

1 **ABSTRACT**

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

20

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

22

23 **INTRODUCTION**

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

32

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

42

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

48

## 49 **CHARACTERISTICS OF THE SQUASH GAME**

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

60

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

70

71 In order to determine which physical qualities and energy systems are important  
72 for squash performance, the rally, game and match durations and distances covered

73 must be understood. In senior player's average rally length has been reported to be  
74 21 s with 10 s rest between rallies and a mean of 26 rallies per game for an average  
75 of 351 shots per game. Separate work has observed that game length can range from  
76 194 (03:14 mm:ss) – 1,113 s (18:33 mm:ss) (average 700 s (11:40 mm:ss)) and the  
77 total distance covered in a game ranging from 254 – 1449 m (average 915 m)  
78 depending on the length of game <sup>2</sup> in senior level players. The authors also reported  
79 average match time was 49 min, of which 59.6% of the time was spent with the ball in  
80 play.

81

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

92

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

97

98            These data indicate squash athletes of all ages are required to perform for an  
99 average  $\geq 7$  min per game with numerous rallies played and the duration seems to  
100 increase with age (See Table 1). Previous work has classified what would be  
101 considered “short, medium and long” duration rallies in elite senior athletes. These  
102 thresholds were set by “two national level squash coaches” as follows; short rallies 4  
103 to 12 s, medium rallies 12 to 25 s and long rallies 25 and over <sup>4</sup>. At the elite level, short  
104 rallies seem to be the most common with 40.2% of rallies lasting between 4 and 12 s  
105 in duration. Combined, these data indicate that senior and junior squash athletes may  
106 require both heightened aerobic and anaerobic capabilities for successful  
107 performance.

108

109 *Table 1 about here*

110

## 111 **PHYSIOLOGICAL DEMANDS OF THE SQUASH GAME**

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

118

119            During match play, senior elite performers can achieve a mean intensity in  
120 excess of 85%  $\dot{V}O_{2max}$  and 90% max HR <sup>3</sup>. It has also been suggested in previous  
121 work that squash match play places high demands on the aerobic energy system <sup>5-9</sup>.  
122 This is likely attributable to the repeated high intensity efforts and short rest periods

123 involved with squash match play <sup>3</sup> (Table 1). Due to the aforementioned findings, it is  
124 reasonable to propose that squash athletes require well developed aerobic physical  
125 qualities to sustain performance and meet the required energy demands of match play.

126

127         The average duration of rest intervals between rallies appears to be largely  
128 consistent between junior age groups then increasing at senior level (Table 1). Blood  
129 lactate concentrations data support this view. In fact, Girard et al. (2007) observed  
130 lactate concentrations notably above what would be considered lactate threshold <sup>10</sup>  
131 (~8 mmol·L<sup>-1</sup>) during simulated squash games. This may indicate that during periods  
132 of high intensity work in squash, energy may be derived from anaerobic glycolysis.  
133 This suggestion is supported by the strong correlation between increases in blood  
134 lactate and playing time spent at intensities above 90%  $\dot{V}O_{2max}$  <sup>3</sup>. It is thus reasonable  
135 to propose that anaerobic capacity and lactate tolerance are important physical  
136 qualities in both junior and senior squash athletes. Despite this, there are presently  
137 limited data pertaining to the anaerobic capabilities of squash athletes and much of  
138 the research efforts have been focused on aerobic capacity. Squash athlete's aerobic  
139 capabilities are in fact the most commonly assessed physical quality in the available  
140 body of published literature (see Table 2).

141

142 *Table 2 about here*

143

144         Whilst  $\dot{V}O_{2max}$  or other measures of aerobic capacity have been assessed in  
145 squash athletes on numerous occasions, more recent research has indicated that in  
146 elite players aerobic capacity (estimated via a 20 m shuttle run) is similar between  
147 athletes of different ages and playing standards (senior trained, transition trained and

148 scholarship trained), across a performance program <sup>11</sup>. This may indicate that  $\dot{V}O_{2max}$   
149 and/or a large aerobic capacity is not predictive of playing ability in a homogeneous  
150 group of elite performers. This is perhaps unsurprising, as squash “performance” is  
151 dependent on the technical and tactical capabilities of the athlete and just like many  
152 other racquet sports cannot be explained solely by one physical quality <sup>12-14</sup>.

153

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

162

163         Anaerobic capacity has been also indicated as a relevant physical quality for  
164 squash players and it has been assessed in senior national level squash athletes via  
165 Wingate testing protocols. Mean power outputs of 12.5-13.5 W·kg<sup>-1</sup> and fatigue  
166 indexes of between -10 and -15 W·s<sup>-1</sup> have been reported <sup>8</sup>. The interest in anaerobic  
167 metabolism in squash players stems from the movement characteristics of match play  
168 which require repeated sprint and acceleration efforts <sup>15</sup>. For this reason, it has been  
169 acknowledged in the body of available literature that multiple sprint ability and fatigue  
170 resistance are important physical qualities in squash athletes (Lees, 2003; Sharp,  
171 1998). Senior international level squash athletes have been observed to outperform  
172 their counterparts who are not yet Senior but at a “Transition” level, in a test of repeat

173 sprint ability, requiring athletes to complete 10 “squash specific” sprint movements as  
174 fast as possible with 20 s recovery intervals <sup>11</sup>. Additionally, performance in the  
175 aforementioned multiple sprint test was related to world ranking in both male and  
176 female squash athletes. When combined, these observations indicate that repeated  
177 sprint/acceleration ability may be a physical quality which needs to be addressed with  
178 appropriate training prescriptions as it is likely to be an important performance  
179 determinant.

180

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



198 correlate with performance in a test of change of direction speed <sup>11</sup> which was also  
199 able to differentiate between full and part time squash players.

200

201 Limited data are available on the physical demands of the junior squash game,  
202 however previous work quantified the physiological responses of junior squash  
203 athletes to squash match play and a bespoke squash simulation protocol <sup>20</sup>. It was  
204 reported that during both squash match play and the simulation protocol, junior players  
205 achieved heart rates of  $\sim 200$  beats $\cdot$ min<sup>-1</sup>, blood lactate concentrations of  $\sim 6$  mmol $\cdot$ L<sup>-1</sup>  
206 and high ratings of perceived exertion ( $\sim 18$ ). These data indicate that like senior level  
207 squash anaerobic and high intensity work capacities are important physical qualities  
208 for junior squash athletes.

209

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

222

## 223 **ASSESSMENT OF PHYSICAL QUALITIES IN SQUASH ATHLETES**

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

236

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

248

249 In attempts to “validate” the squash specific protocols researchers have  
250 compared squash athletes  $\dot{V}O_{2max}$  achieved on the squash specific protocols and  
251 more standard incremental treadmill protocols <sup>5,22,23</sup>. Additionally, Wilkinson et al.  
252 (2009b) compared performance on the squash specific and treadmill protocol between  
253 trained squash players and trained runners. Overall it was observed that well trained  
254 male squash players achieved higher  $\dot{V}O_{2max}$  on the squash specific protocols than  
255 the treadmill protocols <sup>22,23</sup>, whereas university level athletes achieved similar  $\dot{V}O_{2max}$   
256 following squash specific and treadmill protocols <sup>5</sup> (Figure 1). It was also observed that  
257 trained squash athletes achieved greater time to exhaustion on the squash specific  
258 protocol than trained runners, although  $\dot{V}O_{2max}$  was similar between athletes groups  
259 <sup>22</sup>.

260

261 *Figure 1 about here*

262

263 Based on these data it would appear that the tests detailed by Girard et  
264 al., Wilkinson et al., and Micklewright and Papadopolou are valid and useable  
265 measures of determining aerobic capacity in squash athletes, however there are some  
266 confounding factors which may limit the applicability of these protocols for accurately  
267 determining  $\dot{V}O_{2max}$  in squash athletes. Firstly, two of the three squash specific  
268 protocols require participants to repeatedly mimic a powerful stroke <sup>22,23</sup>. It is not  
269 unreasonable to suggest that perceptions of what may constitute a powerful stroke  
270 may differ greatly between practitioners administering the test(s). Anecdotal  
271 observations at our institution have indicated that when squash athletes perform the  
272 test described by Girard et al. (2005) a powerful shot is notably different in stage one

273 of the test than during the later stages; this may result in the test being prolonged or  
274 cut short unduly depending on the test administrator's subjective perceptions. There  
275 is potential for these factors to result in an invalid  $\dot{V}O_{2max}$  being attained. It may also  
276 be suggested that including a skill element to the test(s) detracts from the physical  
277 quality being assessed. This is perhaps reflected in the results reported by Wilkinson  
278 et al. (2009b) indicating greater time to exhaustion in squash athletes than runners in  
279 the squash specific protocol. It was suggested that this was attributable to the lack of  
280 skill of the runners in the techniques of squash movement and racket swing. It can be  
281 argued that these techniques are in no way related to aerobic capacity. This may  
282 indicate that performance in the test described by Wilkinson et al. (2009b) is more  
283 reflective of squash ability and/or fitness rather than  $\dot{V}O_{2max}$ . This suggestion is  
284 supported by the fact that performance in the squash specific test was predictive of  
285 player rank, whereas  $\dot{V}O_{2max}$  in squash athletes (predicted via 20 m shuttle run) is not  
286 able to differentiate between playing ability <sup>11</sup>. It is therefore reasonable to suggest  
287 that if the practitioner requires accurate information on an athlete's aerobic capacity to  
288 prescribe intensities for off court based conditioning, a treadmill based protocol may  
289 be the most appropriate choice. However, if the practitioner requires information on  
290 the athlete's ability to sustain movements' specific to squash match play a squash  
291 specific incremental protocol may be appropriate, in particular if an elite player is the  
292 subject of the assessment. A secondary criticism of the of the squash specific  
293 protocols is there is limited data pertaining to the reliability of the testing protocols.  
294 Only Micklewright & Papadopoulou (2008) reported the reliability of time to  
295 exhaustion in the squash specific protocol. In this case time to exhaustion (s) was  
296 observed to be reliable. An additional criticism of the protocols detailed are the  
297 complexity and in the case of Girard et al. (2005) the random nature of the movement

298 patterns. This may not influence the performance of senior and experienced squash  
299 players but in junior players the complex movement patterns may influence test  
300 performance. Presently there are no data on the validity nor reliability of the tests  
301 detailed in junior squash athletes.

302

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

316

317           As previously stated RSI and CMJ have been reported to correlate with multiple  
318 sprint ability and “Transition” athletes have greater RSI’s than “Scholarship” level  
319 athletes (Senior > Transition > Scholarship). These tests are simple in nature and are  
320 generally reliable <sup>11,25</sup>. Additionally they are related to other physical qualities relevant  
321 to squash performance including speed and change of direction speed <sup>26</sup>. However,

322 this is currently insufficient data available to determine if metrics derived from CMJ or  
323 drop jumps are predictive of playing ability in squash athletes.

324

## 325 **PSYCHOLOGICAL DEMANDS**

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

339

340         The use of temporal occlusion and spatial occlusion tasks by both Abernethy  
341 (1990) and Caudrelier et al. (2005) respectively provide some insight into the  
342 perceptual component of decision-making among squash players of differing abilities.  
343 These methods are not without their weaknesses, however. For example, with  
344 temporal occlusion, if time pressure is different to what is required in actual  
345 competition, a different strategy may be used by the decision-maker. Spatial occlusion,  
346 is limited in that the editing work is very time consuming (Williams, Davids, & Williams,

347 1999), and potential for practice and order effects must be accounted for if the same  
348 stimuli need to be presented on repeated trials. In temporal and spatial occlusion  
349 studies, ecological validity may also be questioned.

350

351 Expert-novice differences in squash were also highlighted by Kerr & Cox  
352 (1990). On a specially-devised squash task, significant differences in attentional style  
353 were reported. 'Skilled' players showed good adaptive abilities, were less distracted,  
354 and were better able to focus on the situational demands. 'Average' level squash  
355 players, however, were found to attend more to unimportant aspects of the competitive  
356 situation and lose perspective on important aspects of the unfolding play. Furthermore,  
357 in a follow-up study, trying to understand psychological processes in successful  
358 squash, Kerr & Cox (1991) examined the impact of arousal levels on players of various  
359 ability levels. Results showed that all players approached games with high levels of  
360 arousal, but this was not necessarily associated with high levels of stress or anxiety.  
361 'Winners' showed slightly higher and more stable levels of arousal across games than  
362 'losers' who demonstrated significant decreases in arousal as lack of success  
363 increased, which was associated with increasing stress.

364

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

372 examine emotional regulation as a strategy for dealing with stress or frustration in  
373 squash.

374

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

394

395

396 **INJURY EPIDEMIOLOGY**



397 Like most other sports squash involves a noteworthy risk of sustaining injury.  
398 The primary factors that contribute to injury risk in squash are the physical demands  
399 of the sport; repeated lunging, accelerations and decelerations, changes of direction  
400 <sup>35</sup>.

401

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

409

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

416

417 Squash has been associated with high number of face and eye injuries <sup>35,44</sup>.  
418 However, as all incidences were reported by non-professional junior and senior  
419 athletes it cannot be ascertained if incidences are in any way related to the playing  
420 standard of the athlete. To date there are no studies to examine incidences of eye

421 injuries in elite junior athletes. Table 3 summarizes the methodological approaches  
422 and findings of musculoskeletal injury research in squash.

423

424 *Table 3 about here*

425

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

430

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

438

## 439 **CONCLUSIONS**

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

443

444 Fitness assessment of squash players seems to be employing field based tests  
445 to assess aerobic capacity. While such approach has merit in its face validity and

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

456

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

469

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

478

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

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591

1 **FIGURE LEGEND**

2 **Figure 1.** Comparisons of mean  $\dot{V}O_{2\max}$  ( $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ) obtained from “Squash  
3 specific” and treadmill protocols. \*SD unavailable.