Specific incremental test in elite squash players

O Girard, P Sciberras, M Habrard, P Hot, R Chevalier, G P Millet

Objectives: To compare cardiorespiratory responses between incremental treadmill (non-specific) and field (sport specific) tests in elite squash players.

Methods: Seven elite players (ranked 1 to 25 in their national federation including the World number 1) randomly performed an incremental treadmill test (TT) and a squash specific graded test (ST) to exhaustion. The ST consisted of repeated displacements replicating the game of squash, at increasing speed on the court. In both tests, ventilatory variables and heart rate were determined at the ventilatory threshold, respiratory compensation point, and maximal loads (max).

Results: Heart rate and percentage maximal oxygen uptake (V\textsubscript{O2MAX}) at the ventilatory threshold and respiratory compensation point were not different between the ST and TT, whereas V\textsubscript{O2MAX} was higher in the ST than in the TT (63.6 (3.0) v 54.9 (2.5) ml/kg/min; p<0.001). Time to exhaustion was not different between the ST and TT (1056 (180) v 962 (71) seconds) but correlated with the ranking of the players only in the ST (r = -0.96, p<0.001).

Conclusions: V\textsubscript{O2MAX} values derived from laboratory testing were not relevant for accurately estimating fitness in elite squash players. So the ST may be used as an additional test for determination of training intensity. Improved training advice for prescribing aerobic exercise or perfecting stroke technique may result from these results.

METHODS

Subjects

Seven well trained male squash players (mean (SD) age 24.9 (4.1) years; height 177.0 (5.9) cm; body mass 72.1 (6.1) kg) volunteered to participate in the study. Three were ranked within the top 50 in the PSA (Professional Squash Association) ranking, including the current number 1 and current World champion. The other subjects were ranked between 8 and 25 in their national squash federation. All subjects played in professional squash tournaments. The average time spent in training during the six months preceding the experiments was 22.8 (2.9) hours a week. All participants were fully informed of experimental procedures and possible discomfort associated with the study before giving their written consent to participate.

The study was approved by the ethics committee of the University of Montpellier, France.

Study protocol

All subjects carried out two incremental protocols to exhaustion in randomised order: a treadmill test (non-specific) and a squash graded test (sport specific). Each test consisted of repeated displacements replicating the game of squash at increasing speed on the court. In both tests, ventilatory variables and heart rate were determined at the ventilatory threshold, respiratory compensation point, and maximal loads (max).

Abbreviations: B\textsubscript{paco2}, isocapnic buffering; HHV, hypocapnic hyperventilation; HR, heart rate; RCP, respiratory compensation point; Te, time to exhaustion; V\textsubscript{O2MAX}, maximum oxygen uptake; Vt, tidal volume; VT, ventilatory threshold
was conducted under standard environmental conditions (temperature 25°C, relative humidity ~60%) at the same time of day. Four subjects performed two squash specific tests within one week to evaluate the reliability. This was done by calculating the relative difference and the coefficient of variation between test and retest.

**Experimental procedures**

**Treadmill testing**

The treadmill incremental test to exhaustion (TT) was performed on a motorised treadmill (S2500; Medical Development, Andrezieux, France). It consisted of an initial two minute workload of 10 km/h followed by increases of 1 km/h every two minutes (0% incline). The test ended with voluntary exhaustion of the subjects.

**Field testing**

A squash specific graded test (ST) was developed in which subjects repeated displacements that simulated the game of squash, at increasing speed on a squash court. Each intensity level (a stage) consisted of two bouts of nine shuttle runs (a sequence), performed from a central base to one of six targets located around the court, alternated with 10 seconds of active recovery (fig 1). Each stage was composed of nine displacements, including two forward, three lateral, and four backward courses, performed randomly. When the subject arrived at the target, he was instructed to mime a powerful stroke in the direction of the front wall with his racket under a 40 cm height marker fixed on the side wall, before moving back to the “T” after each drive. Subjects were asked to use the same running technique as in competition. A 10 second rest period was taken between each stage, and a 30 second rest between the end of stage 3 (end of warm up period) and the beginning of stage 4. The duration of the first sequence was 38 seconds; this was progressively decreased by 1.8 seconds (stages 1 to 2 and 2 to 3) and 0.9 second (stages 4 to 17). Movement velocities and directions were controlled by visual and sound feedback from a PC. Briefly, specialised software was used to simultaneously activate a tune and project a picture of a player indicating with his racquet the target to reach. These velocities and sequences of movement were calculated from data collected during official competitions (unpublished data). The test ended when the player failed to reach the target in time (a 1 m delay was permitted) or was no longer able to fulfil the criteria of the test—that is, perform strokes with acceptable technique. To avoid interruption of data collection, players were not allowed to drink during the ST.

**Physiological measurements**

During the TT (CPX/D; MedGraphics, Saint Paul, Minnesota, USA) and ST (K4b2; Cosmed, Rome, Italy), the following gas exchange data were obtained using breath by breath gas analysers calibrated before each test using the manufacturers’ recommendations: VO₂, carbon dioxide production (VCO₂), respiratory exchange ratio (VCO₂/VO₂), minute ventilation (Ve), breathing frequency, and tidal volume. Five
second heart rate (HR) values were recorded with a HR monitor with the athletes wearing a chest belt (S810; Polar, Kempele, Finland). The discrepancies between the two analysers has been shown to be non-significant, and in our laboratory the differences in VO₂ values between the analysers were less than 2%. In both tests (TT and ST), the gas samples were averaged every 30 seconds, and the highest values for VO₂ and HR over 30 seconds were regarded as maximum oxygen uptake (VO₂MAX) and heart rate (HRmax).

### Table 1: Physiological variables in elite squash players corresponding to the ventilatory threshold for the treadmill incremental test to exhaustion (TT) and squash specific graded test (ST) (n = 7)

<table>
<thead>
<tr>
<th>Variable</th>
<th>TT</th>
<th>ST</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (ml/min/kg)</td>
<td>50.5 (4.3)</td>
<td>57.6 (3.9)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>VCO₂ (ml/min/kg)</td>
<td>42.5 (12.8)</td>
<td>57.8 (4.8)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>RER</td>
<td>0.99 (0.07)</td>
<td>1.00 (0.03)</td>
<td>NS</td>
</tr>
<tr>
<td>VT (litres/min)</td>
<td>97.5 (9.1)</td>
<td>106.6 (13.2)</td>
<td>NS</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>179.8 (10.3)</td>
<td>183.8 (10.6)</td>
<td>NS</td>
</tr>
<tr>
<td>BF (breaths/min)</td>
<td>35.9 (5.7)</td>
<td>44.7 (6.7)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>VT (litres)</td>
<td>2.64 (0.51)</td>
<td>2.43 (0.41)</td>
<td>NS</td>
</tr>
<tr>
<td>%VO₂MAX</td>
<td>92.0 (5.6)</td>
<td>90.5 (3.5)</td>
<td>NS</td>
</tr>
<tr>
<td>%HRmax</td>
<td>92.3 (2.6)</td>
<td>95.2 (2.9)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean (SD). VO₂, Oxygen uptake; VCO₂, carbon dioxide production; RER, respiratory exchange ratio; VT, minute ventilation; HR, heart rate; BF, breathing frequency; %VO₂MAX, maximal oxygen uptake; %HRmax, maximal heart rate.

### Table 2: Physiological variables in elite squash players corresponding to the respiratory compensation point for the treadmill incremental test to exhaustion (TT) and squash specific graded test (ST) (n = 7)

<table>
<thead>
<tr>
<th>Variable</th>
<th>TT</th>
<th>ST</th>
<th>p Value</th>
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<tbody>
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<td>VO₂ (ml/min/kg)</td>
<td>50.5 (4.3)</td>
<td>57.6 (3.9)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>VCO₂ (ml/min/kg)</td>
<td>42.5 (12.8)</td>
<td>57.8 (4.8)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>RER</td>
<td>0.99 (0.07)</td>
<td>1.00 (0.03)</td>
<td>NS</td>
</tr>
<tr>
<td>VT (litres/min)</td>
<td>97.5 (9.1)</td>
<td>106.6 (13.2)</td>
<td>NS</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>179.8 (10.3)</td>
<td>183.8 (10.6)</td>
<td>NS</td>
</tr>
<tr>
<td>BF (breaths/min)</td>
<td>35.9 (5.7)</td>
<td>44.7 (6.7)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>VT (litres)</td>
<td>2.64 (0.51)</td>
<td>2.43 (0.41)</td>
<td>NS</td>
</tr>
<tr>
<td>%VO₂MAX</td>
<td>92.0 (5.6)</td>
<td>90.5 (3.5)</td>
<td>NS</td>
</tr>
<tr>
<td>%HRmax</td>
<td>92.3 (2.6)</td>
<td>95.2 (2.9)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean (SD). VO₂, Oxygen uptake; VCO₂, carbon dioxide production; RER, respiratory exchange ratio; VT, minute ventilation; HR, heart rate; BF, breathing frequency; %VO₂MAX, maximal oxygen uptake; %HRmax, maximal heart rate.
frequency were significantly higher in the ST than the TT, whereas no difference was observed in the other variables (tables 1 and 2). It is of interest to note that HR and \%\textsuperscript{VO}_2\textsubscript{MAX} at VT and RCP were not different between the ST and TT. Again, \textsuperscript{VO}_2, \textsuperscript{CO}_2 and breathing frequency measured at maximal loads were significantly higher in the ST than in the TT (table 3). Figure 3 shows \textsuperscript{VO}_2, \textsuperscript{VE}, and HR during the ST in one subject. The competition ranking of the players correlated with \textit{T}e in the ST (\( r = -0.96, p < 0.001 \)) (fig 4), but not in the TT. Mean values of \textsuperscript{VO}_2 (4.7 (3.4) and 3.2 (4.9) (2.8) and 6.0 (2.2) ml/min/kg) and HR (12.0 (8.2) and 13.7 (5.4)) \( r = 0.90; p < 0.05 \) between the biocapnic and HHV phases did not differ between the TT and ST respectively.

**DISCUSSION**

The incremental field test (ST) allowed high maximal \textsuperscript{VO}_2 values to be reached in elite squash players. It appears to be an efficient method for assessing squash performance as it is very specific—that is, it closely replicates movements characteristic of squash—and shows strong correlation with player ranking. However, the TT results (HR and \%\textsuperscript{VO}_2\textsubscript{MAX}) were similar at submaximal intensities (VT and RCP). So the TT appears to be valid for prescribing HR training intensity zones for “on court” squash training.

In ball and racquet sports such as squash, exercise testing on the treadmill—that is, running—is not specific for the muscles involved and is therefore not adequate for evaluating the specific demands of the sport. Steininger and Wodick\textsuperscript{3} were the first to report a positive correlation (\( r = 0.90; p < 0.05 \)) between performance during a specific squash test and ranking of the players. Therefore we designed a squash specific graded test that included technical characteristics (performed on a squash court; similar displacement technique to competition; uncertain direction of motion; simulation of ball hitting) and compared the cardiorespiratory responses with those obtained in an incremental treadmill test.

**Maximal loads**

In both tests, the criteria of \textsuperscript{VO}_2 plateau, respiratory exchange ratio, and HR\textsubscript{max} were satisfied by all subjects. Therefore the

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<th>ST</th>
<th>( p ) Value</th>
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<tr>
<td>\textsuperscript{VO}_2 \textsubscript{ml/min/kg}</td>
<td>54.9 (2.5)</td>
<td>63.6 (3.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>\textsuperscript{CO}_2 \textsubscript{ml/min/kg}</td>
<td>51.4 (15.2)</td>
<td>68.5 (3.5)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>RER</td>
<td>1.10 (0.05)</td>
<td>1.10 (0.06)</td>
<td>NS</td>
</tr>
<tr>
<td>\textsuperscript{VE} \textsubscript{litres/min}</td>
<td>133.9 (12.8)</td>
<td>149.0 (15.2)</td>
<td>NS</td>
</tr>
<tr>
<td>HR \textsubscript{beats/min}</td>
<td>194.8 (8.6)</td>
<td>193.0 (7.9)</td>
<td>NS</td>
</tr>
<tr>
<td>BF \textsubscript{breaths/min}</td>
<td>50.2 (8.7)</td>
<td>51.9 (6.6)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Vt \textsubscript{litres}</td>
<td>2.70 (0.44)</td>
<td>2.72 (0.30)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values are mean (SD).

\textsuperscript{VO}_2, Oxygen uptake; \textsuperscript{CO}_2, carbon dioxide production; RER, respiratory exchange ratio; \textsuperscript{VE}, minute ventilation; HR, heart rate; BF, breathing frequency; Vt, tidal volume.
low frequency of the “plateau phenomenon” in highly skilled athletes could not explain the differences in $V_{O2\,\text{MAX}}$. It is important to note the $V_{O2\,\text{MAX}}$ values determined from the ST. They confirm that high aerobic power is needed for top level competition in squash. This is in agreement with previous findings. The sport specific nature of the ST—that is, competition in squash. This is in agreement with previous. They confirm that high aerobic power is needed for top level competition in squash.

Training applications

Training regimens have to be designed on the basis of physiological data recorded during competition. A large part of an effective training regimen for the competitive squash player will therefore take place on the court involving activities of real match play. It has been estimated that a good male player makes up to 22 strokes a minute, which compares with the final stages of the ST. In this context, one may argue that the ST places a specific demand on the player and would therefore be an appropriate test to be included in a training routine. The intermittent characteristic of the ST also appears to be a strong point. In 20 professional soccer players, individual results in intermittent and continuous testing protocols were compared with actual soccer performance. The authors reported that only the intermittent test results correlated ($r = 0.83$) with match performance—that is, distance covered. In squash, Sharp described the practice of “shadow training” in which a player has to follow an imaginary opponent around the court. Several work periods (30–60 seconds) and work to rest ratios (0.5–2) were used that produced blood lactate concentrations similar to competition values. As $V_{O2}$ and HR are known to be less variable than blood lactate for monitoring fitness changes, the present study shows that HR values at VT, RCP, and $V_{O2\,\text{MAX}}$, which did not differ in the treadmill and on court graded tests, can be used to define HR training intensity zones.

CONCLUSIONS

In summary, this incremental field test allowed high maximal values to be reached in elite squash players. Time to exhaustion correlated strongly with the ranking of the players. Therefore this test seems to be an efficient and very specific (close to the characteristics of squash competition) protocol for assessing performance level. However, incremental treadmill test results (HR and $\%V_{O2\,\text{MAX}}$) were similar at submaximal intensities. Therefore the latter seem to be valid for prescribing HR intensity zones for “on court” squash training. To conclude, field and laboratory tests appear to be complementary and of different use in monitoring fitness changes in elite squash players.
ACKNOWLEDGEMENTS
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