ABSTRACT

Squash is a sport characterized by complex physical, technical and tactical demands. Despite its increased popularity, there is presently no synthesis of the literature pertaining to the performance requirements of squash. As such, it is difficult to generate evidence based guidelines for applied practitioners working with squash athletes. The purposes of this review were to a) identify the most important aspects of squash performance with reference to junior and senior athletes, b) identify and discuss the available methods of assessment of squash performance and c) identify areas where further research efforts are needed so that the performance requirements of the squash game are understood. Critical analysis of literature pertaining to; movement characteristics and time motion analyses, physiological demands, methods of assessing physical qualities, psychological demands and injury epidemiology were conducted. A summary of the physical characteristics of squash athletes of varying ages and playing standards is presented. Time motion analysis studies present consistent information on the game demands. There are limited data on game demands evolution from youth to senior. There appears to be usable testing protocols available for practitioners supporting squash athletes, although further work is needed to determine the applicability of these measures in junior athletes. Furthermore, better controlled studies are required to establish the injury risks associated with squash.

***Key words*:** Racket Sports, Physiology, Match analysis, Youth, Testing

INTRODUCTION

Despite the complex requirements of squash, its increasing popularity and repeated Olympic candidacy, there is presently no synthesis of the literature pertaining to the performance requirements with particular reference to both junior and senior squash athletes. This leaves practitioners supporting squash athletes without an easily accessible literature summary to guide evidence based practice. As such, the purpose of this scoping review is to provide a summary of the available body of literature examining squash performance from a multi-disciplinary perspective and identify areas for future research efforts

Initially, the review synthesizes the available evidence pertaining to the characteristics of the squash game at senior and junior levels. Subsequently, the physiology of squash and the physical qualities required for successful performance are analyzed. The available assessments of physical qualities for squash athletes and practitioners are then detailed and critiqued. This review also highlights the psychological and skill demands experienced by squash performers. The aforementioned topic areas were selected upon reviewing the body of published literature related to squash performance and determining the quality of the available evidence.

Following review and synthesis of the available evidence on squash performance, evidence based recommendations are made with a view to informing applied sport science service provision to junior and senior squash athletes. This review also highlights areas in which the evidence base is lacking and further work is needed.

CHARACTERISTICS OF THE SQUASH GAME

Before researchers and practitioners can understand the physiology and psychology of the squash athlete, the characteristics of the squash game must be understood. Via time motion and video analyses, previous work has quantified the distances, velocities and accelerations of players of differing standards during match play [1]. A template for the modelling of elite squash matches is an attractive prospect to squash coaches and performance analysts. This has previously been described using data from matches involving some of the top 20 players at the time [1], authors were able to define some of the general characteristics of a match including average number of shots, rallies, rally length and time, as well as some performance variables such as the number of winners and errors played.

There are some data available on the running velocities and accelerations achieved during squash match play. The average running velocity (when the ball is in play) has been reported to be 1.59 $m \cdot s^{-1}$ [2]. Separate work has indicated that accelerations for the elite players can reach 1.47 $m \cdot s^{-1}$, with peak velocities of 1.98 $m \cdot s^{-1}$. It was also reported that elite and sub-elite players had significantly higher velocities and accelerations in losing rallies compared to winning rallies [1]. This may be due to players having to “chase” the ball during losing rallies. Although limited, these data indicate that both elite and sub elite players require well developed speed/acceleration (and deceleration) abilities for successful performance.

In order to determine which physical qualities and energy systems are important for squash performance, the rally, game and match durations and distances covered must be understood. In senior player's average rally length has been reported to be 21 s with 10 s rest between rallies and a mean of 26 rallies per game for an average of 351 shots per game. Separate work has observed that game length can range from 194 (03:14 mm:ss) – 1,113 s (18:33 mm:ss) (average 700 s (11:40 mm:ss)) and the total distance covered in a game ranging from 254 – 1449 m (average 915 m) depending on the length of game [2] in senior level players. The authors also reported average match time was 49 min, of which 59.6% of the time was spent with the ball in play.

Research conducted in "well trained" adult squash athletes has indicated a mean game duration of ~8 min [3], this was consistent with game durations recorded at the 2004 Professional Squash Association (PSA) World Championship in Doha, Qatar. This appears to have changed in recent years. Analysis using data from 5 consecutive years of finals matches from a major PSA tournament (2009-2013) has indicated that mean game duration in senior players has increased to ~15 min (unpublished work). Similar game durations of ~17 min have also been reported at the World Team Championships in 2003 [4]. Although speculative, the increases in game duration may be attributable to the improved physical and technical abilities of squash athletes in more recent years.

Previous analysis has also indicated match duration is influenced by the age of the competing athletes. Total match times were shown to be significantly different between the open (professional) group and the U19, U15, and U13 age groups (see Table 1) suggesting that physical requirements vary with age and technical expertise.

These data indicate squash athletes of all ages are required to perform for an average ≥ 7 min per game with numerous rallies played and the duration seems to increase with age (See Table 1). Previous work has classified what would be considered "short, medium and long" duration rallies in elite senior athletes. These thresholds were set by "two national level squash coaches" as follows; short rallies 4 to 12 s, medium rallies 12 to 25 s and long rallies 25 and over [4]. At the elite level, short rallies seem to be the most common with 40.2% of rallies lasting between 4 and 12 s in duration. Combined, these data indicate that senior and junior squash athletes may require both heightened aerobic and anaerobic capabilities for successful performance.

Table 1 about here

PHYSIOLOGICAL DEMANDS OF THE SQUASH GAME

In order for practitioners supporting squash athlete to effectively improve physical performance it is imperative that the physical demands of the squash game are understood. Research utilizing wearable technologies has attempted to quantify metabolic demands of the squash game. This information can help practitioners to determine which physical qualities are important for performance in squash and guide programming physical development plans.

During match play, senior elite performers can achieve a mean intensity in excess of 85% $\dot{V}O_{2max}$ and 90% max HR [3]. It has also been suggested in previous work that squash match play places high demands on the aerobic energy system [5–9]. This is likely attributable to the repeated high intensity efforts and short rest periods involved with squash match play [3] (Table 1). Due to the aforementioned findings, it is reasonable to propose that squash athletes require well developed aerobic physical qualities to sustain performance and meet the required energy demands of match play.

The average duration of rest intervals between rallies appears to be largely consistent between junior age groups then increasing at senior level (Table 1). Blood lactate concentrations data support this view. In fact, Girard et al. (2007) observed lactate concentrations notably above what would be considered lactate threshold [10] (~8 mmol·L^{-1}) during simulated squash games. This may indicate that during periods of high intensity work in squash, energy may be derived from anaerobic glycolysis. This suggestion is supported by the strong correlation between increases in blood lactate and playing time spent at intensities above 90% $\dot{V}O_{2max}$ [3]. It is thus reasonable to propose that anaerobic capacity and lactate tolerance are important physical qualities in both junior and senior squash athletes. Despite this, there are presently limited data pertaining to the anaerobic capabilities of squash athletes and much of the research efforts have been focused on aerobic capacity. Squash athlete's aerobic capabilities are in fact the most commonly assessed physical quality in the available body of published literature (see Table 2).

Table 2 about here

Whilst $\dot{V}O_{2max}$ or other measures of aerobic capacity have been assessed in squash athletes on numerous occasions, more recent research has indicated that in elite players aerobic capacity (estimated via a 20 m shuttle run) is similar between athletes of different ages and playing standards (senior trained, transition trained and scholarship trained), across a performance program [11]. This may indicate that $\dot{V}O_{2max}$ and/or a large aerobic capacity is not predictive of playing ability in a homogeneous group of elite performers. This is perhaps unsurprising, as squash “performance” is dependent on the technical and tactical capabilities of the athlete and just like many other racquet sports cannot be explained solely by one physical quality [12–14].

Whilst $\dot{V}O_{2max}$ and aerobic fitness may not be predictive of playing ability, it has been suggested that aerobic qualities may influence performance at the elite level [7,11]. For this reason, the aerobic capabilities of the squash athlete should be assessed in order to ensure a player’s squash performance is not inhibited by any incapacity to sustain the required intensity of match play and training efforts. Based on data presented in Table 2 it may be speculated that to compete at elite senior level males and females require $\dot{V}O_{2max}$ of ~60 and ~50 $ml \cdot kg \cdot min^{-1}$. However, more research is needed to confirm this.

Anaerobic capacity has been also indicated as a relevant physical quality for squash players and it has been assessed in senior national level squash athletes via Wingate testing protocols. Mean power outputs of 12.5-13.5 $W \cdot kg^{-1}$ and fatigue indexes of between -10 and -15 $W \cdot s^{1}$ have been reported [8]. The interest in anaerobic metabolism in squash players stems from the movement characteristics of match play which require repeated sprint and acceleration efforts [15]. For this reason, it has been acknowledged in the body of available literature that multiple sprint ability and fatigue resistance are important physical qualities in squash athletes (Lees, 2003; Sharp, 1998). Senior international level squash athletes have been observed to outperform their counterparts who are not yet Senior but at a “Transition” level, in a test of repeat sprint ability, requiring athletes to complete 10 “squash specific” sprint movements as fast as possible with 20 s recovery intervals [11]. Additionally, performance in the aforementioned multiple sprint test was related to world ranking in both male and female squash athletes. When combined, these observations indicate that repeated sprint/acceleration ability may be a physical quality which needs to be addressed with appropriate training prescriptions as it is likely to be an important performance determinant.

The most important aspects of squash match play involve repeated high speed whole body movements such as lunges, jumps, short sprints and changes of direction as well as fast movements of the dominant arm [3,14–16]. Limited data are available on the strength and explosive movement abilities of squash players. Work from Wilkinson et al., (2012) reported that multiple sprint ability showed a significant correlation coefficient with reactive strength index (RSI) which is a ratio of jump height and ground contact time as assessed by a drop jump from a 0.3 m box. Furthermore, in their work the “Transition” athletes had greater RSI’s than “Scholarship” level athletes (Senior > Transition > Scholarship). As RSI was similar between Senior and Transition level athletes it was hypothesized that the ability to perform fast and explosive movements is a characteristic of more experienced squash athletes. This suggestion is supported by countermovement jump height (CMJ) also being similar in Senior and Transition athletes. Unlike many other physical performance measures there are some published data on CMJ in squash athletes (Table 3) however with a total of 43 participants and values ranging from 0.32 – 0.66 m analysed in all published studies [11,17–19] accessed for this review it is difficult to understand if this aspect can discriminate elite from non-elite players. Additionally, in squash athletes RSI has been reported to positively correlate with performance in a test of change of direction speed [11] which was also able to differentiate between full and part time squash players.

Limited data are available on the physical demands of the junior squash game, however previous work quantified the physiological responses of junior squash athletes to squash match play and a bespoke squash simulation protocol [20]. It was reported that during both squash match play and the simulation protocol, junior players achieved heart rates of ~200 beats·min^{-1}, blood lactate concentrations of ~6 mmol·L^{-1} and high ratings of perceived exertion (~18). These data indicate that like senior level squash anaerobic and high intensity work capacities are important physical qualities for junior squash athletes.

When critically analysing the body of work pertaining to the physical demands of squash it is worth noting that in 2009 squash underwent rule changes. In brief, the rule changes involved scoring being changed to an 11 point per rally system and the introduction of a 43.2 cm tin. Recent work has indicated that the consequences of these rule changes are as follows [21]; the number of rallies and distances covered have reduced and elite players have less time to perform shots than previously. The authors identified following the rule changes what constitutes short, medium, long and very long games in elite males. Additionally, short, medium, long and very long rallies were identified. Using these data, the authors were able to design ghosting protocols which accurately simulate the aforementioned game and rally durations for elite males. For specific information regarding these ghosting protocols the reader is directed to the article by Murray et al. [21].

ASSESSMENT OF PHYSICAL QUALITIES IN SQUASH ATHLETES

A fundamental aspect of sports science support to athletic groups is conducting assessments of physical qualities relevant to the sport/event in question to measure progress and effectiveness of the training paradigms used. In order for the data generated by these assessments to provide useable information for the coach, practitioner and athlete, it is imperative that the assessment protocols employed are both valid and reliable for the athlete group being testing. Researchers and applied practitioners have attempted to construct and validate "squash specific" incremental testing protocols for determining $\dot{V}O_{2max}$ [5,22,23]. Methods of assessing a squash athletes $\dot{V}O_{2max}$ via squash specific movements and simulated rallies have high face validity and are attractive prospects to coaches and sports science practitioners. It should however be noted that the current squash specific protocols are not without their limitations.

Girard et al. (2005) constructed a "squash specific graded test" involving repeated movements designed to simulate the squash game. Like the 20 m shuttle run the test was split in stages, with stages progressing via players being given less time per stage to reach the required targets. As per the majority of incremental exercise protocols the test ended when athletes reached volitional exhaustion or could not maintain the required running speed, an additional criterion for test cessation was the athlete not being able to "perform strokes with acceptable technique". Wilkinson et al. (2009b) designed a similar protocol with the only noteworthy difference being the running pattern was not random but pre-determined. Another protocol [5] required athletes to perform movements said to replicate squash match play and run to specific targets on the squash court, without simulating any shots.

In attempts to “validate” the squash specific protocols researchers have compared squash athletes $\dot{V}O_{2max}$ achieved on the squash specific protocols and more standard incremental treadmill protocols [5,22,23]. Additionally, Wilkinson et al. (2009b) compared performance on the squash specific and treadmill protocol between trained squash players and trained runners. Overall it was observed that well trained male squash players achieved higher $\dot{V}O_{2max}$ on the squash specific protocols than the treadmill protocols [22,23], whereas university level athletes achieved similar $\dot{V}O_{2max}$ following squash specific and treadmill protocols [5] (Figure 1). It was also observed that trained squash athletes achieved greater time to exhaustion on the squash specific protocol than trained runners, although $\dot{V}O_{2max}$ was similar between athletes groups [22].

Figure 1 about here

Based on these data it would appear that the tests detailed by Girard et al., Wilkinson et al., and Micklewright and Papapdopoulou are valid and useable measures of determining aerobic capacity in squash athletes, however there are some confounding factors which may limit the applicability of these protocols for accurately determining $\dot{V}O_{2max}$ in squash athletes. Firstly, two of the three squash specific protocols require participants to repeatedly mimic a powerful stoke [22,23]. It is not unreasonable to suggest that perceptions of what may constitute a powerful stroke may differ greatly between practitioners administering the test(s). Anecdotal observations at our institution have indicated that when squash athletes perform the test described by Girard et al. (2005) a powerful shot is notably different in stage one of the test than during the later stages; this may result in the test being prolonged or cut short unduly depending on the test administrator's subjective perceptions. There is potential for these factors to result in an invalid $\dot{V}O_{2max}$ being attained. It may also be suggested that including a skill element to the test(s) detracts from the physical quality being assessed. This is perhaps reflected in the results reported by Wilkinson et al. (2009b) indicating greater time to exhaustion in squash athletes than runners in the squash specific protocol. It was suggested that this was attributable to the lack of skill of the runners in the techniques of squash movement and racket swing. It can be argued that these techniques are in no way related to aerobic capacity. This may indicate that performance in the test described by Wilkinson et al. (2009b) is more reflective of squash ability and/or fitness rather than $\dot{V}O_{2max}$. This suggestion is supported by the fact that performance in the squash specific test was predictive of player rank, whereas $\dot{V}O_{2max}$ in squash athletes (predicted via 20 m shuttle run) is not able to differentiate between playing ability [11]. It is therefore reasonable to suggest that if the practitioner requires accurate information on an athlete's aerobic capacity to prescribe intensities for off court based conditioning, a treadmill based protocol may be the most appropriate choice. However, if the practitioner requires information on the athlete's ability to sustain movements' specific to squash match play a squash specific incremental protocol may be appropriate, in particular if an elite player is the subject of the assessment. A secondary criticism of the of the squash specific protocols is there is limited data pertaining to the reliability of the testing protocols. Only Micklewright & Papapdopoulou (2008) reported the reliability of time to exhaustion in the squash specific protocol. In this case time to exhaustion (s) was observed to be reliable. An additional criticism of the protocols detailed are the complexity and in the case of Girard et al. (2005) the random nature of the movement patterns. This may not influence the performance of senior and experienced squash players but in junior players the complex movement patterns may influence test performance. Presently there are no data on the validity nor reliability of the tests detailed in junior squash athletes.

The multiple sprint ability of squash athletes has been demonstrated to differ between players across a performance program with more senior level players out performing their "Transition" level counterparts (Senior > Transition > Scholarship). This quality was also related to player rank when assessed via a squash specific test [11]. This test previously detailed by Wilkinson et al., (2012) appears to employ movement patterns and work:rest intervals (repeated efforts of 10 multidirectional sprints separated by 20 s recovery) which closely replicate that observed in match play, (Table 1). No simulated shots were required at any point during the test, as such it can accurately be described as a test of squash repeat sprint ability and not a composite measure of squash performance. The test has also observed to display acceptable reliability in senior level athletes [24]. However, like other squash specific protocols there are some concerns over the tests complexity and applicability in junior athletes as no data are available on this.

As previously stated RSI and CMJ have been reported to correlate with multiple sprint ability and "Transition" athletes have greater RSI's than "Scholarship" level athletes (Senior > Transition > Scholarship). These tests are simple in nature and are generally reliable [11,25]. Additionally they are related to other physical qualities relevant to squash performance including speed and change of direction speed [26]. However, this is currently insufficient data available to determine if metrics derived from CMJ or drop jumps are predictive of playing ability in squash athletes.

PSYCHOLOGICAL DEMANDS

Successful performance in squash likely requires heightened perceptual-cognitive skills. Abernethy (1990), examined anticipation of an opponent's stroke in squash using a video-based task. Participants of varying ability undertook both temporal and spatial occlusion tasks. Temporal occlusion involves briefly cutting a video at certain points of an action. Spatial occlusion involves hiding sections of the displayed action. In both tasks, experts performed significantly better than novices at predicting outcomes. Only experts were capable of picking up information on early parts of the opponent's actions (e.g. arm movement). A more recent expert-novice study by Caudrelier, James & Borer, (2005), who temporally occluded various segments of 40 squash video clips, support the view that elite players are superior at anticipating ball trajectories, but only when racket swing was occluded. This suggests that elite players use contextual information to enhance their anticipation skills. These studies highlight the importance of anticipation in squash.

The use of temporal occlusion and spatial occlusion tasks by both Abernethy (1990) and Caudrelier et al. (2005) respectively provide some insight into the perceptual component of decision-making among squash players of differing abilities. These methods are not without their weaknesses, however. For example, with temporal occlusion, if time pressure is different to what is required in actual competition, a different strategy may be used by the decision-maker. Spatial occlusion, is limited in that the editing work is very time consuming (Williams, Davids, & Williams, 1999), and potential for practice and order effects must be accounted for if the same stimuli need to be presented on repeated trials. In temporal and spatial occlusion studies, ecological validity may also be questioned.

Expert-novice differences in squash were also highlighted by Kerr & Cox (1990). On a specially-devised squash task, significant differences in attentional style were reported. 'Skilled' players showed good adaptive abilities, were less distracted, and were better able to focus on the situational demands. 'Average' level squash players, however, were found to attend more to unimportant aspects of the competitive situation and lose perspective on important aspects of the unfolding play. Furthermore, in a follow-up study, trying to understand psychological processes in successful squash, Kerr & Cox (1991) examined the impact of arousal levels on players of various ability levels. Results showed that all players approached games with high levels of arousal, but this was not necessarily associated with high levels of stress or anxiety. 'Winners' showed slightly higher and more stable levels of arousal across games than 'losers' who demonstrated significant decreases in arousal as lack of success increased, which was associated with increasing stress.

The Kerr & Cox (1990, 1991) studies were pioneering in squash, but limitations include a dependency on self-report measures in artificial settings. The authors suggest carrying out similar state-based research in a competitive match situation. The focus on mental and emotional states, as such, appears to be of high relevance. The intensity of squash, combined with fine margins relating to interference of play, often leading to dubious refereeing decisions, can elicit strong emotions, and subsequently impact performance adversely. Future research could, for example, examine emotional regulation as a strategy for dealing with stress or frustration in squash.

While expert-novice differences are well studied in perceptual-cognitive research, more recently, differences in decision-making among experts has been examined in a squash context. Murray et al. (2018) [32] found fine-grained differences in situation awareness among expert squash players using a cluster analysis technique [33]. Situation awareness involves assessing all relevant sources of information, making sense of it all based on domain knowledge from previous experience, and being able to physically respond to a given situation [34]. Murray et al. formed six situation awareness clusters based on the opponent's position when playing the shot and the subsequent movement parameters concerning the shot return. The cluster analysis used revealed a previously undiscovered distinction in the straight drive from the back of the court, the most common shot in squash. It could be classified as either hitting the back wall (maintaining stability) or not (pressing). It was concluded that such a distinction has the potential to discriminate between experts in decision-making and skill level. In sum, while this study has provided a methodology which can lead to determining small differences in elite level behaviour, future research could further consider the use of cluster analysis to focus on players of different standards to identify any differences in their situation awareness. Such information may potentially be useful for identifying areas of development potential among players.

INJURY EPIDEMIOLOGY

Like most other sports squash involves a noteworthy risk of sustaining injury. The primary factors that contribute to injury risk in squash are the physical demands of the sport; repeated lunging, accelerations and decelerations, changes of direction [35].

The literature regarding squash epidemiology is very limited [35,36] with no consensus in the injury collection data methodology [35]. Most published articles are based on survey-questionnaires [36–38] and retrospective data analyses [39] involving players with different ages and levels of performance, from recreational [37,40] to national level players [36]. The study periods vary widely, from four weeks [38] to the total length of time the player is involved in the sport [40]. As such few useable inferences can be gleaned from the current body of published literature.

Injuries in squash can be grouped in three major categories: musculoskeletal and soft-tissue injuries, eye and head traumas, sudden death [35]. From the musculoskeletal category back injuries [40,41] are the most frequent complaint due to repeated bending and rotation movements required to execute forehand and backhand strokes. Cranio-facial traumas [42] and isolated acetabular fracture [43] have been as well reported in the literature.

Squash has been associated with high number of face and eye injuries [35,44]. However, as all incidences were reported by non-professional junior and senior athletes it cannot be ascertained if incidences are in any way related to the playing standard of the athlete. To date there are no studies to examine incidences of eye injuries in elite junior athletes. Table 3 summarizes the methodological approaches and findings of musculoskeletal injury research in squash.

Table 3 about here

A noteworthy limitation of squash injury epidemiology studies is that most data are obtained via self-report via questionnaires or the athlete approaching a medical institution. As a result, it appears that only severe musculoskeletal injuries (primarily acute episodes) are reported with virtually no access to non-acute episodes.

In summary, there is a paucity of injury epidemiology studies involving elite senior and junior squash athletes. Without a standardized injury assessment and data recording methodology including; diagnosis, type, onset, mechanism, affected system, and severity, incident context (training, competition), exposure or time lost, it is likely that our understanding of the training and competitions risks are limited to the acute reporting injuries published in the literature and it as a consequence we are not aware of the real injury risks associated with squash practice at an elite level.

CONCLUSIONS

This review sought to provide a summary and critique of published literature relevant to squash performance, key injury risks and epidemiology were also discussed.

Fitness assessment of squash players seems to be employing field based tests to assess aerobic capacity. While such approach has merit in its face validity and closely replicate the movement patterns associated with squash match play, care should be taken in the interpretation of results. We have in fact highlighted how in young/non-elite population it may be challenging to reach levels of intensity closer to maximal oxygen uptake. As such the tests may represent a measure of “squash endurance” rather than a true measure of the athlete’s aerobic capacity. Additionally, the complexity of the protocols and requirement to simulate numerous powerful shots may not be appropriate for junior squash athletes. Coaches and practitioners wishing to assess the aerobic capacity of junior squash athletes may consider utilizing simple measures of aerobic capacity such as the multi stage fitness test, 20 m shuttle or treadmill based protocols to determine $\dot{V}O_{2max}$.

Tests of multiple sprint ability and change of direction speed in squash athletes appear to be useful measures in senior level athletes, however like the measures of aerobic capacity, the complexity of these tests may not be appropriate for junior level/non elite athletes. Simple measures of anaerobic capacity, vertical jumps and RSI appear to be appropriate ways to track the growth and maturation of young athletes as well as describe their physical abilities. However, while the literature unsurprisingly indicates that elite players are fitter/faster/stronger than non-elite athletes, it is not possible to utilize such measure to predict success from junior to elite. Normative reference data on junior athletes are scarce at best as well as information about the demands of the game at various stages of growth and maturation. Therefore, it becomes challenging to be able to devise coaches involved with young athlete on the best development strategies.

While there is a clear shortage of psychological research in squash, existing studies addressing cognitive-perceptual factors are arguably of great relevance when it comes to understanding the demands of the sport due to the quick decision-making required. However, just like with the physical requirements, there is no squash-specific literature outlining psychological skill level at particular ages. In particular, there is a lack of information on the development of perceptual-cognitive skills from early adolescence to senior competitors which could inform better coaching practice in young cohorts.

This article adds a summary and critical synthesis of the literature related to performance in Squash. The information presented in this review may serve as a point of reference for applied practitioners supporting either/both senior and junior level Squash athletes. The synthesis of the literature pertaining to the physiological, psychological, tactical and injury demands of squash may enable practitioners to implement evidence based practice scientific support to their athlete group.

REFERENCES

1. Hughes M, Franks IM. Dynamic patterns of movement of squash players of different standards in winning and losing rallies. *Ergonomics* 1994; 37: 23–9.
2. Vučković G, Dežman B, Erčulj F, et al. Comparative movement analysis of winning and losing players in men's elite squash. *Kinesiol Slov* 2003; 9: 74–84.
3. Girard O, Chevalier R, Habrard M, et al. Game analysis and energy requirements of elite squash. *J Strength Cond Res* 2007; 21: 909–14.
4. Vučković G, James N. The distance covered by winning and losing players in elite squash matches. *Kinesiol Slov* 2010; 16: 44–50.
5. Micklewright D, Papapdopoulou E. A New Squash Specific Incremental Field Test. *Int J Sports Med* 2008; 29: 758–763.
6. Beaudin P, Zapiec C, Montgomery D. Heart Rate Response and Lactic Acid Concentration in Squash Players. *Res Quarterly Am Alliance Heal Phys Educ Recreat* 1978; 49: 406–412.
7. Brown D, Weigland D., Winter E. Maximum oxygen uptake in junior and senior elite squash players. In: Lees A, Maynard I, Hughes M, et al. (eds) *Science in Racket Sports II*. London: E & FN Spon, 1998, pp. 14–19.
8. Sharp NC. Physiological demands and fitness for squash. In: Lees A, Maynard I, Hughes M, et al. (eds) *Science in Racket Sports II*. London: E & FN Spon, 1998.
9. Montpetit RR. Applied physiology of squash. *Sports medicine (Auckland, N.Z.)* 1990; 10: 31–41.
10. Faude O, Kindermann W, Meyer T. Lactate Threshold Concepts. *Sport Med* 2009; 39: 469–490.
11. Wilkinson M, Cooke M, Murray S, et al. Physiological correlates of multiple-

sprint ability and performance in international-standard squash players. *J Strength Cond Res* 2012; 26: 540–7.

12. Vuckovic G, Dezman B, Pers J, et al. Motion analysis of the international and national rank squash players. In: *ISPA 2005. Proceedings of the 4th International Symposium on Image and Signal Processing and Analysis, 2005.* IEEE, 2005, pp. 334–338.
13. Chin M, Steininger K, So RCH, et al. Physiological profiles and sport of. *Br J Sports Med* 1995; 29: 158–164.
14. Lees A. Science and the major racket sports: a review. *J Sports Sci* 2003; 21: 707–732.
15. Eubank C, Messenger N. Dynamic moves and stepping patterns typical to the game of squash. *J Sports Sci* 2000; 18: 471–472.
16. Williams B, Kuitunen S. Lunge Forces and Technique of Junior Squash Players. *ISBS-Conference Proc …* 2010; 1–3.
17. Brookes FB., Winter E. A comparison of 3 measures of short-duration, maximal performance in trained squash players. *J Hum Mov Stud* 1985; 11: 105–112.
18. Todd MK, Mahoney C. Determination of pre-pre season physiological characteristics of elite male squash players. In: Reilly T, Hughes M, Lees A (eds) *Science in Racket Sports*. London: E & FN Spon, 1994, pp. 81–86.
19. Mahoney C., Sharp NC. The physiological profile of elite junior squash players. In: Reilly T, Hughes M, Lees A (eds) *Science in Racket Sports*. London: E & FN Spon, 1995, pp. 76–80.
20. Kingsley M, James N, Kilduff LP, et al. An exercise protocol that simulates the activity patterns of elite junior squash. *J Sports Sci* 2006; 24: 1291–6.

21. Murray S, James N, Hughes MD, et al. Effects of rule changes on physical demands and shot characteristics of elite-standard men's squash and implications for training. *J Sports Sci* 2016; 34: 2170–2174.
22. Wilkinson M, Leedale-Brown D, Winter EM. Validity of a squash-specific fitness test. *Int J Sports Physiol Perform* 2009; 4: 29–40.
23. Girard O, Sciberras P, Habrard M, et al. Specific incremental test in elite squash players. *Br J Sports Med* 2005; 39: 921–6.
24. Wilkinson M, McCord A, Winter EM. Validity of a squash-specific test of multiple-sprint ability. *J Strength Cond Res* 2010; 24: 3381–6.
25. Flanagan EP, Ebben WP, Jensen RL. Reliability of the Reactive Strength Index and Time to Stabilization During Depth Jumps. *J Strength Cond Res* 2008; 22: 1677–1682.
26. Foden M, Astley S, Comfort P, et al. Short Communication Relationships between speed, change of direction and jump performance with cricket specific speed tests in male academy cricketers. *J Trainology* 2015; 4: 37–42.
27. Abernethy B. Expertise, visual search, and information pick-up in squash. *Perception* 1990; 19: 63–77.
28. Caudrelier T, James N, Borer K. Anticipatory ability of elite squash players. *J Sports Sci* 2005; 23: 1241.
29. Williams AM, Davids K, Williams JGP. *Visual perception and action in sport*. New York; London: E & FN Spon, 1999.
30. Kerr JH, Cox T. Cognition and mood in relation to the performance of squash tasks. *Acta Psychol (Amst)* 1990; 73: 103–114.
31. Kerr JH, Cox T. Arousal and individual differences in sport. *Pers Individ Dif* 1991; 12: 1075–1085.

32. Murray S, James N, Perš J, et al. Using a situation awareness approach to determine decision-making behaviour in squash. *J Sports Sci* 2018; 36: 1415–1422.

33. Hair JF, Anderson RE, Tatham RL, et al. *Multivariate data analysis with readings*. 4th ed. Englewood Cliffs, NJ: Prentice-Hall, 1995.

34. Endsley MR. Toward a Theory of Situation Awareness in Dynamic Systems. *Hum Factors J Hum Factors Ergon Soc* 1995; 37: 32–64.

35. Finch CF, Eime RM. The Epidemiology of Squash Injuries. *Int Sport Med J* 2001; 2: 1–11.

36. Okhovatian F, Ezatolahi AH. Sport injuries in squash. *Pakistan J Med Sci* 2009; 25: 413–417.

37. Berson BL, Passoff TL, Nagelberg S, et al. Injury patterns in squash players. *Am J Sports Med* 1978; 6: 323–5.

38. Meyer L, Van Niekerk L, Prinsloo E, et al. Prevalence of musculoskeletal injuries among adolescent squash players in the Western Cape. *South African J Sport Med* 2009; 19: 3–8.

39. Chard MD, Lachmann SM. Racquet sports--patterns of injury presenting to a sports injury clinic. *Br J Sports Med* 1987; 21: 150–3.

40. Berson BL, Rolnick AM, Ramos CG, et al. An epidemiologic study of squash injuries. *Am J Sports Med* 1981; 9: 103–6.

41. Macfarlane DJ, Shanks A. Back injuries in competitive squash players. *J Sports Med Phys Fitness* 1998; 38: 337–43.

42. Atik A, Krilis M, Parker G. Squash(ed): Craniofacial and vertebral injury from collision on squash court. *J Emerg Trauma Shock* 2012; 5: 360–2.

43. Patel ND, Trehan RK. Acute isolated acetabular fracture following a game of

squash: a case report. *J Med Case Rep* 2007; 1: 156.

44. Clavisi O, Finch C. Striking out squash injuries – What is the evidence No Title. *Int J Consum Prod Saf* 1999; 6: 145–157.

FIGURE LEGEND

Figure 1. Comparisons of mean $\dot{V}O2max$ (ml·kg·min^{-1}) obtained from "Squash specific" and treadmill protocols. *SD unavailable.