to 0.95)
				2-3	1.93 (-2.22 to 6.09)	0.05 (0.04 to 0.08)	0.92 (0.80 to 0.97)
Rear-Back	1.19 ± 0.17	1.15 ± 0.20	1.13 ± 0.19	1-2	-3.98 (-10.41 to 2.45)	0.11 (0.09 to 0.17)	0.66 (0.30 to 0.85)
				2-3	-1.55 (-6.19 to 3.08)	0.08 (0.06 to 0.12)	0.86 (0.67 to 0.94)
Rear-Mid	0.96 ± 0.06	0.95 ± 0.10	0.93 ± 0.12	1-2	-0.42 (-2.57 to 1.74)	0.03 (0.02 to 0.05)	0.89 (0.73 to 0.95)
				2-3	-2.25 (-7.29 to 2.79)	0.07 (0.05 to 0.11)	0.63 (0.26 to 0.84)
Rear-Fore	0.90 ± 0.10	0.90 ± 0.12	0.88 ± 0.15	1-2	-0.33 (-5.31 to 4.65)	0.07 (0.05 to 0.10)	0.65 (0.30 to 0.84)
				2-3	-2.32 (-7.59 to 2.95)	0.07 (0.06 to 0.11)	0.73 (0.44 to 0.88)

Table 9. Reliability of the multi-directional cyclic change of direction test.

Variables	Mean ± SD (s)			Trial	% Change in Mean (lower to upper)	Typical Error (s) (lower to upper)	Intraclass Correlation Coefficient (lower to upper)
	Day 1	Day 2	Day 3				
Front-Back	2.17 ± 0.34	2.28 ± 0.32	2.25 ± 0.30	1-2	5.37 (3.22 to 7.52)	0.07 (0.05 to 0.10)	0.97 (0.91 to 0.99)
				2-3	-1.26 (-3.71 to 1.18)	0.08 (0.06 to 0.12)	0.95 (0.86 to 0.98)
Front-Mid	1.79 ± 0.33	1.75 ± 0.34	1.75 ± 0.36	1-2	-1.89 (-7.65 to 3.87)	0.15 (0.12 to 0.23)	0.82 (0.59 to 0.93)
				2-3	-0.12 (-2.67 to 2.42)	0.07 (0.05 to 0.10)	0.97 (0.93 to 0.99)
Front-Fore	2.32 ± 0.30	2.25 ± 0.30	2.26 ± 0.28	1-2	-3.39 (-7.07 to 0.29)	0.12 (0.09 to 0.18)	0.87 (0.68 to 0.95)
				2-3	0.84 (-0.97 to 2.66)	0.06 (0.04 to 0.09)	0.97 (0.92 to 0.99)
Centre-Back	1.27 ± 0.45	1.28 ± 0.43	1.31 ± 0.42	1-2	0.72 (-2.46 to 3.90)	0.06 (0.05 to 0.09)	0.98 (0.96 to 0.99)
				2-3	2.30 (-1.63 to 6.22)	0.08 (0.06 to 0.11)	0.97 (0.93 to 0.99)
Centre-Fore	1.36 ± 0.22	1.38 ± 0.31	1.35 ± 0.29	1-2	2.06 (-6.14 to 10.26)	0.17 (0.13 to 0.25)	0.63 (0.28 to 0.83)
				2-3	-2.16 (-9.70 to 5.39)	0.16 (0.12 to 0.24)	0.74 (0.46 to 0.89)
Rear-Back[1]	1.79 ± 0.23	1.84 ± 0.24	1.82 ± 0.22	1-2	2.90 (0.09 to 5.72)	0.07 (0.05 to 0.11)	0.92 (0.81 to 0.97)
				2-3	-0.89 (-2.95 to 1.16)	0.05 (0.04 to 0.08)	0.96 (0.89 to 0.98)
Rear-Mid	1.53 ± 0.33	1.51 ± 0.26	1.52 ± 0.33	1-2	-1.46 (-6.11 to 3.19)	0.10 (0.08 to 0.15)	0.90 (0.76 to 0.96)
				2-3	0.34 (-3.54 to 4.22)	0.08 (0.06 to 0.13)	0.93 (0.83 to 0.98)
Rear-Fore	1.88 ± 0.30	1.84 ± 0.27	1.94 ± 0.26	1-2	-2.57 (-9.55 to 4.41)	0.20 (0.15 to 0.29)	0.57 (0.17 to 0.81)
				2-3	5.87 (1.28 to 10.46)	0.13 (0.10 to 0.19)	0.81 (0.57 to 0.92)

[1] – 14 athletes completed this direction.

Discussion

The primary purpose of this research was to assess the reliability of two newly designed badminton specific multi-directional COD tests. The main findings were that the MDLT and MDCT have acceptable reliability, as indicated by the low percent change in the mean, low TE and high ICC ranges. Interestingly, the MDCT was more reliable than the MDLT based on lower percent changes in the mean and higher ICC ranges. As expected, the TEs were greater for the MDCT given the longer movement times. The specific findings of the MDLT and MDCT are discussed herein.

The MDLT appears to be a reliable measure of lunge COD ability (Table 8). Systematic error which is often caused by inadequate familiarisation does not appear to greatly influence the results, as indicated by the percentage change in the mean. The technological and biological error does not appear to negatively influence the results, as identified by minimal differences between the TEs in sessions 1-2 and 2-3. The ICC ranges indicate that familiarisation may potentially influence the results, as the mean ICC increased from 0.74 during Days 1-2 to 0.84 during Days 2-3. However, as the TE between sessions was approximately 0.02 s, small differences in performance may alter athlete ranking, thereby reducing the ICC. The reliability of multi-directional lunge performance has not been established previously; however, the results are comparable to previous studies investigating multi-directional CMJ performance (20, 57). These studies found H-CMJ (CV = 1.9 to 3.3%), V-CMJ (CV = 3.3 to 9.6%) and lateral-CMJ (3.9%) to be reliable. Since, the lunge pattern is utilised in approximately 90% of all movement patterns in badminton, the efficacy of the MDLT as a horizontal assessment is apparent. The V-CMJ may be maintained as a vertical neuromuscular (ballistic) capability assessment, due to mechanical similarities to in-game vertical jumps.

The MDCT was identified as a reliable measure of cyclic COD (Table 3). The reliability outcomes were unaffected by systematic error, as observed by the percentage change in the mean, which decreased between Days 1-2 and Days 2-3. The mean MDCT TE was greater on the forehand (0.14 s) side than the backhand (0.07 s), likely due to a greater quantity of steps performed to the forehand. When moving to the backhand, athletes complete a 180° pivot to rotate from forwards to backwards facing. This 180° pivot movement allows the dominant foot to move an approximate two shoulder width distance, whereas when moving to the forehand side, athletes complete two chasses to travel an equivalent distance. The increased quantity of steps likely increases potential variability, thereby increasing the TE. In an attempt to compare the reliability of the MDCT to existing tests, the following four badminton specific cyclic COD tests were identified: badminton specific speed test (3, 48), four corners (4), sideways (4) and speed specific test (5). However, the reliability of these four tests was not reported, therefore eliminating the potential for reliability comparisons. The MDCT differs to these four tests in that it allows for independent assessment of eight horizontal directions as opposed to a single overall temporal measure. The specificity of the MDCT should provide enhanced COD diagnostics, therefore increasing the specificity, quality and individualisation of programming.

While the MDLT and MDCT were deemed reliable to assess multi-directional COD ability, the reader should be aware of a number of limitations. Due to athlete availability, researchers were only able to test participants during their regular training sessions. This resulted in athletes beginning the MDLT and MDCT with varying levels of fatigue. In an attempt to minimise the effect of fatigue, athletes were tested at the same time during each training session and were provided a 10 min rest prior to beginning the MDLT. Secondly, athletes were advised to complete as many trials as required until they considered themselves to be familiarised with the process. Differences between athletes in what they considered familiarised may have negatively influenced the reliability of the tests. Despite these limitations, reliability was acceptable across all directions for both tests, if these limiting aspects are controlled it is likely that the reliability of these test would increase.

Practical Applications

Intuitively, the tests have face validity in that the movement patterns assessed are fundamental movements of badminton. Given the validity and acceptable reliability, it is recommended that these tests be incorporated into a BSA battery. In comparison to other COD tests, the MDLT and MDCT provide greater diagnostic information to individualise programming and improve directional specific weaknesses of badminton athletes. Many multi-directional COD tests provide a single measure (total time) of performance (see Table 10). This type of reporting provides information as to which athletes perform better overall in a COD test, but not why they perform better.

In Table 10 the total times of three players to complete the MDLT and MDCT are provided, the colour coding denotes above average (green), average (yellow) and below average (red) performance. At this level of analysis, it can be observed that some athletes (Athletes 1 and 2) have better acyclic lunge ability than cyclic COD ability. In these two cases it would seem the acyclic lunge abilities are sufficient and programming should emphasise cyclic movement efficiency. The total times are composite scores of multiple directions, so the feedback thus far is global and moving forward should become planar specific. By way of illustration, in Table 11 it is clear that acyclic and cyclic COD is directionally specific, as Athlete 2 has acyclic dominance to the front-forehand direction, but not to the front-backhand and front–mid directions. Further, it would seem that

Athlete 2 has poor footwork to the front-forehand direction, due to a large difference between the MDLT and MDCT results. To quantify the degree to which cyclic COD is influenced by acyclic COD, MDLT performance may be analysed as a percentage of MDCT time (see Table 12). A high MDLT percentage suggests that the athlete is limited by their acyclic lunge ability (Athlete 1 and 3), whereas a low MDLT percentage indicates that performance may be limited by cyclic COD ability (Athlete 2). Diagnosis of these specific weaknesses assists in the individualisation of programming to maximise physical and technical performance.

Finally to gain an overview of the athlete's multi-directional ability, analysis may be presented as a spider plot. Figure 7 presents each of the eight directions as played by a right-handed athlete, values are represented as positive or negative Z-scores (standard deviation units) indicating if the athlete's performance for a given direction is above or below the group mean. From the spider-plot it is clear that Athlete 2 has a MDLT dominance to the forehand direction, but performs near to the mean in the backhand direction. Whereas Athlete 3 performs poorly to the front of the court, but performs near to the mean at the back of the court. Such plots should assist coaches and athletes in visually identifying directionally specific strengths and weaknesses and in turn better inform training.

Table 10. Multi-directional lunge test and multi-directional cyclic change of direction test combined results.

	Total MDLT	Total MDCT
Athlete 1	7.40	12.52
Athlete 2	6.93	14.49
Athlete 3	8.11	14.34

Table 11. Multi-directional lunge test and multi-directional cyclic change of direction test directional analysis.

	Front-Fore		Front-Mid		Front-Back	
	MDLT	MDCT	MDLT	MDCT	MDLT	MDCT
Athlete 1	0.88	1.86	0.85	1.45	0.89	1.88
Athlete 2	0.70	2.62	0.86	2.10	0.92	2.21
Athlete 3	0.97	2.34	1.06	1.88	1.08	2.40

Table 12. Multi-directional lunge test percent directional analysis.

	Front-Fore			Front-Mid			Front-Back		
	MDLT	MDCT	MDLT%	MDLT	MDCT	MDLT%	MDLT	MDCT	MDLT%
Athlete 1	0.88	1.86	47%	0.85	1.45	59%	0.89	1.88	47%
Athlete 2	0.70	2.62	27%	0.86	2.10	41%	0.92	2.21	42%
Athlete 3	0.97	2.34	42%	1.06	1.88	56%	1.08	2.40	45%

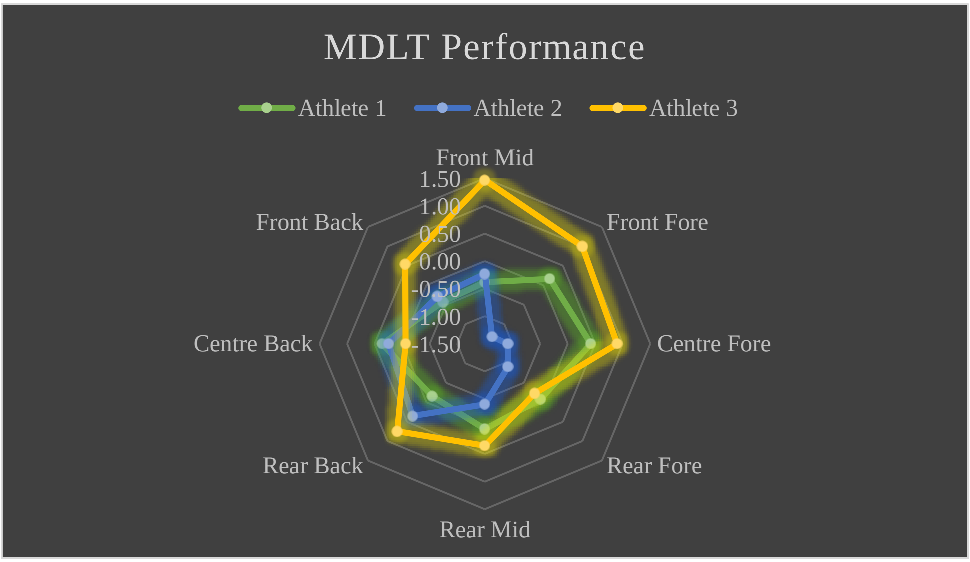

Figure 7. Multi-directional lunge test spider chart analysis.

CHAPTER FOUR:

BADMINTON SPECIFIC ASSESSMENT BATTERY: PREDICTORS OF CHANGE OF DIRECTION AND BADMINTON ABILITY

Prelude

The previous study confirmed that the MDLT and MDCT were reliable in assessing lunge and cyclic COD performance, respectively. The two tests were included in a BSA along with height, body mass, leg length, eight site sum of skinfold, frontal split flexibility, sagittal split flexibility and V-CMJ. Each of these measures were identified in the literature review as potentially beneficial to badminton assessment. The purpose of this study was to establish which components of the badminton specific assessment (BSA) best predict COD and overall performance in badminton.

Introduction

Played by approximately 200 million people world-wide, badminton is one of the most popular sports in the world. A key attraction of badminton, is the high speed nature of the sport, with shuttle speeds reaching in excess of 250 km/h at the instance following a smash (50-52). The high shuttle speeds require athletes to react and move rapidly about the court, this is termed agility. Agility involves two components, the perceptual and decision making component and the physical COD component (1). These two components are closely connected as in response to either shuttle trajectory or the opposition they first utilise the perceptual and decision making component to evaluate and plan the required direction change and then execute the required movement with the physical COD. The perceptual and decision making component of agility is crucial when changing direction in badminton, as elite athletes process COD at a faster rate than sub-elite athletes (24). The enhanced performance of the elite athletes occurs due to an increased recognition of anticipatory cues of an opponent’s technique, for example a differing of jump height between a smash and a drop shot. However, the physical component is equally as important, as following the decision of what needs to occur, the direction change is determined by an athlete’s capacity to execute the planned movement (24). As such, the primary focus of this study is to assess the physical COD component of agility.

Current badminton COD assessment includes the following four tests; the badminton specific speed test (3, 48), four corners (4), sideways test (4) and the specific speed test (5). Beginning in the centre court, the badminton specific speed test measures the time taken for an athlete to complete a mock shot in four areas of the court, with a return to centre court between shots (3, 48). As this test only assesses four of the eight horizontal directions and presents the results as a single composite time, it lacks the specificity required to influence programming. The specific speed test was adapted from the badminton specific speed test and involves athletes completing mock shots in each of the four corners and two lateral directions with a sprint through a timing gate in the front-mid and rear-mid directions (5). While the test assesses a greater range of directions than the badminton specific speed test it again presents results as a single composite time. Ooi and colleagues (34) assessed cyclic COD ability with the side-ways and four-corner agility tests. The side-ways test provides a lateral COD assessment while the four-corner agility test provides a diagonal COD assessment. These two tests combine for the most specific assessment of whole court cyclic COD ability, but lack the potential to distinguish between individual directional weaknesses. Each of these tests may be enhanced by the inclusion of a jump mat in centre court, so that each direction may be individually assessed as the athlete returns to centre court.

No research to date has examined the influence of leg length on COD or performance in badminton. However, it is thought that an optimal leg length exists for each athlete relative to standing height and muscle mass. Hip flexibility was identified by Cronin et al. (6) as a key indicator of absolute lunge performance. The lunge movement pattern is incorporated into approximately 90% of all badminton movement patterns; therefore it is suggested that hip flexibility influences badminton specific COD performance (30). Leg strength qualities and neuromuscular capabilities are directionally specific, as neuromuscular capability in one direction (e.g. vertical), may be unrelated to the neuromuscular capabilities in other directions (e.g. horizontal) (20). As such, it is proposed that vertical neuromuscular (ballistic) capability be assessed with the V-CMJ and horizontal neuromuscular capability with the MDLT. The MDLT assesses acyclic lunge capabilities in eight horizontal/lateral directions, allowing for a complete horizontal and lateral lunge COD assessment. Finally, to understand how athletes perform during an actual direction change, it is recommended that athlete's complete the MDCT, which is designed to mimic an athlete's cyclic movement capabilities. The reliability of each BSA measure has been quantified previously (Chapter three), however the relationships between each measure and overall badminton performance has not yet been investigated. Therefore, the focus of this investigation was to determine which physical components best predict COD ability and overall performance in badminton.

Methods

Experimental Approach to the Problem

An acute experimental design was adopted for this study to determine the interrelationships between the BSA measures and badminton ability. The BSA measures included: 1) height, 2) body mass, 3) eight site sum of skinfold, 4) leg length, 5) frontal split hip flexibility, 6) sagittal split hip flexibility, 7) V-CMJ, 8) MDLT and 9) MDCT. Each of these measures was assessed during a single session to determine relationships between the BSA measures and badminton ability.

Participants

Forty-one participants (16 female and 25 male) from Malaysia (F – 11, M – 14) and New Zealand (F – 5, M – 11) were recruited for this study. The participants ranged in badminton ability (level) as follows: club (3 male), junior National (13 female and 14 male) and senior National (3 female and 6 male) level athletes. Badminton ability was determined by national senior and junior rankings. In the event that an athlete was not on a ranking list, they were ranked according to recent competition results relative to those that were ranked. The mean age, body mass, height and playing experience is detailed in Table 1. Additionally, 37 athletes were right hand dominant and 4 were left hand dominant. The Auckland University of Technology Ethics Committee approved all aspects of the research. All participants were required to sign an informed consent form prior to participating in the study.

Table 13. Physical characteristics of participants.

Physical Characteristics	Female (16)	Male (25)	Combined (41)
Age (years)	17.1 ± 1.8	18.8 ± 3.7	18.1 ± 3.2
Height (cm)	161.9 ± 7.1	176.5 ± 7.0	170.5 ± 10.0
Mass (kg)	57.4 ± 5.6	70.0 ± 10.2	65.1 ± 10.6
Experience (years)	8.3 ± 1.9	8.8 ± 4.0	8.6 ± 3.3

Test Protocol

Testing was completed during a single session. The session began with the recording of the following athlete characteristics: age, height, body mass, handedness and training experience. An ISAK Level 3 accredited assessor measured eight skinfold sites (abdominal, bicep, front thigh, iliac crest, mid-calf, subscapular, supraspinale and tricep) and leg length. Leg length was measured from the lateral malleolus to the mid-point of the greater trochanter. Following the body composition and anthropometric measures, a standardised dynamic warm-up consisting of a five minute jog at a self-selected pace followed by dynamic warm up drills (high knees, high skips, long skips and butt kicks) was performed prior to the physical performance tests.

Upon completion of the dynamic warm-up, the athlete was instructed to stand with feet shoulder width apart on a contact mat (Kinematic Measurement System, Fitness Technology, Skye, SA, Australia). The athlete performed three sub-maximal practice V-CMJ’s, which included an arm swing and a sink to a self-selected depth to become familiarised with the testing protocol. During testing, the athlete was instructed to perform three acyclic V-CMJ with arm swing for maximum height, while maintaining straight legs in the air. The height of the jumps were calculated by the contact mat and recorded to the nearest 0.1 cm. The V-CMJ was calculated as the mean of the highest two jumps.

In preparation for the MDLT the athlete stood facing the net with the dominant foot placed in the centre of the contact mat and the non-dominant foot placed at a shoulder width distance laterally. Tape markers were then placed at a distance of 1.5 times leg length in each of the eight directions, in-line with the nearest point of the non-dominant shoe (see Figure 5). Athletes were instructed to complete a lunge as quickly as possible by placing their dominant foot over the tape marker and return back to the centre of the contact mat. The non-dominant foot was to remain planted, however it could pivot when necessary. The athlete was provided the opportunity to complete five practice lunges in each direction prior to testing, to allow for familiarisation. The athlete then performed the eight different lunges in a randomised order three times, with a 10 s rest between lunges. This was considered adequate as badminton athletes complete approximately 500 lunges (30) in a badminton match, thus a total of 24 lunges for the test was not considered excessive. The total time between dominant foot contacts was recorded to the nearest 0.001 s. The final result used for analysis for each direction was calculated as the mean of the fastest two trials in each direction.

During the MDCT a shuttle was placed on the net (numbers 1-3 in Figure 6) or on a stack of three taped shuttle tubes at a height of 1.26 m (numbers 4-8 in Figure 6). The location for each shuttle can be observed in Figure 2, with shuttle 7 placed at an arm and racquet length from the centre of the contact mat. The athlete starts the test by standing with his/her feet shoulder width apart and his/her dominant foot placed on the centre of the contact mat. The athlete was instructed to use a self-selected footwork to move to one of the eight shuttles and with their racquet complete a net kill for shuttles 1-3 and a self-selected shot that moves the shuttle towards the net for shuttles 4-8. Following the shuttle strike the athlete returned to centre court with the entire sequence of movements to be completed as quickly as possible. The athlete was provided the opportunity to complete five practice lunges in each direction prior to testing to allow for familiarisation. The athlete than performed the eight directional shots in randomised order three times, with a 10 s rest between movements to ensure fatigue did not influence results. The total time for each direction was recorded to the nearest 0.001 s. The final result for each direction was calculated as the mean of the fastest two trials in each direction.

Hip flexibility was measured via the frontal split and sagittal split stances, respectively. Frontal split hip flexibility was measured as follows; the athlete's non-dominant foot was placed against a wall with both feet flat facing forward, the athlete moved his/her front foot as far forward as possible, the distance between the medial malleolus of each foot was recorded (see Figure 8). During the sagittal split hip flexibility assessment, the athlete placed the lateral side of their non-dominant foot against a wall with both feet flat facing forward, the athlete moved his/her front foot as far forward as possible (see Figure 9). The distance between the medial malleolus of each foot was recorded.

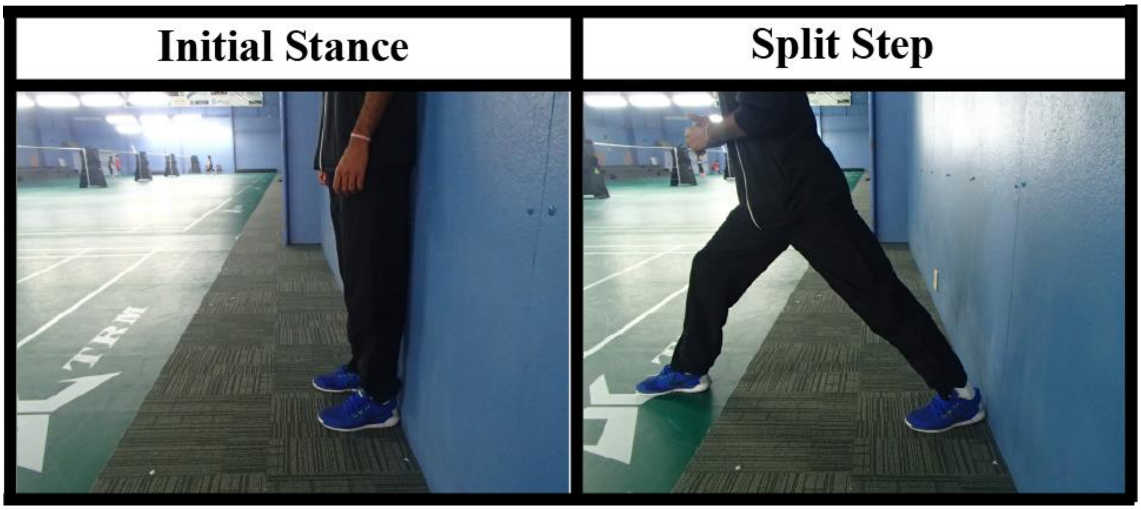

Figure 8. Frontal split hip flexibility test.

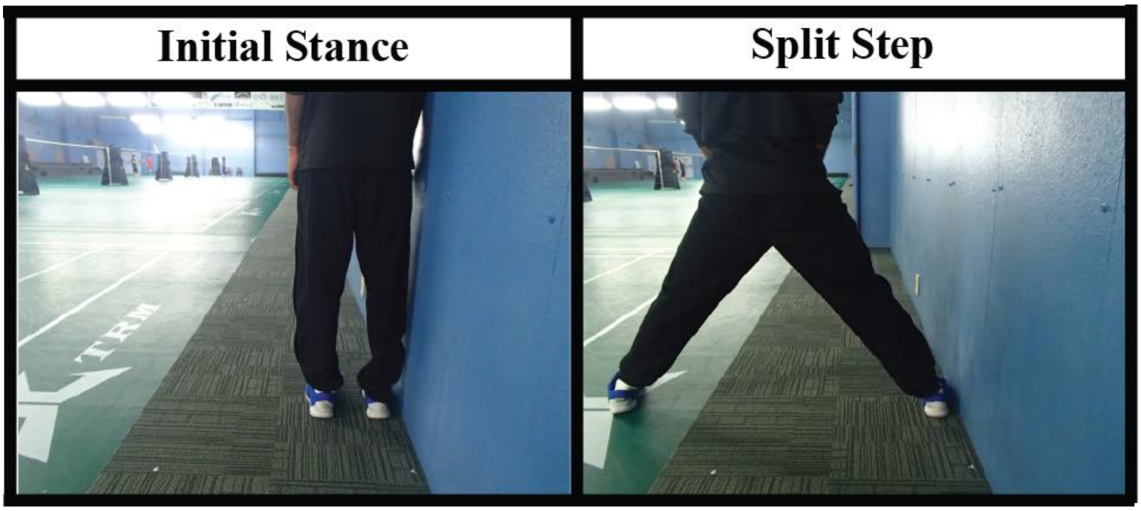

Figure 9. Sagittal split hip flexibility test.

Statistical Analysis

The athletes were separated by gender (female and male) for analysis. Means and standard deviations were calculated to represent the centrality and spread of the data. Box and whisker plots and the Shapiro-Wilk statistic were used to assess statistical normality. Pearson product-moment correlations were used to determine relationships between each of the physical measures. Spearman rank order correlations were also used to determine relationships between badminton ranking and the physical performance measures (BSA). Statistical significance was set at $p < 0.05$ for the above correlations. The magnitudes of correlations were described as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and nearly perfect (0.9-1.0) (58). All statistical analyses were performed using SPSS software (Version 22, Chicago, Illinois).

Results

The means and standard deviations for all the variables of interest for females, males and pooled data is presented in Table 14. Overall males were taller (9%), heavier (22%), had longer legs (8%) and a lower eight site sum of skinfold (30%) than females. Female athletes had greater hip flexibility than male athletes in both the sagittal (5%) and the frontal (7%) splits. The largest difference between genders was observed in the V-CMJ with males exceeding females by (30%). In the MDLT and MDCT, male athletes were faster than female athletes in all directions by a mean of 6% and 16%, respectively.

The relationship of anthropometric and performance measures to MDLT and MDCT can be observed in Tables 15 and 16, respectively. For the female athletes, a higher sum of eight skinfolds was associated with increased time-to-complete both the MDLT and MDCT (r = 0.50 to 0.65). For the male athletes, being taller was associated with increased time-to-complete the MDLT and MDCT (r > 0.43 to 0.61). Finally the frontal split appears the best assessment for predicting MDLT and MDCT in females (r = -0.69 to 0.72) whereas frontal split and vertical jump were best predictors for the males (r = -0.45 to -0.49).

Of interest was the strength of association between each of the movements (n = 8) within each test (MDLT and MDCT). The movements within the MDLT were strongly correlated to each other ($r > 0.75$, $p < 0.001$), however, this was not the case for the MDCT. The strongest correlation between directions (n = 8) was observed between the front-forehand and rear-forehand (r = 0.82), most of the correlations however, were less than 0.50 for male, female and combined data sets.

Also of interest was whether acyclic (MDLT) movement in one direction was strongly associated with cyclic movement (MDCT) in the same direction (Table 17). The strongest correlations were front-backhand ($r = 0.66$, $p = 0.014$) in females and the centre-backhand ($r = 0.54$ to 0.69, $p < 0.05$) in males and the combined data. It needs to be noted that all directional correlations were less than $r = 0.70$ indicating that the directional shared variance is less than 50%.

Badminton ability (ranking) significantly correlated with height and a number of MDLT measures ($r = 0.51$ to 0.65) as can be observed in Table 18. However, in male athletes badminton ability was poorly correlated with all MDLT directions ($r < 0.16$) and with all MDCT directions ($r < 0.36$) with the exception of the front-mid COD ($r = 0.46$, $p = 0.037$).

Table 14. Means and standard deviations of all measured variables.

	Female	Male	Combined
Leg Length (cm)	75.8 ± 3.9	82.5 ± 4.4	79.9 ± 5.3
Sum of Skinfold (mm)	118.1 ± 30.6	82.9 ± 35.2	109.4 ± 41.0
Sagittal Split (%)	199.0 ± 11.0	190.0 ± 14.0	194.0 ± 13.0
Frontal Split (%)	196.0 ± 18.0	183.0 ± 18.0	188.0 ± 19.0
V-CMJ (cm)	36.9 ± 6.6	48.1 ± 6.3	43.7 ± 8.4
MDLT			
Front-Backhand (s)	0.91 ± 0.17	0.87 ± 0.15	0.89 ± 0.16
Front-Mid (s)	0.90 ± 0.19	0.81 ± 0.17	0.85 ± 0.18
Front-Forehand (s)	0.89 ± 0.19	0.82 ± 0.15	0.84 ± 0.17
Centre-Backhand (s)	0.96 ± 0.17	0.89 ± 0.14	0.92 ± 0.15
Centre-Forehand (s)	0.90 ± 0.18	0.80 ± 0.16	0.84 ± 0.17
Rear-Backhand (s)	1.02 ± 0.15	0.98 ± 0.17	0.99 ± 0.16
Rear-Mid (s)	0.99 ± 0.18	0.95 ± 0.17	0.96 ± 0.18
Rear-Forehand (s)	0.94 ± 0.19	0.87 ± 0.22	0.90 ± 0.21
MDCT			
Front-Backhand (s)	2.32 ± 0.32	1.95 ± 0.18	2.10 ± 0.31
Front-Mid (s)	1.73 ± 0.25	1.46 ± 0.21	1.57 ± 0.26
Front-Forehand (s)	2.18 ± 0.32	1.84 ± 0.29	1.98 ± 0.34
Centre-Backhand (s)	1.31 ± 0.19	1.15 ± 0.17	1.22 ± 0.19
Centre-Forehand (s)	1.33 ± 0.37	1.15 ± 0.25	1.22 ± 0.31
Rear-Backhand (s)	2.04 ± 0.18	1.78 ± 0.16	1.88 ± 0.21
Rear-Mid (s)	1.61 ± 0.19	1.38 ± 0.26	1.80 ± 0.27
Rear-Forehand (s)	2.04 ± 0.25	1.47 ± 0.26	1.89 ± 0.28

Key: MDLT – multi-directional lunge test, MDCT – multi-directional cyclic COD test, sum of skinfold – eight site sum of skinfold, V-CMJ – vertical counter-movement jump.

Table 15. Relationship of anthropometric and performance measures to the multi-directional lunge test.

	Female	Male	Combined
Height (cm)	0.28	0.61**	0.08
Mass (kg)	0.33	0.26	0.18
Leg Length (cm)	0.18	-0.01	-0.17
Sum of Skinfold (mm)	0.50	0.18	0.48**
Sagittal Split (%)	-0.29	-0.35	-0.13
Frontal Split (%)	-0.69**	-0.45*	-0.32
V-CMJ (cm)	-0.30	-0.39	-0.38*
MDCT (s)	0.58*	0.57**	0.56**

Key: MDLT – multi-directional lunge test, MDCT – multi-directional cyclic COD test, sum of skinfold – eight site sum of skinfold, V-CMJ – vertical counter-movement jump, * - $p \leq 0.05$, ** - $p \leq 0.01$.

Table 16. Relationship of anthropometric and performance measures to the multi-directional cyclic change of direction test.

	Female	Male	Combined
Height (cm)	0.10	0.43	-0.36
Mass (kg)	0.38	0.05	-0.25
Leg Length (cm)	0.09	-0.28	-0.48**
Sum of Skinfold (mm)	0.65*	0.25	0.58**
Sagittal Split (%)	-0.31	-0.11	0.20
Frontal Split (%)	-0.72**	-0.36	-0.10
V-CMJ (cm)	-0.28	-0.49*	-0.61**
MDLT (s)	0.58*	0.57**	0.56**

Key: MDLT – multi-directional lunge test, MDCT – multi-directional cyclic COD test, sum of skinfold – eight site sum of skinfold, V-CMJ – vertical counter-movement jump, * - $p \leq 0.05$, ** - $p \leq 0.01$.

Table 17. Relationship between directions for the multi-directional lunge test and the multi-directional cyclic change of direction test.

Direction	Female	Male	Combined
Front-Backhand (s)	0.66*	0.23	0.48**
Front-Mid (s)	-0.30	0.33	0.25
Front-Forehand (s)	0.35	-0.10	0.23
Centre-Backhand (s)	0.42	0.69**	0.54**
Centre-Forehand (s)	-0.03	0.24	0.40*
Rear-Backhand (s)	0.34	0.25	0.34
Rear-Mid (s)	0.50	0.26	0.38*
Rear-Forehand (s)	0.45	0.23	0.39*

Key: MDLT – multi-directional lunge test, MDCT – multi-directional cyclic COD test, sum of skinfold – eight site sum of skinfold, V-CMJ – vertical counter-movement jump, * - $p \leq 0.05$, ** - $p \leq 0.01$.

Discussion

The BSA consisted of height, mass, eight site sum of skinfold, leg length, frontal split hip flexibility, sagittal split hip flexibility, V-CMJ, MDLT and MDCT. The inclusion of each measure in the BSA is due to the multi-faceted nature of COD performance in badminton (1). Previous COD assessments included a single test, which provided a measure of the COD ability that inadequately informed programming for COD enhancement in badminton athletes. In the current study it was identified that a range of measures closely correlated with COD performance, as assessed by the MDCT. In the male athletes, MDCT performance correlated best with the leg strength measures (MDLT and V-CMJ). In the female athletes, MDCT performance correlated best with frontal split hip flexibility, eight sum of skinfold and MDLT. As such, it would appear that leg strength, anthropometry and hip flexibility are important influencers of COD performance.

Table 18. Relationship between variables and badminton ability.

	Female	Male
Height (cm)	0.51*	-0.09
Mass (kg)	-0.09	-0.18
Leg Length (cm)	0.14	0.16
Sum of Skinfold (mm)	0.01	0.00
V-CMJ (cm)	-0.42	-0.12
Sagittal Split (%)	-0.15	-0.32
Frontal Split (%)	-0.33	-0.16
MDLT Front-Backhand (s)	0.49	0.15
MDLT Front-Mid (s)	0.52*	0.13
MDLT Front-Forehand (s)	0.52*	-0.11
MDLT Centre-Backhand (s)	0.65**	0.05
MDLT Centre-Forehand (s)	0.55*	-0.14
MDLT Rear Backhand (s)	0.48	0.02
MDLT Rear-Mid (s)	0.31	-0.03
MDLT Rear-Forehand (s)	0.39	0.05
MDCT Front-Backhand (s)	0.08	0.21
MDCT Front-Mid (s)	-0.24	0.46*
MDCT Front-Forehand (s)	-0.01	0.12
MDCT Centre-Backhand (s)	-0.42	0.01
MDCT Centre-Forehand (s)	0.08	0.23
MDCT Rear Backhand (s)	-0.10	-0.35
MDCT Rear-Mid (s)	-0.16	0.04
MDCT Rear-Forehand	-0.11	-0.18
Total MDLT	0.59*	0.04
Total MDCT	0.02	0.08

Key: MDLT – multi-directional lunge test, MDCT – multi-directional cyclic COD test, sum of skinfold – eight site sum of skinfold, V-CMJ – vertical counter-movement jump, * - $p \leq 0.05$, ** - $p \leq 0.01$.

In the current study athletes were primarily under the age of 19 (73%), thereby classifying them as juniors. The female athletes (height – 162 cm, weight – 57 kg) were comparable to junior athletes in previous research in both height (~163 cm) and weight (~60 kg) (15, 17, 19). While male athletes (height – 177 cm, weight – 70 kg) were also comparable to previous junior populations (height – 172 cm, weight – 67 kg) (11, 15, 17, 19). The eight site sum of skinfold has not previously been used with junior badminton populations, however as may be expected the athletes in the current study had a greater eight sum of skinfold (F – 119, M – 83) than those completing at the most elite level of the sport (F – 97, M – 67) (7). In assessing Brazilian junior athletes, Campos et al. (17) used the seven site sum of skinfold (F – 132, M – 83), with female athletes exceeding and male athletes matching the eight site sum of skinfold in the current study. The V-CMJ has been assessed in four previous studies (F – 33 cm, M – 46 cm) (2, 4, 17, 18) with results similar to those of the current study (F – 37 cm, M – 48 cm). These results suggest that the current athletes are likely representative of the wider badminton community. However, as frontal split hip flexibility, sagittal split hip flexibility, MDLT and MDCT have yet to be assessed with badminton athletes, it is unclear how these results compare to other badminton populations.

The body fat (eight site sum of skinfolds) measures of the current study were largely correlated with MDLT ($r = 0.50$) and MDCT performance in female athletes ($r = 0.65$), indicating that a higher fat mass is associated with slower COD times in female athletes. This occurs because fat mass increases athlete total mass without a concomitant increase in their force production capabilities, thereby reducing the velocity of the direction change. In male athletes eight sum of skinfold was not significantly related to COD performance, however an increase in height did indicate slower COD times. The precise reasons for this are unclear, however, it may be that better COD ability is associated with a lower centre of mass which provides better stability for changing direction, or it might be that the tests are step frequency dominant rather than step length dominant. This contention is somewhat supported as leg length was identified as a poor predictor of COD performance. These findings align with those of Crill et al. (59), who noted leg length to poorly correlate with lunge performance in a non-badminton population. However, Cronin et al. (6) identified leg length to be the third most important predictor of absolute lunge performance, behind time to peak force and frontal split hip flexibility. Large correlations were noted between frontal split flexibility and COD performance in female athletes, but less so with males. This may be due to shorter female leg length, thereby requiring an increase in hip flexibility to achieve a greater distance with each step and in turn reducing the quantity of steps required in a COD cycle. Sagittal split hip flexibility was included in the BSA as a measure of lateral hip flexibility, however it poorly correlated with MDLT and MDCT, suggesting that it does not aid performance assessment and may be excluded from the BSA.

In establishing the BSA battery it is suggested that horizontal lunge ability be assessed via a single forward lunge. Most assessment batteries measure horizontal neuromuscular capabilities through a single H-CMJ (2, 3, 18). Previous H-CMJ and COD relationships were comparable to current findings (F – $r = 0.60$, $p < 0.001$, M – $r = -0.23$, $p > 0.05$) (3), where the MDLT and MDCT (cyclic COD test) were significantly correlated in male ($r = 0.57$, $p = 0.007$) and female ($r = 0.58$, $p = 0.030$) athletes. In comparison to the H-CMJ, the lunge would appear a more ecologically valid measure of the horizontal neuromuscular and mechanistic qualities required for badminton. When comparing between the various lunge directions of the MDLT, very large to nearly perfect correlations ($r > 0.75$, $p < 0.001$) were observed. While no research has assessed the relationships between multi-directional lunges, jump performance qualities were identified as being directionally specific; hence the need to assess jump performance in each direction (20). However, based on the findings of this study, it appears that there is a high proportion of shared variance (>55%) between the lunge directions, therefore decisions around assessing all directions might be worthy of deliberation e.g. a single lunge directional test to assess horizontal neuromuscular and mechanical qualities in badminton athletes.

It is recommended that cyclic COD be assessed through the MDCT. Within the MDCT, small to moderate correlations were identified between the eight directions, suggesting a small shared variance. This indicates that COD in badminton is directionally specific and therefore strong performance in one direction, does not indicate strong performance in another. However, current cyclic COD tests, combine all directions into a single composite time, which cannot diagnose directionally specific deficiencies as the results of this study indicate as necessary (3-5). While the directional specificity of the MDCT was achieved, trivial to small correlations were noted between badminton ability and MDCT performance. These poor correlations may be due to the current design of the MDCT, which involves a single COD, possibly reducing the athlete's capacity to utilise elastic energy of the stretch-shorten cycle. In badminton, athletes aim to maximise the elastic energy contribution during direction changes by including a split step or a hop lunge prior to the COD (33, 60, 61). Both of these movements have been identified to increase the speed of direction change; therefore altering the MDCT to more effectively utilise elastic energy may improve the badminton specificity of the test. In a revised MDCT, it is suggested that the athletes complete four consecutive COD cycles in a single direction. By implementing the new protocol each preceding direction change should enhance the elastic energy in the musculo-tendon unit similar to that of the split step and hop lunge (33, 60-62). To further develop the MDCT a reactive component can be added, requiring the athlete to react to a stimulus that randomises the direction change. The inclusion of a stimulus would modify the test creating a multi-directional agility test (MDAT) with a perceptual and decision making component of agility. Previous agility tests have required athletes to respond to randomised lights (18, 63) or a computer screen displaying a direction to move towards (35), which assesses the athletes perceptual and decision making abilities, two key aspects of agility (24, 64).

While the MDCT poorly correlated with badminton ability, mostly large correlations were noted between badminton ability and total MDLT in females. This supports the premise that the lunge as a crucial predictor of multi-directional COD performance the authors suggesting that a sole forward lunge should be included in the BSA. The poor correlations in male athletes between the leg strength measures and badminton ability is in agreement with the findings of Fuchs et al. (18), whom also found trivial to small negative correlations between the Badminton World Federation Rankings and H-CMJ (r = -0.16) and V-CMJ (r = -0.21) performance in elite male athletes. However, the findings were in disagreement to Jeyaraman et al. (2), whom found badminton ability to be largely correlated with H-CMJ (r = 0.55) and V-CMJ (r = 0.57) in club level male athletes. It should be noted, that Jeyaraman et al. (2) assessed badminton ability via a scale, with a greater score indicating a greater ability, as opposed to the current study and Fuchs et al. (18), which utilised Spearman's rank order correlation coefficient. Due to the inconsistent findings between studies, the effect of jump and lunge performance on badminton ability remains unclear and requires further investigation to confirm or refute the relationships between horizontal and vertical lower body neuromuscular capabilities and badminton ability in junior, sub-elite and elite male and female populations. Based on current findings, it appears that shorter female athletes were ranked higher and had greater V-CMJ capabilities. However, standing height was unrelated to badminton ability in male athletes. The reason for these correlations is unclear and has not been identified in previous studies. However, due to differences in maturation status between elite adult and junior athletes and within the junior population, further assessment of these relationships in fully matured and physically developed adult populations is essential.

A limitation of this study was that a number of the assessments were novel to badminton player assessment (leg length, frontal split hip flexibility, MDLT and MDCT) and therefore the comparison of findings to other research is problematic. Further, as the athletes in the current study were primarily junior level, the results should not be considered representative of senior or elite badminton populations. As such, further research will be required into each of these measures to establish if the data collected in the current study is representative of the wider badminton community. Additionally, to increase the diagnostic understanding of testing, future research should utilise a force plate to measure leg force and strength directly instead of proxy measures such as height or movement time. The decision to use a jump mat as opposed to a force plate for testing, however, was based on the premise that jump mats are less expensive and therefore more readily available to the badminton associations, hence the findings having greater utility and impact.

Practical Applications

The purpose of this study was to establish which components of a BSA best predict COD and overall performance in badminton. Given the results of this study the following recommendations are made for the development of a BSA.

1) Ballistic and neuromuscular assessments in badminton should incorporate vertical and horizontal measures. The V-CMJ with arm swing is an effective vertical ballistic assessment, as two footed vertical jumps are frequently performed in badminton. However, since, the mechanics of the H-CMJ differ greatly to the horizontal direction changes performed in badminton, practitioners should consider implementing the MDLT as the horizontal neuromuscular performance assessment of choice. Due to similarities in multi-directional lunge performance, consideration may be given to a single lunge test to effectively assess overall horizontal lunge ability e.g. forward lunge test.

2) Cyclic COD ability in badminton is directionally specific and therefore it is recommended that the MDCT be utilised in assessment. It would seem ecologically valid to alter the MDCT to include four consecutive COD cycles in each direction, which may better simulate game play by more effectively testing the elastic energy storage and utilisation of players. Such changes should mimic the repetitive COD nature of badminton, while maintaining the directional specificity of assessment. The MDCT may be further adapted into an agility test (MDAT) through the inclusion of a stimulus such as a video of an opponent striking the shuttle. When completed alongside the MDCT, the MDAT may distinguish a players perceptual and decision making deficiencies, to further enhance overall assessment.

3) The inclusion of the frontal split hip flexibility assessment seems logical, as it is a badminton specific flexibility assessment potentially replacing the more frequently utilised less specific sit-and-reach test. However, when assessing frontal split hip flexibility, it is important to normalise the results to leg length to allow for comparisons between athletes of varying heights.

In summary, the following measures should be included in the BSA: height, body mass, eight site sum of skinfolds, leg length, frontal split hip flexibility, V-CMJ with arm swing, the MDLT and a revised MDCT.

CHAPTER FIVE:

SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS

General Summary

The overall purpose of this thesis was to develop a BSA and to establish which measures best predict overall badminton performance. The BSA battery was designed and implemented to improve diagnostic capabilities of directional specific ballistic and neuromuscular capabilities and COD qualities. The multi-faceted BSA proposed herein includes the following nine measures: height, body mass, leg length, eight site sum of skinfold, hip flexibility (frontal and sagittal split), V-CMJ, MDLT and MDCT.

The MDLT was developed as a measure of horizontal lunge COD ability and required athletes to complete a dominant leg lunge in eight directions. The time taken to complete each lunge was measured to allow practitioners to analyse directional specific performance (e.g. backhand vs. forehand, front court vs. rear court); data was also pooled to provide a measure of overall horizontal lunge performance. The MDCT was designed as a cyclic COD assessment and required athletes to complete a mock shot in eight areas of the court. Similar to the MDLT, the MDCT allowed the practitioner to assess directional specific COD performance, thereby distinguishing it from other COD tests which only provide a single composite time to complete the test (3, 5). Due to the directional specificity of the MDCT, the potential to enhance training is increased, as practitioners gain a greater quantity of information from assessment.

Chapter Three quantified the reliability of the newly designed MDLT and MDCT. As an assessment of horizontal lunge capabilities, the MDLT was moderate to highly reliable (change in the mean = 0.33 to 6.78%; TE = 0.03 to 0.11 s; ICC = 0.55 to 0.96); the MDCT was also found to be moderate to highly reliable (change in the mean = 0.12 to 5.87%;

TE = 0.05 to 0.20 s; ICC = 0.57 to 0.98). In confirming reliability the MDLT and MDCT were included in the BSA as horizontal lunge and cyclic COD assessments, respectively.

The purpose of the final study was to establish which components of the badminton specific assessment (BSA) best predict change of direction (COD) and overall performance in badminton. COD performance was identified to strongly correlate with a number of the tests, including the eight site sum of skinfold in female athletes. This relationship occurs because fat mass increases athlete total mass without a concomitant increase in their force production capabilities, thereby reducing the velocity of the direction change. In male athletes an increase in standing height correlated with slower COD times. It may be that better COD ability is associated with a lower centre of mass which provides better stability for changing direction, or it might be that the tests are step frequency dominant rather than step length dominant. Large correlations were noted between frontal split hip flexibility and COD performance in female athletes, but less so with males. This may be due to shorter female leg length, thereby requiring an increase in hip flexibility to achieve a greater distance with each step and in turn reducing the quantity of steps required in a COD cycle. Sagittal split hip flexibility was included in the BSA as a measure of lateral hip flexibility, however it poorly correlated with MDLT and MDCT, suggesting that it does not aid performance assessment and may be excluded from the BSA.

It is suggested that the MDLT be replaced by a single forward lunge as an assessment of horizontal lunge COD ability as very large to near perfect correlations were identified between all MDLT directions ($r > 0.75$, $p < 0.001$). The lunge appears a more ecologically valid measure of the horizontal neuromuscular and mechanistic qualities required for badminton than a H-CMJ. It is recommended that the MDCT be adopted as a cyclic COD measure, due to small to moderate correlations between directions within the test. This study has established that cyclic COD performance in badminton is directionally specific and therefore each direction requires an individual assessment. However, in doing so it is suggested that the MDCT be altered to include four consecutive COD cycles to more effectively utilise the elastic energy of the stretch shorten cycle. This change should increase the specificity of the test to badminton, thereby ensuring maximal diagnostic benefits.

In female athletes the MDLT was identified as a better predictor of badminton ability than the MDCT. This aligns with the premise that the lunge is a critical movement in the sport and the inclusion of a single forward lunge in the BSA appears beneficial. Badminton ability for male athletes appears relatively unrelated to each of the BSA measures. The reasons for this is unclear, however, may indicate a greater reliance on additional physical (e.g. aerobic capacity, arm strength, hand strength) and/or mental (e.g. perception and strategy) qualities to overall badminton ability.

Limitations

The primary limitations of the research, involved participant recruitment and availability. This was most prevalent in the reliability study, due to the small sample size (n = 15, 3 F and 12 M) gender pooling was required. While the gender pooling may have negatively influenced the results, the effect of this was likely minimal, as the female participants performed comparably to the males. A second limitation was the participant's time constraints, therefore the reliability testing was only able to be completed during regular training sessions. As a result, the pre-testing fatigue levels were unable to be standardised across athletes and sessions. To minimise the effect of fatigue, athletes were tested at the same time during each training session and were provided a 10 min period of minimal exertion prior to the MDLT. Further, as the athletes in the current study were primarily junior level, the results should not be considered representative of senior or elite badminton populations. As such, further research will be required into each of these measures to establish if the data collected in the current study is representative of the wider badminton community.

The BSA included a number of the assessments that were novel to badminton assessment (leg length, frontal split hip flexibility, MDLT and MDCT), therefore the comparison of findings to other research was problematic. Additionally, to increase the diagnostic understanding of testing, future research should utilise a force plate to measure lower body force directly instead of proxy measures such as jump height or movement time. The decision to use a jump mat as opposed to a force plate for testing was based on the premise that jump mats are less expensive and therefore more readily available to the badminton associations, hence the findings having greater utility and impact.

The final limitation is that due to the discrete nature of the direction changes in the MDCT, the specificity to badminton is reduced. Badminton requires athletes to complete numerous consecutive direction changes, however the decision was made for athletes to complete a single pre-determined COD to ensure that the decision making component of agility was eliminated. This protocol was successful at eliminating the decision making component, but in doing so reduced the specificity to badminton. To enhance the diagnostic capacity of the MDCT, four consecutive direction should be implemented in each direction, thereby allowing for a greater elastic energy contribution. The reliability and validity of such alterations would need to be assessed prior to inclusion within the BSA.

Practical Applications

- The BSA battery may be used as an overall badminton assessment, with additional tests to be added as thought relevent. The BSA is currently effective at measuring anthropometry, vertical and horizontal lower body neuromuscular capabilities, multi-directional COD ability and hip flexibility.
- Lower body assessments should incorporate the V-CMJ (vertical ballistic capability) and a forward lunge (horizontal neuromuscular capability/lunge COD ability). The V-CMJ with an arm swing is an effective vertical ballistic capability measure as two footed vertical jumps are frequent in badminton. A forward lunge is suggested as opposed to H-CMJ in badminton assessment due to greater similarities in COD movement patterns of the lunge compared with H-CMJ.
- Due to the directional specificity of COD performance in badminton, the MDCT should be utilised to allow for individual direction assessment. In further enhancing the diagnostic capacity of the MDCT, four consecutive direction changes should be implemented in each direction, thereby allowing for a greater elastic energy contribution. The MDCT may also be altered into the MDAT through the inclusion of a perceptual and decision making component.
- Frontal split hip flexibility should be incorporated into future assessment due to its specificity to badminton as opposed to the less specific sit and reach test. The results should be normalised to leg length to allow for comparison between athletes of varying height.

Future Research

With the suggested changes to the MDCT and addition of the MDAT, future research should reassess the reliability and validity of these tests, while also reconfirming relationships to the other BSA measures. This would also provide an additional population sample for all BSA measures, thereby increasing the capacity of the assessment to rank performance in each measure. It is suggested that future research utilises a senior elite population to establish if the findings of this thesis are representative of non-junior populations. Future research may also investigate if colour scaling, spider plots or alternative analysis methods enhance the coaches and athletes comprehension of the utility of the BSA. If alternative analysis methods appear beneficial, the research may aid in more closely aligning the philosophies of the coach and practitioner. Finally, the BSA battery should be further developed to include other badminton specific performance measures, such as aerobic capacity, sprint acceleration ability, handgrip strength, core strength, mental fitness and technique.

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APPENDICES

Appendix 1. Participant Information Sheet.

Participant Information Sheet

Date Information Sheet Produced: 17th March 2015

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Title

Reliability and discriminative ability of badminton specific change of direction testing.

Introduction

My name is Sam Paterson. I am completing my Masters Degree in Sport and Exercise at AUT University, with supervisors Dr Travis McMaster and Dr John Cronin. We would like to formally invite you to assist in our study which aims to establish the reliability and discriminative ability of change of direction testing in badminton athletes.

I propose to do this by; 1) comparing all change of direction measures to the Badminton New Zealand Rankings and 2) testing the inter- and intra-session reliability. Throughout the scientific literature there is little research analysing change of direction performance in badminton athletes. Therefore, I hope that this study can advance current badminton knowledge and potentially athlete performance.

Invitation to participate

- You are invited to take part in the above mentioned research project. Your participation in this research is entirely voluntary and you are under no obligation to participate in anyway. Together, you and your whanau should decide whether or not you would like to be involved. You are not required to be involved and it will not affect your standing in badminton. Additionally, you may withdraw from the study at anytime up until the completion of data collection, which will occur on approximately July 31, 2015.
- Your consent to participate in this research will be indicated by your signing and dating of a consent form. Signing the consent form indicates that you have freely given your consent to participate, and that there has been no coercion or inducement to participate by the researchers from AUT.

What is the purpose of the study?

- The purpose of this study is to establish the reliability and discriminative ability of badminton specific change of direction measures.
- This study is to be conducted as part of a Master's Degree thesis. The results of this study will be submitted to peer-reviewed journals.

How was I identified to participate in the study?

- You have been identified and invited to participate in the study through your affiliation with either Badminton New Zealand, Badminton North Harbour or New Zealand Badminton Academy. Each of these aforementioned associations have advised that I may provide a brief presentation to affiliated athletes, as to the purposes and requirements of the study.

What happens in the study?

We will ask you to come to either Active Badminton Centre, New Zealand Badminton Academy or North Harbour Badminton, depending on which you indicate is most convenient for you, to complete a testing session lasting 30 to 60 minutes.

- During the testing session you will be asked to:
    1. Have your height, weight, leg length and skin fold measurements recorded.
    2. Complete three maximal vertical jumps.
    3. Complete a lunge test.
    4. Complete a badminton specific multiple change of direction test.

What are the discomforts and risks?

- You will experience discomforts and risks which are similar to that of regular badminton training.

What compensation is available for injury or negligence?

- In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

What are the benefits?

- Findings of this study will be used to assist badminton athletes to identify their weaknesses when moving around the court and could therefore enhance performance. You will be provided with your individual results, as well as the mean and median results of the study so that you may identify your personal weaknesses, which can then be altered to enhance performance.

How is my privacy protected?

- The data from the project will be coded and held anonymously in secure storage under the responsibility of the principal investigator of the study in accordance with the requirements of the New Zealand Privacy Act (1993).
- All reference to participants will be by code number only, in terms of the research thesis and publications. Identification information will be stored on a separate file and computer from that containing the actual data.
- Only the investigators will have access to computerised data.

What are the costs of Participating?

- There is no monetary cost to you to be involved in this research, the only cost is time. The testing will be conducted at either Active Badminton Centre, New Zealand Badminton Academy or North Harbour Badminton and will take approximately 30 to 60 minutes.

Opportunity to consider invitation

- Please take the necessary time you need to consider the invitation to participate in this research.
- It is reiterated to you that your participation in this research is entirely voluntary and a decision not to participate will not adversely affect your standing in badminton.
- If you require further information about the research topic please feel free to contact Sam Paterson or Travis McMaster (details are at the bottom of this information sheet).
- You may withdraw from the study at any time before the conclusion of data collection without there being any adverse consequences of any kind. Data collection will conclude on approximately July 31, 2015.

How do I join the study?

- If you are interested in participating in this research feel free to contact either Sam Paterson or Travis McMaster (details are at the bottom of this information sheet).

Participant concerns

- If you have any questions please feel free to contact Sam Paterson or Travis McMaster. Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor – Travis McMaster.
- Concerns regarding the conduct of the research should be notified to the Executive Manager, AUTEC, Kate O'Connor, ethics@aut.ac.nz or phone +64 9 921 9999 x6038.

Researcher Contact Details:

Sam Paterson, School of Sport and Recreation, AUT University. Email: sam4paterson@gmail.com or phone +64 27 757 4260

Project Supervisor Contact Details

Primary Supervisor: Dr Travis McMaster, Sports Performance Research Institute New Zealand, School of Sport and Recreation, AUT University. Email: travis.mcmaster@aut.ac.nz

Secondary Supervisor: Dr John Cronin, Sports Performance Research Institute New Zealand, School of Sport and Recreation, AUT University. Email: john.cronin@aut.ac.nz or phone + 64 9 921 9999 ext. 7523

Thank you for considering participating in this research.

Approved by the Auckland University of Technology Ethics Committee on 01/05/15. AUTEC Reference number 15/88.

Appendix 2. Consent Form.

Consent Form For use when laboratory or field testing is involved.	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: Reliability and discriminative ability of badminton specific change of direction testing.

Project Supervisor: *Dr Travis McMasters*

Researcher: ***Sam Paterson***

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 17th March 2015.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from any current injury or illness that may impair my ability to perform the required tasks nor am I below the age of 16 years.
- ○ I agree to answer questions and provide physical effort to the best of my ability throughout testing.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature:.............................……………………………………………………

Participant's name:...................................…………………………………………………

Participant's Contact Details (if appropriate):…...……………………………………..……..……

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Date:

Approved by the Auckland University of Technology Ethics Committee on 01/05/15 AUTEC Reference number 15/88

Note: The Participant should retain a copy of this form.

Appendix 3. Ethics Approval.

AUTEC SECRETARIAT

1 May 2015

Travis McMaster
Faculty of Health and Environmental Sciences

Dear Travis

Re Ethics Application: **15/88 Reliability and discriminative ability of badminton specific change of direction testing.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 30 April 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 30 April 2018;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 30 April 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Sam Paterson sam4paterson@gmail.com

Appendix 4. 3 Minute Thesis Presentation Slide.

Appendix 5. Abstract Chapter 2: Strength and Conditioning Journal.

Paterson SJ, McMaster T, Cronin J. Assessing change of direction in badminton athletes. Strength Cond J. 2016;38(5):18-30. (Chapter 2)

This review provides a stock take of badminton specific change of direction research and provides recommendations to practitioners for change of direction (COD) assessment. The review will examine relationships between change of direction and the following measures: anthropometry, elastic strength, concentric strength, leg muscle imbalances, technique, straight-line sprint speed and flexibility. A badminton specific COD assessment battery is proposed with the inclusion of two new tests: a multi-directional lunge test and a multi-directional cyclic COD test.

Appendix 6. Abstract Chapter 3: Journal of Strength and Conditioning Research.

Paterson SJ, McMaster T, Cronin J. Reliability and diagnostic applications of novel badminton specific multi-directional change of direction tests. J Strength Cond Res. 2016. (Under review). (Chapter 3)

The purpose of this study was to assess the reliability of two newly designed badminton specific change of direction (COD) tests: multi-directional lunge test (MDLT) and multi-directional cyclic change of direction test (MDCT). Fifteen badminton players (3 females, 12 males) completed the MDLT and MDCT over 3 testing occasions. The reliability was assessed with three statistics: percentage change in the mean, typical error (TE) and intraclass correlation coefficient (ICC). It would seem that the tests provide reliable measures of multi-directional reactive leg strength (MDLT) and cyclic COD ability (MDCT). The diagnostic applications of these tests were discussed.

Appendix 7. Abstract Chapter 4: Journal of Strength and Conditioning Research.

Paterson SJ, McMaster T, Cronin J, Tang LV. Relationship between badminton ability and multi-directional change of direction tests. J Strength Cond Res. 2016 (Under review).

The purpose of this study was to establish which components of the badminton specific assessment (BSA) best predict change of direction (COD) and overall performance in badminton. Forty-one athletes (16 female and 25 male) completed nine assessments: height, body mass, leg length, eight site sum of skinfold, frontal split flexibility, sagittal split flexibility, vertical counter-movement jump (V-CMJ), multi-directional lunge test (MDLT) and multi-directional cyclic COD test (MDCT). The best predictors of COD performance were the MDLT (female – r = 0.58; male – r = 0.57), frontal split hip flexibility (F – r = -0.72, M – r = -0.36), eight site sum of skinfold (F - r = 0.65) and V-CMJ (M – r = -0.49). The BSA was most effective for predicting badminton ability in female athletes; specifically the MDLT (r = 0.59), height (r = 0.51) and V-CMJ (r = -0.48). Future research should aim to establish normative data for each test, particularly frontal split hip flexibility and the MDCT, which have not previously been measured in badminton athletes. It is recommended that practitioners include the V-CMJ, forward lunge (horizontal leg strength) and frontal split hip flexibility tests due to their specificity to badminton performance.