TITLE:
Comparison of two aerobic field tests in young tennis players

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Tennis field tests.

Authors:
Marie-Agnès FARGEAS-GLUCK¹, and Luc LÉGER²

¹Faculté des Sciences du Sport, LAPHAP-EA3813, Université de Poitiers and Faculté des Sciences, département des Sciences du Sport, Université de Limoges, FRANCE

²Département de kinésiologie, Université de Montréal, CANADA

Corresponding author:
Luc LÉGER
Kinésiologie
Université de Montréal
CP 6128 Centre ville
Montréal, Qc
CANADA
H3C 3J7
Tel 514 343 7792
ABSTRACT

COMPARISON OF TWO AEROBIC FIELD TESTS IN YOUNG TENNIS PLAYERS

This study compares the maximal responses of a new aerobic tennis field test, the NAVTEN to a known aerobic field test, often used with young tennis players, i.e. the continuous multistage 20-m shuttle run test (20m SRT). The NAVTEN is an intermittent (1-min/1-min) multistage test with side to side displacements and ball hitting. Ten young elite tennis players aged 12.9±0.3 (Mean±SD) randomly performed both tests and were continuously monitored for heart rate (HR) and oxygen uptake (VO₂) using the Vmax ST (Sensormedics). The 20m SRT and NAVTEN show similar HRpeak (202±6.1 vs. 208±9.5, respectively) and VO₂peak (54.2±5.9 vs. 54.9±6.0 ml kg⁻¹ min⁻¹). Pearson correlations between both tests were 0.88 and 0.92 for VO₂peak and maximal speed, respectively. NAVTEN yielded VO₂peak values that are typical for active subjects of that age and are similar to the 20m SRT supporting its use to measure aerobic fitness of young tennis players in specific and entertaining field conditions. The fact that two thirds of the tennis players achieved a different ranking (± 1 rank) with the NAVTEN and the 20-m SRT, suggests that the NAVTEN may be more specific than the 20-m SRT to assess aerobic fitness of tennis players. From a practical point of view, the NAVTEN test is more specific and pedagogical for young tennis players even though both tests yield similar maximal values.
**Key words:** Specific, Children, 20-m shuttle run test, SRT, Validity, VO$_2$peak, VO$_2$max, Heart rate
INTRODUCTION

This study measured peak VO$_2$ and peak HR of young tennis players during two aerobic field tests, a specific tennis field test, the NAVTEN$^1$ (27) and a semi-specific test, the 20-m Shuttle Run Test (20-m SRT) (19) in order to see if the NAVTEN can elicits maximal values like the known 20-m SRT.

Aerobic fitness is important in tennis. For example, improving the maximal aerobic speed in a forward running field test is inversely related to fatigue and inaccuracy of ball return during an agility 10-m intermittent (30-s/30-s) shuttle test (15). Aerobic fitness is also known to delay fatigue during repeated sprints in other sports (17,18,30). Reported mean VO$_2$max of elite tennis players between 55 to 60 ml kg$^{-1}$ min$^{-1}$ (6,10,11,14,29) also underlines the relative importance of that parameter in tennis.

VO$_2$max is specific to the type of activity and to the muscles mass involved (20, 22). Indirect aerobic field tests are thus useful to measure athletes in a specific environment. The 20-m SRT (19) originally designed to estimate VO$_2$max of school children, is often used for the follow-up of athletes engaged in intermittent running sports with multiple direction changes such as soccer (4; 23). Although counter-validated many times for different purposes (1,7,8,24,31), the 20-m SRT may not be specific enough for the tennis players. The 20-m SRT is a continuous multistage test (no rest between stages) with 180º change in displacement direction every 20 m using conventional forward running. In tennis, typical displacements are much shorter in both duration and distance.

From one side of the court to another, tennis players run 10 m at the most and often only

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$^1$ NAVTEN was designed in France, the word literally means Navette-Tennis or, in English, Shuttle-Tennis.
half of that when the ball is being sent on the same side. The players are running laterally either with shuffle or crossover steps and sometime backwards keeping the head towards the opponent to optimally position themselves to hit the ball back. Furthermore, there are rest intervals between points and every second game. It was previously demonstrated that the energy cost of running increases from forward, backward and lateral motion (32). That further supports the need for a specific aerobic test for tennis players.

The NAVTEN, a specific tennis test was thus designed in 2001 (27). This intermittent multistage test incorporates lateral shuttle displacements while hitting the ball at each end of runs. Using young elite tennis players, the objectives of the study were to see if the NAVTEN, a pedagogical, entertaining and specific tennis test, can elicit maximal responses (VO$_2$ and HR) similar 1) to those typically observed in such subjects and 2) to those observed for the well known semi-specific 20-m SRT.

MATERIAL AND METHODS

Experimental approach to the problem

In order to compare the maximal physiological responses attained for the NAVTEN and the SRT, subjects randomly performed these two tests with at least one day rest in between. Measurements of submaximal and peak heart rate and VO$_2$ were obtained continuously during both tests. Maximal speed and stage were also recorded.

Subjects
Ten young regional elite tennis players (5 males and 5 females) with an average age (± SD) of 12.9±0.3 years, a weight of 40±6 kg, a height of 155±7 cm and a VO$_2$peak of 52.5±5 ml kg$^{-1}$ min$^{-1}$, participated in this study. Subjects use to train 3x 1.5 h per week at the club excluding the weekend competitions. The subjects’ parents signed a written informed consent form. This form, along with all procedures and recruitment material, were approved by the investigators’ Institutional Review Board (IRB).

**Procedures**

*Testing protocols.* Both tests were conducted in June in the morning or afternoon on a GreenSet indoor hard-court (www.greenset.net) made of synthetic resin and classified as category 4 (medium fast court) by the International Tennis Federation (http://www.itftennis.com/technical/equipment/courts/courtlist.asp)

In the 20-m shuttle test, subjects ran back and forth on a 20-m course and adjusted their speed by reaching the 20-m line at the same time a "beep" was emitted. Thus, the speed was increased by 0.5 km h$^{-1}$ every minute from an initial speed of 8.5 km h$^{-1}$ until the subjects could no longer follow the pace (19).

The NAVTEN is an intermittent multistage shuttle run for tennis players with 1-min work/1-min rest ratio). From a central position 1 m behind the baseline, the player is moving slightly forward inside the baseline and towards the right or left side lines to hit balls sent by the coach in a 1.0 x 1.5 x 1.5 m triangle target zone located 1.5 m from the back line along the side line (Fig. 1). With a portable CD player, the coach, 1.5 m behind the net, hand throws the balls directly (no lob) with just enough speed to hit the target zone at a frequency that increases at each 1-min stage with a 1-min rest in between. Only
the coach hears the sound and the player must adjust himself to the thrown balls. The balls are sent in the following sequence: F, B, B, F, F, B, F, F, B, B where F and B represent forehand and backhand strokes. Shots are thus equally split between forehand and backhand and between half-court (2x 5 m) and full-court shuttle displacements (1x 10 m). Between each ball, the player has to come back to the central position 1 m outside the back line. Players were instructed to try to return the balls deep close to either side lines. Using forehand or backhand straight and lifted hit (no easy drop shot). The test stops when the subject can no longer follow the pace or is out of balance or too late to hit the ball three times in a row. The initial speed is either set at 5 or 6 km h$^{-1}$ for subjects below and above 12 years old, respectively, and increases by 0.5 km h$^{-1}$ at each stage thereafter with a 1-min rest between stages. Time between balls is based on an average displacement of 10 m whether the subjects goes back on the same side or the opposite side. For example, at 5 km h$^{-1}$, or 1.389 m s$^{-1}$, the time interval between beep or between balls to cover 10 m, is 7.2 s.” Depending on initial speed, 9 or 10 balls are thrown for stage 1 with an increment of 1 ball each stage, up to 15 balls per stage on the average and 18 balls per stage for the best subjects in this study. A total of 75 balls per test were hit by the average subject and up to 141 for the best fit subjects. A secondary goal of the NAVTEN test is to measure the ability of a player to accurately return balls in defined zones as fatigue increases. But this aspect is not reported in this study.

The kinetics of the 20 m SRT and NAVTEN protocols are drawn side by side in Figure 2. Compared with the 20-m SRT, the NAVTEN is ran at lower speeds because it is harder to do shorter lateral shuttles (5 or 10 m) than longer ones (20 m) at the same speed even with rest between stages.
**Instrumentation.** HR was measured with a Polar heart rate monitor (Polar, Oulu, Finland, www.polar.fi). VO$_2$ was measured with a portable breath-by-breath metabolic system (Vmax ST). The VmaxST system (Sensormedics, Bilthoven, The Netherlands), is identical to the MetaMax3B system (Cortex, Leipzig, Germany), which has been found valid and reliable by (9,25). The VmaxST was set in breath by breath mode (BxB), data was filtered to remove values more than 5 ml kg$^{-1}$ min$^{-1}$ among consecutive values, and average of 6 consecutive BxB values were computed to further dampen irregularities.

**Statistical analyses.**

Reported values are means and standard deviations. A pair t test and regression analyses (first degree Pearson correlation and standard error of the estimate between) and Spearman rank order correlation for non parametric data were used to compare and assess differences between maximal values of HR, VO$_2$ stage and speed for both tests. Level of significance was set at p<0.05.

**RESULTS**

VO$_2$peak and peak heart rate were similar (n.s.) for the 20-m shuttle run and the NAVTEN with values of 54.2±5.9 and 54.9±6.0 ml kg$^{-1}$ min$^{-1}$ and 202±6.1 and 208±9.5 beat min$^{-1}$, respectively (Fig 3). However, and as expected from the shorter and harder shuttles of the NAVTEN, the maximal speed was higher (p<0.01) in the 20-m shuttle run (11.4±0.88 vs. 8.3±1.04 km h$^{-1}$).
Relatively high Pearson correlations between both tests were observed: 0.88 and 0.92 (p<0.001) for VO₂peak and maximal speed, respectively. Standard errors of the estimate were 3.1 ml kg⁻¹ min⁻¹ and 0.43 km h⁻¹, respectively (Fig 4). The mean of absolute individual differences between VO₂peak of each test was 2.2±1.9 ml kg⁻¹ min⁻¹.

**PLACE FIG 3 and FIG 4 AROUND HERE.**

Spearman rank order correlation for non-parametric data yielded similar correlation values to first degree Pearson correlations with values of 0.81 and 0.95 (p<0.05) between both tests for VO₂peak and maximal speed values, respectively. However, comparing rank for the maximal speed achieved in both tests indicates that three out of ten players were 0.5 to 1.5 ranks above for the NAVTEN; three players had the same rank and three players were 1 rank above for the 20-m test and one player was 2 ranks above for the 20-m test (Fig 5). A similar pattern was observed for VO₂peak rankings with three out of ten players achieving a better rank by 2 for the NAVTEN and another player by 1 rank; three players had the same rank and two players were 3 ranks above for the 20-m test and one player 1 rank above for the 20-m test (Fig 5).

**PLACE FIG 5 AROUND HERE.**

**DISCUSSION**

The main purpose of the NAVTEN is to obtain an appropriate index of aerobic fitness while doing amusing, pedagogical and specific tennis drills. One way to answer that
question is to compare maximal VO$_2$ and HR values obtained in the NAVTEN test to those measured with the 20-m SRT. The 20-m SRT have been shown repeatedly to elicit maximal values.(1,7,8,19,24,31).

Indeed, our results show that NAVTEN VO$_2$peak values are well correlated and are similar to the 20-m SRT VO$_2$peak values. Furthermore, VO$_2$peak and HRmax values (54.2±5.9 and 54.9±6.0 ml kg$^{-1}$ min$^{-1}$ and 202±6.1 and 208±9.5 beat min$^{-1}$ (Fig 3) are also among the highest reported in the literature for subjects of that age (3,11,21,28). This indicates that the NAVTEN stimulates the aerobic metabolism to its maximum and that it may be used to assess aerobic fitness of young tennis players. The same conclusion was reached for VO$_2$max attained for other tennis field tests (16, 14).

Although the correlation between NAVTEN and 20-m SRT VO$_2$peak is high ($r=0.88$) corresponding to a coefficient of determination ($r^2$) of 77%, twenty three percent of the variance remains unexplained. This is in line with observed ranking differences between both tests (Fig. 5) and with intra pair absolute difference of 2.2±1.9 ml kg$^{-1}$ min$^{-1}$ indicating some specific response from the players to these tests. This also suggests that the NAVTEN is more tennis specific than the 20-m SRT which is expected from the respective motor tasks required in these two tests.

It is interesting to note that the correlation is slightly better with maximal speeds attained in both tests ($r=0.92$ vs. 0.88 for VO$_2$peak) which may be explained by the measurement error of VO$_2$ that often occurs even though meticulous attention is paid to the calibration (5) and normal variance in mechanical efficiency. In fact we feel more confident using speed rather than measured VO$_2$ to compare the NAVTEN to the 20-m shuttle run or to simply assess the functional maximal aerobic power of subjects on the
field, particularly during growth when the body weight variance and allometric effects on direct VO\(_2\) measure, are large (2, 26). Furthermore and after all, in field conditions these two tests are done without any VO\(_2\) measurement. Equivalence between performance scores is what coaches and athletes are looking for.

In the studies by Smekal et al. (29) and Girard et al (16), maximal responses to tennis specific tests were compared to maximal responses of a treadmill test. They observed VO\(_2\)\(_{\text{max}}\) differences and also reported low correlations (0.6 and 0.58 respectively). That may be due to the low specificity of the treadmill test. In support to that explanation, Ferrauti et al. (14) observed higher correlations between their Hit & Turn tennis test and a Ball Machine test than between their Hit & Turn and the Treadmill test (0.81 vs. 0.66 for performance score and 0.96 vs. 0.80 for VO\(_2\)\(_{\text{peak}}\)).

This also questions the use of a treadmill test to validate a tennis specific test when the goal is to assess aerobic fitness while performing tennis drills or playing tennis which is different goal than predicting treadmill VO\(_2\)\(_{\text{max}}\) using a tennis field test. VO\(_2\) peak values obtained during the field test itself using a portable system seems to be a better criterion. In this regard, Ferrauti et al (14) used VO\(_2\)\(_{\text{peak}}\) measured during their tennis specific Hit & Turn test to develop regressions to predict VO\(_2\)\(_{\text{peak}}\) instead of their treadmill VO\(_2\)\(_{\text{peak}}\) values.

Even though NAVTEN has a 1-min rest between stages and the same speed increment of 0.5 km h\(^{-1}\) per stage, subjects achieved higher speed during the 20-m shuttle run (11.4 vs. 8.3 km h\(^{-1}\) for approximately the same VO\(_2\)\(_{\text{peak}}\), Fig. 3). Possible explanations are
numerous: 1) at the same average running speed, the accelerations and decelerations due to direction changes are more frequent and more important for the 5-m or 10-m shuttles of the NAVTEN than for the 20-m SRT, 2) players are also running laterally with either sliding or crossing steps during the NAVTEN compared to forward running during the SRT and 3) in the NAVTEN, the players are not only running but are also hitting the ball at each end of the course. These results are consistent with the ones of Williford et al. (32) who found that the energy cost of running increases from forward, backward and lateral motion.

To our knowledge, three other specific tennis field tests have been developed over the last decade (14,16 and 29). In the Smekal’s tennis test (29), players are running laterally to hit the ball at a certain frequency starting at 12 balls per minute with an increase of 2 balls per minute every 3-min stages. Thus as opposed to the NAVTEN, there is no rest between stages and they last much longer (3 min vs. 1 min). Based on Smekal’s Figure 1 (29), subjects appear to run laterally back and forth on the full width of the court (8.23m) and, at 12 shots min⁻¹ at stage 1 with 2 shots min⁻¹ increments per stage, that corresponds approximately to an average initial speed of 6.0 km h⁻¹ with speed increments of 1.0 km h⁻¹ per 3-min stage or 0.33 km h⁻¹ per minute. Considering the 1-min rest between NAVTEN 1-min stages, the “per minute” incremental speed rate (0.25 km h⁻¹ per min) is very close to the Smekal tennis field test. As it was the case for NAVTEN, it is expected that this test will be harder than the 20-m shuttle run since the shuttles are shorter (10 m) and imply lateral motion and hitting the ball. Furthermore and since there is no rest between stages, the test may be more difficult and less specific than the NAVTEN.
In Girard’s tennis test (16), the stage duration initially set at 40.5 s, decreases by 0.8 s per stage which means that the average stage speed increased exponentially contrary to most incremental tests. There is a 15-s rest between stages and each stage includes 7 short shuttle runs split in 2 offensive forward run (~3.5 m), 3 lateral runs (~4.15 m) and 2 defensive backward run (~3 m) with ball stroke fake at the end of the run from a central position behind the baseline. Speed and motion directions are set with a computer using a, specialized software to simultaneously activate a tune and project a picture of a player moving towards the target. The number, length and variety of displacements used in this test make it very specific but faking a ball stroke, using an exponential incrementation of speed and a sophisticated PC software to set the pace make the test less interesting.

In another recent tennis field test, Ferrauti et al (14) introduced an interesting tennis specific test, the Hit & Turn test. From the central baseline position, the player runs forward to hit the ball on the side of the double court line (stroke simulation over a cone or ball pendulum), comes back to the central position using sidesteps and does the same thing toward the other side of the court alternating forehand and backhand on a 11 meter shuttle course. With a CD player, the time between strokes is 4.9 s at level 1 and decreases by 0.1 s at each other level. Each level lasts between 47 and 50 s with 12 to 16 strokes from level 1 to level 20. A 10 s rest is inserted after each level except for a 20-s rest after every fourth level. These rest intervals are closer to the game of tennis than the ones seen in the NAVTEN test. In terms of displacement speed, it increases exponentially from 8.08 to 13.20 km h$^{-1}$ from level to level as in Girard’s protocol (16) but as opposed
to the NAVTEN and Smekal’s protocol (29). As it was the case for the NAVTEN, Ferrauti et al. (14) reported similar VO₂max values between their tennis specific Hit & Turn test and a Ball Machine criterion test. Correlations between both tests were also similar (0.81 and 0.96 for performance and VO₂max, respectively vs. 0.92 and 0.88).

It would certainly be interesting to compare these four tennis specific tests either with direct VO₂ measures to see if they all solicit the aerobic metabolism to its maximum or to the same extend or solely with the performance score to know their equivalences. Regarding tennis field tests, Fernandez-Fernandez (13) recently proposed a few other interesting avenues but their study only focused on submaximal responses while playing on different types of surface.

In order to validate a tennis specific field test to assess aerobic fitness, we have to 1) demonstrate that maximal values can be reached during that test and 2) develop regressions to predict VO₂peak with minimal random error. That second issue still has to be investigated with the NAVTEN since we did not have enough subjects to get a reliable regression. Smekal et al. (29) and Girard et al. (16) did not have enough subjects either to fulfill these conditions and did not propose prediction equations either. Ferrauti et al. (14) are probably the first to have developed age-gender specific regressions to predict VO₂peak from the performance achieved during the Hit & Turn tennis test. Although the total number of subjects is high (n=98), the number of subjects for each age-gender regression is much lower (13-20 with an average of 16). This yielded low and disparate r values (0.32-0.78). Also the absolute intra pair differences were sometimes quite large.
For example, it was $5.2 ± 4.5 \text{ ml kg}^{-1} \text{ min}^{-1}$ for the boys under 16 which implies
differences of up to $±10 \text{ ml kg}^{-1} \text{ min}^{-1}$ (95% confidence interval= $±2x4.5$). It remains to
be demonstrated that lower random prediction errors could be obtained with larger
samples sizes with the NAVTEN or any of the other tennis specific protocol proposed by
Smekal et al. (29), Girard et al. (16) and Ferrauti et al. (14).

Whether we consider the NAVTEN or any other tennis field test to determine aerobic
fitness of tennis players in specific conditions, we must be aware of limitations of such
tests and understand the inescapable need of standardization in evaluating athletes. As
pointed out by some (12), the hand throwing of the ball in the NAVTEN or the use of
throwing machine with regular pattern and speed may not exactly duplicate what is
happening in tennis but in order to test players with rigor, reliability and discrimination, a
middle ground has to be found between full specificity and standardization. In this
regard, we found that with a little practice, the coaches always manage to throw the balls
(about 75 balls per test in this study) within the $1.5 \times 1.5 \times 1.0 \text{ m}$ target triangle located at
10 m from him. That was also confirmed in situations where 6 adults were tested
consecutively with 150 balls per test on the average. The use of an educator instead of a
throwing machine is not a problem in terms of accuracy and reliability of the thrown
balls. Wherever the ball falls within the triangle, the ball is well within the reach of the
player with his racquet. We also feel that random inconsistencies about the exact ball
placement or the type of rebound compensate each other over the whole stage, from stage
to stage, from test to test or from one subject to another. With a human thrower, the test is
more accessible than with an automatic throwing machine. Also, unless one has access to
a very sophisticated automatic throwing system, it would be impossible to randomly
distribute the ball between left and right triangle and between long displacements (side to
side) and half displacements (center to side). The wear and tear of the balls (pressure
decrease) is also a possible factor affecting the validity and reliability of the test.
The power with which the players hit the ball affects the energy cost and may also affect
the result of the test (maximal stage, speed or predicted VO$_2$peak). Our results are based
on a specific age group and other studies on other and larger gender-age groups are
necessary in order to properly predict VO$_2$peak with enough confidence and to widely use
the test. Similarly, the reliability of the test also has to be demonstrated. We also have to
determine the usefulness of assessing the accuracy of ball return with increasing fatigue
state, an attribute of the test that we did not record in this study. Keeping these limitations
in mind, the fact that the NAVTEN enabled maximal responses in young tennis players is
encouraging for future studies.

**PRACTICAL APPLICATIONS**

This study has demonstrated the feasibility of the NAVTEN in young tennis players and
its capability to solicit the aerobic power to its maximum. Compared to the semi-specific
20-m SRT and based on the ranking disparities between the two tests and also on the type
of displacements and movements, the NAVTEN appears more pedagogic and more
specific to tennis than the 20m SRT but only one person could be tested at the same time.
Beginners may be best tested by the 20m SRT and the elite players, by the NAVTEN.
Still the NAVTEN is a field test and does not require the sophisticated equipment and
technical personal for its administration. The NAVTEN is thus readily accessible to the
coaches. Further studies are however necessary to develop regressions to predict 
VO$_2$peak and to demonstrate its reliability with various age groups before using the 
NAVTEN on a large scale.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Pierre Le Grill, Tennis Technical Specialist of the 
Limousin Region, Mr. Philippe Autier, director of the Limousin Tennis League as well as 
coaches Stéphane Dal Soglio; Benoît Fredon; Cyril Picat who facilitated our work, the 
Isle Tennis club and their athletes and facilities, Eric Trezel, our computer specialist, for 
the electronic recording of the NAVTEN and Professor Benoit Dugué for his precious 
advices. The authors have no undisclosed professional relationships with companies or 
manufacturers that would benefit from the results of this study. The results of this study 
do not constitute endorsement of the product by the authors or the National Strength and 
Conditioning Association.

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Legends of figures

Figure 1. NAVTEN protocol. From a central position 0.5 m behind the back line, the player is moving laterally and forward to hit the ball being sent to him by the coach randomly to the left or right side in the target zone. With portable CD player, the coach sends the balls at a frequency that increases at each 1-min stage with a 1-min rest in between. Upper part: Displacements of the player and ball on the court. Lower part: Point system to measure accuracy of returned ball in increasing fatigue state.

Figure 2. Speed as a function of time in the NAVTEN and 20-m shuttle run test.

Figure 3. Peak values of stage, speed, heart rate and VO$_2$ for the NAVTEN and 20-m shuttle run test.

Figure 4. VO$_2$ peak (top) and maximal speed (bottom) regressions and correlations between NAVTEN and the 20-m shuttle run.

Figure 5. Individual ranks for VO$_2$ peak (top) and maximal speed (bottom) in the 20-m SRT and the NAVTEN.
Coach with
ball basket

Target ball zone

Player’s central position and player’s path (10 m)

BALL PATH

Net

8.23 m

8.885 m
PROTOCOLS

20-m SHUTTLE

NAVTEN: 2x5 or 10 m lateral shuttles

SPEED (km h\(^{-1}\))

TIME (min)
\[ y = 0.8942x + 6.4596 \]
\[ R = 0.88, \text{ Syx } = 3.1 \]

\[ y = 1.0995x - 4.2324 \]
\[ R = 0.92, \text{ Syx } = 0.43 \]