REVIEW

Health benefits for veteran (senior) tennis players

B L Marks

Br J Sports Med 2006;**40**:469–476. doi: 10.1136/bjsm.2005.024877

To explore the health benefits of tennis participation in veteran players and to identify future research needs, an electronic literature search using the Ovid (Cinhal, Medline, Sport Discus) library databases from 1966–2005 was undertaken. Specific search words were employed related to tennis, aging, exercise, health, and the psychophysiological systems. Public access internet search engines were also used (Google, PubMed), along with non-electronic searches of library holdings. There is ample research documenting the health benefits of regular participation in moderately intense aerobic activity. There have been research studies targeting veteran tennis players but most were cross sectional. No tennis related study successfully eliminated all confounding cross training effects. The health of veteran tennis players is improved by enhanced aerobic capacity, greater bone densities in specific regions, lower body fat, greater strength, and maintained reaction time performance in comparison with age matched but less active controls. However, it is not certain whether tennis alone can be a sole contributor to these physiological variables. Well controlled longitudinal research among elite veteran and novice older adult players is needed.

Correspondence to: Dr Bonita L Marks, Department of Exercise and Sport Science, Fetzer Gym, Campus Box 8700, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-8700, USA; marks@email.unc.edu

Accepted 14 December 2005

Decreased physical activity and declining health are often associated with the aging process, yet it is not uncommon to see veteran tennis players well into their eighth decade of life engaged in competitive match play. Can this vigour be attributed, at least in part, to their tennis participation? The tennis media and professional tennis organisations often espouse the health benefits of tennis participation, but are those proclamations based upon empirically driven experimental interventions, epidemiological associations, or simply logical deductions? Competitive and recreational tennis players routinely engage not only in tennis, but also often augment their game with off-court training regimens (cross training) such as resistance training, running, and yoga.

It has been well established that regular physical activity and endurance exercise in sufficient doses (frequency, duration, intensity factors) improves psychophysiological health, decreases health risks associated with various chronic disease conditions, and reduces premature death.[1–4] More specifically, sufficient participation in regular physical activity or exercise has been shown to result in decreased cardiovascular work at any given submaximal exercise intensity, higher aerobic capacity, lower resting heart rate and blood pressure responses, increased mitochondrial and skeletal capillary densities, increased tolerance to lactic acid production, improved insulin sensitivity, improved lipoprotein profile, and reduced blood platelet aggregation and adhesiveness.[1 2] Furthermore, research suggests that both aerobic and anaerobic weight bearing activities may positively affect skeletal integrity and lessen osteoporotic risk.[5 6] Health benefits such as those listed above are critical for successful aging, especially at a time when there is a global increase in life expectancy and an increased demand on healthcare worldwide.[7]

Thus the focus of this review was to differentiate the health benefits attributed to tennis participation from those of general exercise in veteran (or senior) tennis players.

AGING AND THE VETERAN (SENIOR) PLAYER

In Europe and Canada, the term ''veteran'' tennis player refers to the male player aged 45+ years and the female player aged 40+ years.[8] Rather than using the term ''veteran'', the classification term ''senior'' is used in the USA, and this category is applied to all players (male and female) aged 50+ years. However, scientific aging research often refers to the population in terms of ''life stages'' and assigns an ''adult'' as 25–44 years of age, a ''middle aged'' adult as 45–64 years of age, a ''young old'' adult as 65–74 years of age, an ''old'' adult as 75–84 years of age, and an ''old old'' adult as 85–99 years of age.[9] As such, some of the ''veteran/senior'' tennis research studies reviewed for this paper, by virtue of the subjects' ages, may not be considered bona fide ''aged'' studies. Hence, for this paper, all of the discussed research should be viewed as studies exploring the impact of tennis on the aging *process*.

Aging is often associated with a multitude of waning factors collectively termed ''functional decline''. These include: decreased aerobic function (lower maximum heart rate and cardiac output, reduced lung compliance, higher residual volumes, lower vital capacities), increased vascular resistance contributing to hypertension and atherosclerosis, a reduction in muscle mass and strength with a concurrent increase in body fat, decreased bone mass, stiffer connective tissue giving rise to loss of flexibility and arthritic conditions as well as proneness to joint injuries, and a decline in cognitive function.[9–12] However, there is evidence that many of these aging outcomes are not truly a function of aging but rather are related to physical inactivity and therefore amendable to sufficient dosages of physical activity.[9–11 13] Tennis has long been hailed as a lifetime sport with both physiological and psychosocial benefits. The following sections will explore the corroborating evidence for these claims.

DECREASED MORTALITY: EPIDEMIOLOGICAL EVIDENCE

There have been many epidemiological studies investigating the relation between sedentary lifestyles and health; however, the most notable research is probably the Harvard Alumni study reporting the results of 16 000 male alumni for the past 20 years.[3] In the first of many reports to follow, it was stated that men who regularly expended between 500 to 3500 kcal weekly in physical activity showed a reduced incidence of myocardial infarcts and sudden death when compared with their more sedentary counterparts. The following year, the MRFIT trial reported that even modest amounts of exercise were associated with a reduced risk of dying from heart disease.[14] In 1988, the Lipid Research Clinics Study reported that unfit men were nine times more likely to die from a cardiovascular event than moderately and highly fit men.[15] Finally in 1989, women were included in physical activity studies and the Aerobics Center Longitudinal Study confirmed that sedentary less fit women were at as much risk for cardiovascular disease related deaths as men.[16]

In 1993, Paffenbarger and colleagues released an update to the original Harvard alumni work providing detailed information on the quantity and quality of physical activity needed to reduce the risk of mortality.[17 18] The overall conclusion was that participation in ''moderately vigorous'' sports activities, regardless of whether it was lifelong participation or newly acquired, was independently associated with a lower risk of mortality in middle aged to older men ($n = 10\,269$, 45 to 84 years old). Engaging in a ''moderately vigorous'' sports activity (minimally 4.5 METs, where 1 MET $\approx$ 3.5 ml. $kg^{-1}.min^{-1}$ of oxygen consumed) was associated with a 23% reduction in mortality risk ($p = 0.015$). More detailed analyses showed that those who reported participating in three or more hours of moderately vigorous sports weekly reduced their all cause mortality risk by 50% and their coronary heart disease death risk by 51%. Furthermore, those alumni who not only increased their weekly physical activity kcal to 2000+ but did so through moderately vigorous activity had a 41% lower risk of death from heart disease ($p = 0.04$).

That follow up report was embraced by the tennis community and used to promote the health benefits of tennis through the following racquet sports industry news release which is still in circulation[19]:

> ''In a study of more than 10 000 men who played tennis 3 times a week it was found that risk from death from any cause was reduced by 50%. In addition, when scientifically tested, tennis players who played tennis at least 3 hr a week had a 41% lower risk of death from coronary heart disease''.

Contrary to the tennis media release, the research paper did not mention how many subjects participated in tennis; it only commented that tennis was one of many reported vigorous sport activities. In addition, the study stated that only 25% (or 4000) of all respondents met the above mentioned activity participation quota for the mortality benefits. Paffenbarger *et al*[17] stated that it is difficult to make determinations regarding the intensity of the exercise participation and warned that one should not interpret the results as causal. Thus the extrapolated relation drawn between tennis and mortality risk should be viewed cautiously.

According to the scoring instructions in the Paffenbarger survey,[20] tennis participation was scored as 7 METs, with no differentiation between styles of play (that is, singles, doubles, triples, drills). Further, the only directives provided to the subject for estimating sports intensity were vigorous activity listed as ''strenuous sports'' and moderate activity listed as ''light sports''. Thus it is possible that the tennis intensity component was overestimated, either by the subject, the data coder, or both. These problems aside, tennis participation has been reported to range from 3 to 7 METs, from very light triples and doubles play to intense competitive match situations.[21] As long as the veteran tennis player did not participate in triples or non-competitive doubles play, his intensity could minimally qualify as ''moderately vigorous'' (4.5+ METs).

A 1987 study conducted by Morgans *et al*[22] indicated that only singles competition, and not doubles, would be sufficient to meet heart rate intensity guidelines to promote aerobic fitness based upon attaining at least 60% of the maximum heart rate reserve (HRR), where $HRR = ([HRmax - HRrest] \times \%\ intensity) + HRrest$. A more recent report has suggested that health benefits may be accrued at lower intensities (40% HRR).[11] These new recommendations open the door for attaining health benefits from doubles participation.

Furthermore, a small cross sectional study comparing elite male tennis players (40 to 60+ years of age) with active age matched controls reported that male tennis players did in fact expend more energy weekly during recreation, work, and exercise, engaged in more vigorous activity, and consequently scored significantly higher on the Yale Physical Activity Survey (YPAS).[23] Thus it may be reasonable to extrapolate the mortality risk findings from this research providing that one knows the intensity requirement for the level of tennis play.

PSYCHOPHYSIOLOGICAL BENEFITS

There is a preponderance of cross sectional evidence lending support to the notion of greater physiological fitness and improved mental health in tennis players across the lifespan in comparison with less active controls. However, no longitudinal study tracking junior players into their veteran years has been reported and none was designed to look specifically at tennis minus the confounding factors of cross training, genetics, and nutrition. Often, control groups and statistical analyses were not ideal. With these limitations acknowledged, a few notable age specific cross sectional studies will be highlighted to build the premise for potential health benefits incurred by the veteran tennis player.

Junior players

In junior players, research has shown that regular tennis training is associated with higher aerobic capacities,[24] quicker reaction times,[25] and greater knee extension strength[24] than in their sedentary peers. Junior players also reported being more physically active when compared with their non-tennis peers throughout the entire year.[25] Body fat percentages tended to be within normative values for their age.[29] Interestingly, lower back and internal shoulder rotation flexibility was less in junior tennis players than in juniors engaged in other athletic endeavours.[26 27]

Younger adult players

As with the junior players, enhanced aerobic capacities (between 50 and 65 ml.$kg^{-1}.min^{-1}$) have been reported in college aged players.[28–31] Kuels *et al*[29] suggested that greater heart volumes (20–30%) accounted for the improved aerobic capacities in the college tennis players compared with their untrained counterparts. Lower body fat percentages in competitive men (18–34 years old) have also been reported (8% mean, ranging from 3.6% to 18.8%).[29 32] However, these lower body fat ranges are unlikely to result from competitive play and practice alone, but also from nutrition and genetic factors. Body fat has not been the only body composition concern; bone density has also been investigated. In the early 1980s, female college tennis players were shown not only to have greater bone mineral density in their dominant playing arm (16% greater) but also to have increased lumbar vertebral density in comparison with collegiate swimmers and non-athletic controls.[33] Similarly, Haapasalo *et al* reported significantly greater bone mineral densities in the dominant forearms of both male and female players (10 to 34 years old) when compared with non-tennis-playing controls (16 to 37 years old).[34]

Veteran players

Research studies involving veteran players mirror the findings in junior and younger adult tennis players. The physical fitness of veteran players is definitely better than in their age matched sedentary peers and, at times, comparable to the younger players as well.

One of the earliest comprehensive tennis profiling studies was conducted by Vodak *et al* in 1980.[35] That study showed that middle aged tennis players (31 to 55 years old) had above average aerobic capacities, low resting heart rates and blood pressures, a lower percentage of body fat, and higher dominant grip strengths than age matched active (non-tennis-playing) control subjects.

Aerobic adaptations

Maximum oxygen consumption ($\dot{V}O_2max$) values of male tennis players in a study by Vodak *et al*[35] averaged 50 ml.kg^{-1}.min^{-1}, whereas in female players it averaged 44 ml.kg^{-1}.min^{-1}. Normative $\dot{V}O_2max$ values for sedentary adults range between 30 and 40 ml.kg^{-1}.min^{-1}. Furthermore, the resting heart rates (RHR in beats/min) of this middle aged tennis sample also reflected an endurance trained state (men: 54 beats/min; women: 61 beats/min) as opposed to a sedentary value of 75 to 90 beats/min. However, the study's conclusion was non-committal over whether tennis was the sole determinant of this aerobic outcome. In contrast to the study of Vodak *et al*,[35] research reported by Swank *et al*[23] found no resting heart rate or resting blood pressure differences between elite veteran tennis players and age matched moderately active controls, but estimated that aerobic fitness was significantly greater in the tennis players. Although considered ''elite'' tennis players, the use of the Yale Physical Activity Survey resulted in them being categorised as only ''moderately'' active. Even so, the veteran tennis players' activity scores and estimated weekly energy expenditures were found to be significantly higher than in the control group.[23]

Vigorous exercise results in an increased blood flow to the working muscle along with greater ability to extract oxygen into the tissues. This peripheral adaptation has been attributed to the ability of the skeletal muscle vasculature to vasodilate according to need during maximum exercise. Research by Sinoway *et al* investigated whether tennis would enhance peripheral blood flow to the working forearm in veteran tennis players compared with a control group.[36] The veteran players (n = 6, 33 to 48 years old) had a tennis history of playing for at least the previous nine years, five hours a week; most held a national tennis ranking of 4.5. The control group (n = 6, 25 to 52 years old) did not play tennis; half were completely sedentary and the other half jogged. Aerobic capacities were not significantly different between the two groups (mean: 46 ml.kg^{-1}.min^{-1}). In an effort to evaluate peripheral vascular adaptation to training, vasodilatation was compared in both the dominant and the non-dominant arms. Both the tennis players and the control subjects had greater forearm circumferences and greater static grip strength on their dominant side, but the results were not significantly different between the two groups, even though the tennis players' grip strength in the dominant hand was slightly greater (52 kg *v* 56 kg, respectively). Despite this, the results of the venous plethysmography measurements showed a 42% increase in blood flow during maximum hand grip ischaemic exercise to the dominant forearm in tennis players whereas no differences in blood flow were noted between the control subjects' dominant versus non-dominant forearms. The conclusion was that the tennis players were better able to deliver and utilise oxygen in the working forearm muscles than the non-tennis-playing controls, and this effect was not the result of aerobic conditioning or forearm dominance.

With aging, it is generally believed that the heart's efficiency decreases, resulting in lower achievable maximum heart rates and work capacities.[11] This suggests that tennis competition could present a greater cardiovascular strain upon veteran players.

Research investigating heart rate responses during a tennis match which pitted young female competitive tennis players (15 to 30 years old) against middle aged veteran female tennis players (40 to 51 years old) seems to confirm this.[37] While the younger players' mean heart rate intensity attained a steady state during a two hour match (30 min heart rate = 157 beats/min; end of match heart rate = 156 beats/min), the veteran players' heart rates continued to rise as the match progressed (30 min heart rate = 151 beats/min; end of match heart rate = 161 beats/min). With lower achievable maximum heart rates and lower aerobic capacities (young, 47.2 ml.kg^{-1}.min^{-1} *v* veteran, 39.8 ml.kg^{-1}.min^{-1}), the veteran players competed at a greater relative exercise intensity than the younger players (92% *v* 81% of maximum heart rate, respectively). Although the veteran players' maximum heart rates and $\dot{V}O_2max$ responses were much greater than their age predicted ''normative'' maximums, their maximum attained values were nevertheless lower than in their younger competitors. This research also determined that lactic acid accumulation was not a factor for fatigue, as neither the young nor the old had significant lactate accumulation (1.8 mmol/l). Thus lactate accumulation was ruled out as a limiting factor to the oxygen transport system for the veteran players who reported stopping because of exhaustion. Rather, the scientists proposed decreased kinetics for heart rate recovery as the possible fatigue producing mechanism.[37]

Hence, while it is apparent that the cardiovascular system becomes less efficient with aging, some tennis research suggests that the peripheral rather than the central component of the oxygen transport system may play a more crucial role in maintaining aerobic fitness and attenuating cardiovascular decline in veteran tennis players.

Thermoregulation

A related issue to cardiovascular control is thermoregulation. Aging per se has not been shown to be the cause of an increased core temperature in response to heat stress in older adults. Rather, increased core temperature is caused by inadequate heat acclimatisation (attenuated thirst and fluid conservation mechanisms) coupled with a physically deconditioned state.[13 38–40] Maintenance of cardiac output must then be achieved by a rise in heart rate response. While some thermoregulatory research has shown that exercising in the heat can result in a reduction of plasma volume in older adults,[38] other research has suggested that older and younger men do not differ in their thermoregulatory responses.[39]

The study conducted by Therminarias *et al*[37] which compared heart rate responses when playing tennis during the summer in a ''well ventilated'' gymnasium for two hours did not result in statistically different thermal responses between the veteran (38.6℃) and younger adult players (38.1℃). Most of the players did not experience unusual heat stress symptoms, even though the combined ambient temperature (27° to 28℃) plus 70% humidity factor yielded a heat index warning of moderate to borderline high.[11] However, a core temperature exceeding 38.3℃ is considered hyperthermic and therefore clinically relevant. The core temperatures of six of the 10 younger players and seven of the 10 veteran players met or exceeded this criterion. Of these 13 hyperthermic players, three veteran players quit playing from exhaustion. Two of those players' core temperatures reached 38.8℃ and the third player's core temperature was 40.4℃. No younger player had a core temperature above 38.5℃. Two papers were published from this research population. In the first,[37] the investigators did not discuss a hyperthermic, dehydrated condition as a potential factor in the veteran players' exhaustion. Rather, they surmised that exhaustion was caused by the increased heart rate response from either a lower aerobic capacity or a heightened emotional stress response to competition, or both. Neither hydration factors nor the environmental heat index were mentioned as potential mediators for the increased heart rate response.

A paper published a year later provided the critical hormonal and metabolic data collected during that study. Catecholamine responses were not markedly different between the young and veteran players. Hence it is unlikely that ''stress'' was the cause of the raised heart rates seen in the veteran players. It was thereby acknowledged that a decrease in plasma volume contributed to the cardiovascular strain demonstrated in the veteran players.[41] This secondary analysis hypothesised that differences in the shifting of fluid volumes from the intravascular to the interstitial or intracellular compartments most probably occurred in the veteran players and was the explanation for the decreased plasma volume. Environment issues were discounted (that is, training and heat acclimatisation were similar between the groups), as was inadequate hydration (younger players did not experience a plasma volume fall despite similar fluid intakes, urine outputs, and weight loss). Thus, veteran tennis players need at a minimum to follow the same established hydration guidelines as younger players, that is to drink 200–400 ml electrolyte based fluids every 15 to 20 minutes whether they feel thirsty or not. A study exclusively investigating older veteran players' (65+ years) physiological responses to the new sports drinks could provide more detailed information on their hydration response.

Lipoprotein status

Raised cholesterol (C) and triglyceride levels are known risk factors for coronary artery disease. It is also acknowledged that physical activity in sufficient dose improves the lipid profile independently of other lifestyle changes such as dietary modification and cessation of smoking.[11] Three older studies were found that addressed the lipoprotein status of veteran tennis players in a limited fashion. Two simply provided a descriptive lipoprotein profile,[23 42] while the other was a six week training study using two different training modes (skill based *v* running based).[43] Vodak *et al*[42] reported that 25 male tennis players (mean age 42 years; nine years playing history) had better lipid profiles than matched sedentary controls, but both groups still had values that would be considered ''somewhat protective'' (high density lipoprotein, HDL-C, 57.8 *v* 46.2 mg/dl, respectively). Very low density lipoprotein subfractions (VLDL-C) and triglycerides were also significantly lower in the tennis players; however, total cholesterol (TC) and LDL-C concentrations were similar to the controls. On the other hand, Swank *et al*[23] reported mixed results with no significant differences in lipid profiles of an older sample of elite male veteran players (aged 40–60+ years) versus less active controls. According to the 2002 report from the National Cholesterol Education Program,[44] desirable total cholesterol levels should be below 200 mg/dl (5.18 mmol/l) with the subfraction LDL-C level being below 130 mg/dl (3.37 mmol/l). Further, the TC/HDL-C ratio should be less than 4.5. Only the younger veterans and controls (aged 40 to 59 years) met these three recommendations.[23] As in the study by Vodak *et al*,[42] these older subjects also had ''somewhat protective'' HDL-C levels (above 40 mg/dl).[23]

The third study evaluated the effects a six week running–intensive tennis training (RIT) program on lipid response in veteran players aged 43 to 47 years old.[43] The RIT subjects (n = 22 compliant) participated in 90 minute sessions three days a week, while the controls (n = 16) continued with their usual (tennis) habits. Although there were minor trends towards healthful lipid profile changes, no lipid change was significantly different before and after testing, nor were the lipoprotein profiles different between the controls and the RIT group. However, the limited but potentially promising changes were independent of body mass loss (the RIT group lost 1 kg; no significant weight change was noted for the control group).

Based upon the above studies, it is not clear whether tennis participation alone is sufficient for achieving or maintaining a healthy lipoprotein profile in the veteran player.

Body composition and musculoskeletal factors

Aging is often associated with two disease processes: sarcopenia and osteoporosis. Sarcopenia, the wasting away of muscle tissue, is associated with general weakness, decreased physical activity, and decreased health. If left unchecked, sarcopenia can lead to lack of independence, frailty, and increased fracture risk from falls.[13] It has been suggested that 25% of the population has some degree of sarcopenia by the age of 70, with the prevalence increasing to 50% by age 80. This muscle wasting is non-gender-specific, with both men and women experiencing a 40% loss in muscle tissue and strength by their eighth decade.[45 46] Concurrent with muscle mass loss is a 15% decline in metabolic rate by age 80, resulting in a net body fat gain of 10–20%.[47] In addition, menopause has been cited as an independent factor contributing to a woman's declining metabolic rate.[48] Thus aging can result in unfavourable body composition changes for both men and women.

Energy expenditure

Owing to the rising prevalence of obesity worldwide, in part related to sedentary behaviour,[49] tennis is often promoted as an excellent way of burning calories and therefore managing body mass, or more specifically, reducing fat mass. Research using expired air measurements as well as accelerometer devices suggested that young adult tennis players engaged in singles play could expend between 7.8 and 10.1 kcal/min.[28 50] These values are similar to the results obtained by Ferrauti *et al*,[51] where nationally ranked senior tennis players competed in a two hour tennis match while having expired air analysed with portable oxygen consumption systems. Thus 30 minutes of tennis (actual play, discounting rest periods) has the potential to burn approximately 234 to 300 kcal. For those who play tennis regularly (for example, three days a week), this could amount to expending an extra 700 kcal weekly and contribute to long term weight management.

Hence embarking upon 90 minutes of a running–intensive tennis training programme thrice weekly may produce a slow, steady weight reduction without alterations to dietary intake in veteran players desiring to lose weight. If one were to extrapolate the findings of Ferrauti *et al*[43] over a year, a player engaged in the running–intensive programme could lose up to 8 kg and lessen the fat gain risk. However, a well controlled study specifically examining the weight management effectiveness of tennis has not yet been reported for any age group. The Cardio-Tennis™ programme being promoted by the United States Tennis Association (USTA) may be one way to achieve this outcome. Actual intervention research incorporating this programme is needed to support this speculation.

Body fat

Supportive evidence for leaner body compositions in veteran tennis players was provided by Swank *et al*.[23] The percentage of body fat estimated from hydrostatic weighing showed that the elite male veteran players had significantly less fat than an age matched active control group ($p \leqslant 0.05$). Both the younger veterans (aged 40 to 59) and the older veterans (60+) were on average 3% leaner than the non-tennis-playing moderately active controls (17–20.5% *v* 21–25%, respectively). This placed the tennis players in the 60–70th centile (above average) while the controls were in the 30–50th centile (average to below average) for body composition.[11] Similarly, LaForest *et al*[52] obtained leaner body fat estimations with a 10-site skinfold technique on their recreational tennis sample who had played twice a week for the previous 10 years. The mean per cent body fat estimate of the tennis players (age range 23 to 69 years) was almost 4% less than in the age matched sedentary controls (20.4 *v* 23.9%, $p<0.05$).

Strength

Although it has been acknowledged that muscle atrophy is a consequence of aging, there is evidence that it can be reversed or at least slowed down with appropriate resistance training protocols.[53–55] Without considering past resistance training history, LaForest *et al*[52] found that tennis players, regardless of age, had knee extensor and flexor muscles that were stronger and more resistant to muscle fatigue than their age matched sedentary counterparts (using both isokinetic dynamometer and electromyographic testing, $p<0.001$). Conversely, using similar isokinetic testing of the knee extensors, Swank *et al*[23] found no significant differences in knee extensor strength between elite veteran tennis players and controls. The authors stipulated this may have been because 32% of the tennis players reported knee injuries or knee surgery versus only 5.6% of the controls. Maintaining a good grip strength for tennis assists with preventing injuries to the shoulder and elbow,[56] but it can have functional importance for completing simple activities of daily living. As acknowledged earlier, it has been noted that there is enhanced grip strength in the dominant arm of tennis players,[35 57] but not all studies have reported significant differences between tennis players and their control subjects.[36] The variability in grip strength results may be a reflection of individual non-controlled lifestyle factors that may affect the forearm outside of tennis play.

Bone mass

The relation between bone mass and athletic participation has been a topic of intense interest. The impact of tennis participation on bone remodelling has been investigated in terms of specific side to side differences in the forearm as well as the broader whole body effect of weight bearing exercise, especially on the spine and hip. The evidence that muscle mass is related to bone mass suggests an interrelation between the muscle wasting sarcopenia and the bone wasting in osteoporosis.[58] It is generally accepted that exercise (especially weight bearing and resistance training) positively influences peak bone mass in youth through young adulthood and may also minimise bone loss in older adults,[11] but there are few clear cut studies which empirically show that tennis per se is the causative factor for bone mass maintenance and improvement. However, there is circumstantial evidence that lifelong tennis participation may affect bone mass to varying degrees. In the 1970s, it was shown that professional tennis players had increased bone diameter and cortical thickness in their dominant playing arm.[59 60] To determine if this was a lifelong effect, the bone mineral content (BMC) in 35 lifetime male tennis players aged 70 to 84 years was investigated.[61] It was reported that the mean difference in BMC for the dominant playing arm in comparison with the non-dominant arm was 13%. This contrasts with another study consisting of healthy non-athletes whose BMC for the dominant arm was only 6–9% greater than the non-dominant arm.[62] Huddleston *et al*[61] concluded that lifetime tennis can increase the BMC of the dominant playing arm but not the non-playing arm and that the increased BMC is 4–7% greater for male tennis players. Moysi *et al*[63] confirmed that middle aged male lifelong tennis players continue to reap the rewards of the sport in that their muscle and bone mass (lumbar spine, femoral neck, legs) is preserved or enhanced in comparison with age and sex matched controls. However, it appears that the same cannot be said for women.

In women, bone mineral density peaks around age 40 and then, without weight bearing activity or oestrogen replacement, decelerates through the menopause and beyond.[13] A 1984 study compared bone density of college athletes (tennis and swimming) to older athletic women and aged matched normal women.[33] The older active women ''primarily'' consisted of dedicated tennis players, but also included swimmers, golfers, aerobic exercisers, and weight lifters. The results, presented within three age groupings (20 to 40 years, 40 to 55 years, and 55 to 75 years), suggested that athletic women had greater bone densities than the control subjects. However, women aged 40 to 55 years only had significantly greater BMC in their distal radius and greater bone mineral density (BMD) in their lumbar spine, whereas the 55 to 75 year old group had significantly greater BMC and BMD throughout the radius, while lumbar BMD was not significantly greater than in the controls.

Another large weight bearing study of ex-elite athletes, which included 16 female veteran tennis players aged 40 to 65 years, was conducted 12 years later.[64] This research suggested that BMD was associated with length of long term weight bearing exercise, with ex-athletes having the highest BMD, followed by active controls, then the inactive controls. Within the athletic population, the BMD in the lumbar spine of the tennis players was 12% greater than in 27 ex-elite runners ($p = 0.0004$). It was theorised that the torsional strains on the spine in tennis playing were a better stimulus for bone mineral development than running. As in the research in men, the women's BMD in the dominant playing arm was 5.9% greater than in the non-dominant arm ($p = 0.036$). Haapasalo *et al*[34] further explored the impact of tennis on BMD by studying the length of years of playing in relation to bone remodelling. Their conclusions were that humeral BMC, BMD, and cortical wall thickness (CWT) are affected the most when intensive tennis training begins in childhood, regardless of sex, and that mature bone—while able to increase BMD—does not remodel the width of the humerus but rather thickens the bone cortex, thereby narrowing the marrow cavity.

Continued research by Moysi *et al*[65] investigated BMC in post-menopausal women who were recreational master level tennis players (mean age 63 years, 27 year tennis history, three sessions a week). A strong relation was found between inter-arm asymmetry and BMC ($r = 0.91$, $p<0.01$), and its magnitude was proportional to the length of time they had played tennis. No differences in BMD was found between arms, nor were there any femoral or lumbar bone mass/density differences between the players and the controls.[65] Furthermore, a two year follow up study found no change in these variables. These results are in contrast to the men's results discussed earlier, thereby suggesting that sex differences exist in bone adaptation to exercise as one ages. Moysi *et al* suggested that the sex difference in osteopathic adaptation could reflect the mechanical impact produced by the men's game style, which is greater in quantity and magnitude than in the women's game.[65]

Neurobehavioural and sociological issues

Claims for healthy tennis brains range from neuroscientific evidence of increased cerebral activity with eye movement tracking[66] to behavioural issues like stress reduction.[67] Early research showed that reaction time slowing was not necessarily inevitable with the aging process. As with the junior players, veteran tennis players showed significantly quicker reaction times than their non-active age matched peers.[68] In another study, it was reported that older active men were able to react to stimuli and move their forearms as quickly as young sedentary men.[69] Further, a behavioural study found that a single session of tennis alleviated stress and tension in a group of Japanese women veteran players.[67]

The cerebral truth resides in the neuroscience field, with neuroimaging studies investigating exercise and aging.[12] Cognitive researchers have demonstrated a 5% to 15% increase in cerebral activation during motor and cognitive tasks.[70–73] Long term walking programmes have been associated with cognitive benefits[74 75] and executive function (for example, the planning of mental procedures) appears to be maintained in older adults who are more aerobically fit.[76] Emerging research is describing how complex hand–eye movements are coordinated by the cerebellum.[66]

Hence, it may be inferred that tennis exercises the brain as well as the body. The skill acquisition components of tennis should increase cerebral activity. The aerobic nature of tennis should encourage retention of cognitive function. Future cognitive studies involving imaging (for example, functional magnetic resonance imaging) should seek out veteran tennis players to validate these assumptions.

Enhanced cognitive alertness would not only benefit one's tennis, but may also reduce fall risk and enable the older adult to participate more fully in life. Stress reduction helps to improve the cardiac risk profile.[77] Tennis is not an individual isolated sport. Backboard hitting aside, it requires a partner. Tennis participation encourages social interaction and will help ward off the loneliness sometimes encountered by older individuals living apart from loved ones. Thus participation in a moderate to vigorous weight bearing physical activity such as tennis may afford the veteran player a host of psychosocial health benefits.[21 78 79]

INJURIES

Tennis participation is not without its health risks. It is known that lifelong tennis participation can cause both acute and recurrent injuries to the wrist, elbow, rotator cuff, and Achilles tendon, promote osteoarthritis, bursitis, tendonitis, sprains, strains, contusions, occasional fractures, exacerbate the risk for skin cancer and eye problems, and in rare instances cause sudden death.[80–85] Many of the above problems can be prevented or reduced by using appropriate racquets designed to reduce impact, speed, and vibration on the arm; or by wearing protective athletic braces, sunglasses, sunblock, cushioned supportive shoes; or by maintaining good biomechanics, stretching to improve flexibility, and having a more balanced training schedule.[21 23 82 83] Despite all these precautions, there will be times when veteran players must undergo surgery. For the most common shoulder injury, rotator cuff repair, return to tennis play at their pre-injury level approaches 80%.[86] Returning to tennis after hip or knee arthroplasty may be equally promising. After knee surgery, only 21% of the surgeons approved of their patients playing tennis, with 45% suggesting only doubles play.[87] Despite the negative warnings from their surgeons, at both one year and seven years post-surgery, the knee patients (n = 33; 46 total knee replacements, mean age 64 years) were playing both singles and doubles on average three days a week. A similar resumption in tennis play was achieved by 58 veteran players (mean age 70 years) who underwent total hip arthroplasty.[88] This time, only 14% of the surgeons approved their patients playing tennis and 34% recommended doubles only. At the one year mark, all the hip patients were playing both singles and doubles three times weekly and were very pleased with their progress. The authors of these two studies cautioned that it is currently unknown what the long term outcome (over 15 years) of tennis play on the repaired knees and hips will be.

FUNCTIONAL HEALTH

The health and fitness benefits such as those discussed above can directly translate into functional health benefits as one ages. The lifelong benefits attributed to tennis participation go far beyond the concept of improved physical fitness. Improvements in leg strength have been associated with improved balance, gait mechanics, and the ability to rise from a chair.[89] Better balance and a strong steady gait can enable older individuals to avert a fall, but should a fall occur, maintenance of bone density may reduces fracture risk. Fall related injuries contribute to billions of dollars in health care costs.[90] Moderately active older adults are twice as likely to obtain optimal scores on the ability to engage in daily living functions.[91] Something as simple as maintaining grip strength can enable older adults to open jars easier or hold onto a handrail more firmly when walking on slippery surfaces. The social and behavioural contributions of tennis also contribute to healthful living. Alert minds contribute to an engaging, meaningful life.

CONCLUSIONS, RECOMMENDATIONS, FUTURE DIRECTIONS

In summary, it is apparent that the health of veteran tennis players is positively affected by enhanced aerobic capacities, greater bone densities and lower body fat, greater strength, and less diminished cognitive function in comparison with less active controls. However, the evidence remains inconclusive as to whether tennis alone can be a sole contributor to these physiological variables. Most of the studies have been weakly controlled cross sectional descriptive studies. A clear limitation with all of the tennis research is the lack of non-confounded longitudinal experimental research, isolating tennis as the factor for improved physiological outcomes. The ideal study would be one which introduced the game of tennis to five experimental groups of inactive, tennis-naive subjects. The experimental groups could include a true control (remaining sedentary), plus five other groups (tennis only, running only, resistance training only, tennis + running, tennis + resistance training, tennis + running + resistance training). After establishing equivalent weekly training doses, their training adaptations could be compared over a minimum of three to six months. To determine lifelong benefits, a random sample of these subjects could be tracked over the course of their lifetimes. The reason why this has not yet been done obviously reflects the impractical nature of such a task in terms of funding, recruitment, and retention issues. Hence, select cross sectional studies and small longitudinal studies have provided glimpses into potential tennis contributions for improved health outcomes.

What is already known about this topic?

It is widely accepted that regular participation in tennis affords a host of mind-body health benefits for both young and veteran players. These health benefits are related to the general benefits of regular exercise participation including, but not limited to, higher aerobic capacities, lower resting heart rate and blood pressure responses, improved metabolic function, maintained or improved skeletal integrity, improved reaction time, and decreased stress reactivity.

What this study adds?

This review elucidates the impact that lifetime tennis participation has had on various health indices as opposed to the assumed benefits resulting from general exercise participation. Most early tennis studies attributing positive health benefits to tennis participation have been limited because of their inability to control for various confounding factors. Based upon the pitfalls of the historical tennis research, this study provides recommendations for designing well controlled future research studies investigating lifelong tennis benefits.

Despite a lack of ideally designed tennis research, it seems prudent to make training recommendations based upon the general exercise literature as it would apply to the veteran tennis player. It is clear that participation in activities that can raise and keep the heart rate within the 55–90% of maximum on three days a week for 20 to 60 minutes would promote cardiorespiratory, metabolic, and cognitive health, especially if 2000 kcal of energy expenditure weekly were achieved.[3 11 17 71] The addition of resistance training two to three times a week would provide complementary health gains in bone and muscle maintenance. For veterans, staying fit to play competitively or recreationally requires a well balanced routine consisting not only of the tennis match itself, but also practice which incorporates tennis drills, running/jogging, and resistance training.[92] Participation in these modes in the quantities suggested for general exercise will benefit the veteran tennis player. Successful aging ''proof'' resides in the profiles of the elite veteran tennis players described in the various tennis research studies.

Future tennis research needs to replicate some of the junior/younger adult studies in novice veteran players. For instance, it is not known to what degree tennis participation affects various health, fitness, and cognitive functions in older adults (50+) new to the sport of tennis. Owing to the specificity of the research population, traditional grant funding agencies for health research is severely limited. Given the anticipated worldwide population growth of aged individuals, the professional tennis organisations should earmark some funds for updating tennis research in the aged rather than focusing entirely on junior development. Finally, the leading tennis organisations should jointly fund projects to track junior players across their lifespan in order to facilitate a better understanding of the impact that tennis may have on lifelong health.

ACKNOWLEDGEMENT

Dr Marks received partial support for manuscript preparation from NIH grant AG00029.

Competing interests: none declared

REFERENCES

1 **Kesaniemi YI**, Danforth E, Jensen MD, *et al.* Dose-response issues concerning physical activity and health: an evidenced-based symposium. *Med Sci Sports Exerc* 2001;**33**:S351–8.
2 **US Department of Health and Human Services**. *Physical activity and health: a report of the Surgeon General.* Atlanta, GA: National Center for Chronic Disease Prevention and Health Promotion, 1996.
3 **Paffenbarger RS**, Wing AL, Hyde RT, *et al.* Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* 1986;**314**:605–13.
4 **Blair SN**, Kownl HW, Paffenbarger SRS, *et al.* Physical fitness and all-cause mortality. *JAMA* 1989;**262**:2395–401.
5 **Liu-Ambrose T**, Khan K, McKay H. The role of exercise in preventing and treating osteoporosis. *Int Sport Med J* 2001;**2**:1–13.
6 **American College of Sports Medicine**. Position stand: osteoporosis and exercise. *Med Sci Sports Exerc.* 1995;27: i–vii.
7 **World Health Organisation**. *Ageing and health: a global challenge for the 21st century.* Geneva: WHO, 1999.
8 **Tennis Canada**. Seniors, 2005 (http://www.tenniscanada.ca/federation/english/seniors/).
9 **Spirduso WW**, Francis KL, MacRae PG. *Physical dimensions of aging*, 2nd edition. Champaign, IL: Human Kinetics Publishers, 2005:212–86.
10 **Pluim B**, Safran M. *From breakpoint to advantage. A practical guide to optimal tennis health and performance.* Vista, CA: Racquet Tech Publishing, 2004:291–6.
11 **American College of Sports Medicine**. *ACSM's guidelines for exercise testing and prescription*, 7th edition. Philadelphia: Lippincott Williams & Wilkins, 2004, 4–6, 45–46, 66–67, 144, 206, 301, 246–251.
12 **Marks, BL**. Cognitive function: its relationship with functional status, fitness, vascular and cerebral blood flow. *Top Geriatr Rehab* 2002;**17**:36–44.
13 **Marks, BL**. Physiologic responses to exercise in older women. *Top Geriatr Rehab* 2002;**18**:9–20.
14 **Leon AS**, Connett J, Jacobs DR, *et al.* Leisure-time physical activity levels and risk of coronary heart disease and death. *JAMA* 1987;**158**:2388–95.
15 **Ekelund L**, Haskell WL, Johnson JL, *et al.* Physical fitness as a predictor of cardiovascular mortality in asymptomatic North American men. *N Engl J Med* 1988;**319**:1379–84.
16 **Blair SN**, Kohl HW, Paffenbarger RS, *et al.* Physical fitness and all-cause mortality. *JAMA* 1989;**262**:2395–401.
17 **Paffenbarger RS**, Hyed RT, Wing AL, *et al.* The association of changes in physical activity level and other lifestyle characteristics with mortality among men. *N Engl J Med* 1993;**328**:538–45.
18 **Paffenbarger RS**, Blair SN, Lee IM, *et al.* Measurement of physical activity to access health effects in free-living populations. *Med Sci Sports Exerc* 1993;**25**:60–70.
19 **Patterson B**. Tennis…fit, fast, and for a lifetime. Tennis = Longer Life. Press release, SGMA International (http://www.sgma.com/press/1997/press988318804-6263.html).
20 **Kriska A**, Caspersen C, editors. A collection of physical activity questionnaires for health-related research. Paffenbarger Physical Activity Questionnaire. *Med Sci Sports Exerc* 1997;**29**(6 suppl):S83–8.
21 **Marks BL**. What's your racquet for fitness? *N Carolina J* 1998;**34**:22–6.
22 **Morgans LF**, Jordan DL, Baeyens DA, *et al.* Heart rate responses during singles and doubles tennis competition. *Physician Sportsmed* 1987;**15**:74–6.
23 **Swank AM**, Condra S, Yates JW. Effect of long term tennis participation on aerobic power, body composition, muscular strength, flexibility, and serum lipids. *Sports Med Training Rehab* 1998;**8**:99–112.
24 **Bloomfield J**, Blanksby BA, Beard DF, *et al.* Biological characteristics of young swimmers, tennis players, and non-competitors. *Br J Sports Med* 1984;**8**:97–103.
25 **Mero A**, Jaakkola L, Komi PV. Neuromuscular, metabolic, and hormonal profiles of young tennis players and untrained boys. *J Sport Sci* 1989;**7**:95–100.
26 **Kibler WB**, McQueen, C Uhl T. Fitness evaluation and fitness findings in junior tennis players. *Clin Sport Med* 1988;**7**:403–16.
27 **Chandler JT**, Kibler WB, Uhl TL, *et al.* Flexibility comparisons of junior elite tennis players to other athletes. *Am J Sport Med* 1990;**18**:134–6.
28 **Marks BL**, Galleher EW, Moore T, *et al.* Energy balance monitoring in tennis players. *Med Sci Tennis J* 2003;**8**:8–9.
29 **Keul J**, Stockhausen W, Pokan R, *et al.* Metabolische und kardiozirkulatorische adaptation sowie leistungsverhalten professioneller tennisspieler [Metabolic and cardiovascular adaptation and performance of professional tennis players]. *Deutsche Medizinische Wochenschrift* 1991;**116**:761–7.
30 **Buono MJ**, Constable SH, Stanforth PR. Maximum oxygen uptake and body composition of varsity collegiate tennis players. *Ariz J Health Phys Educ Recr Dance* 1980;**23**:6–7.
31 **Davey PR**, Thorpe RD, Williams C. Simulated tennis matchplay in a controlled environment. *J Sport Sci* 2003;**21**:459–67.
32 **Marks BL**, Moore T, Angelopoulos, et al. Nutrition and hydration profile of male competitive tennis athletes. In: Miller S, eds. *Tennis science and technology 2.* London: International Tennis Federation, 2003:261–70.
33 **Jacobson PC**, Beaver W, grubb SA, *et al.* Bone density in women: college athletes and older athletic women. *J Orthop Res* 1984;**2**:328–32.
34 **Haapasalo H**, Sievanen H, Kannus P. Dimensions and estimated mechanical characteristics of the humerus after long-term tennis loading. *J Bone Miner Res* 1996;**11**:864–72.
35 **Vodak PA**, Savin WM, Haskell WL, *et al.* Physiological profile of middle-aged male and female tennis players. *Med Sci Sport Exerc* 1980;**12**:159–63.

36 **Sinoway LI**, Musch T, Minotti JR, *et al.* Enhanced maximal metabolic vasodilation in the dominant forearms of tennis players. *J Appl Physiol* 1986;**61**:673–8.
37 **Therminarius1 A**, Dansou PI, Chirpau-Oddou MF, *et al.* Effects of age on heart rate response during a strenuous match of tennis. *J Sports Med Phys Fit* 1990;**30**:389–96.
38 **Kenney WL**, Buskirk ER. Functional consequences of sarcopenia: effects on thermoregulation. *J Gerontol A Biol Sci Med Sci* 1995;**50**(special issue):78–85.
39 **Pandolf KB**, Cadarette BS, Sawka MN, *et al.* Thermoregulatory responses of matched middle-aged and young men during dry-heat acclimatization. *J Appl Physiol* 1988;**65**:65–71.
40 **Pandolf KB**. Aging and human heat tolerance. *Exp Aging Res* 1997;**23**:69–105.
41 **Therminarius A**, Dansou P, Chirpaz-Oddou M-F, *et al.* Hormonal and metabolic changes during a strenuous tennis match. Effect of aging. *Int J Sports Med* 1991;**12**:10–16.
42 **Vodak PA**, Wood PD, Haskell WL, *et al.* HDL-cholesterol and other plasma lipid and lipoprotein concentrations in middle-aged male and female tennis players. *Metabolism* 1980;**29**:745–52.
43 **Ferrauti A**, Weber K, Struder HK. Effects of tennis training on lipid metabolism and lipoproteins in recreational players. *Br J Sports Med* 1997;**31**:322–7.
44 **National Cholesterol Education Program**. Third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (Adult Treatment Panel III), 2002. NIH Publication No 02–, 5215.
45 **Aoyug Y**, Shepard RJ. Aging and muscle function. *Sports Med* 1992;**14**:376–96.
46 **Rogers MA**, Evans WJ. Changes in skeletal muscle with aging effects of exercise training. In:Holloszy JO, editor. *Exercise and sport science reviews.* vol 21 Baltimore: Williams and Wilkins, 1993:65–102.
47 **Evans WJ**. What is sarcopenia? *J Gerontol A Biol Sci Med Sci* 1995;**50**(special issue):5–8.
48 **Poehlman ET**, Toth MJ, Fishman PS, *et al.* Sacopenia in aging humans: the impact of menopause and disease. *J Gerontol A Biol Sci Med Sci* 1995;**50**(special issue):73–7.
49 **DiPietro L**, Kohl WW, Barlow CE, *et al.* Improvements in cardiorespiratory fitness attenuate age-related weight gain in healthy men and women: the Aerobics Center Longitudinal Study. *Int J Obes* 1998;**22**:55–62.
50 **Seliger V**, Ejem M, Pauser M, *et al.* Energy metabolism in tennis. *Internationale Zeitschrift fur Angewandte Physiologie* 1973;**31**:330–40.
51 **Ferrauti A**, Bergeron MF, Pluim B, *et al.* Physiological responses in tennis and running with similar oxygen uptake. *Eur J Appl Physiol* 2001;**85**:27–33.
52 **Laforest S**, St-Pierre DMM, Cyr J, *et al.* Effects of age and regular exercise on muscle strength and endurance. *Eur J Appl Physiol* 1990;**60**:104–11.
53 **Fiatarone MA**, Marks EC, Ryan ND, *et al.* High intensity strength training in nonagenarians. *JAMA* 1990;**263**:3029–34.
54 **Black R**. Muscle strength as an indicator of the habitual level of physical activity. *Med Sci Sport Med* 1991;**23**:1375–81.
55 **Booth FW**, Criswell DS. Molecular events underlying skeletal muscle atrophy and the development of effective countermeasures. *Int J Sports Med* 1997;**18**(suppl):S365–9.
56 **Groeppel JL**, Roetert EP. Applied physiology of tennis. *Sports Med* 1992;**14**:260–8.
57 **Green DJ**, Fowler DT, O'Driscoll JG, *et al.* Endothelium-derived nitric oxide activity in forearm vessels of tennis players. *J Appl Physiol* 1996;**81**:943–8.
58 **Marcus R**. Relationship of age-related decreases in muscle mass and strength to skeletal muscle. *J Gerontol A Biol Sci Med Sci* 1995;**50**(special issue):86–7.
59 **Lewis CWD**. Who's for tennis? *NZ Med J* 1971;**74**:21–4.
60 **Jones JJ**, Priest JD, Hayes WC, *et al.* Humeral hypertrophy in response to exercise. *J Bone Joint Surg Am* 1977;**59**:204–8.
61 **Huddleston AL**, Rockwell D, Kulund DN, *et al.* Bone mass in lifetime tennis athletes. *JAMA* 1980;**244**:1107–9.
62 **Karjalainen P**, Alhava EM. Bone mineral content of the forearm in a healthy population. *Acta Radiol Oncol Radiat Phys Biol* 1976;**16**:199–208.
63 **Moysi JS**, Vicente-Rodriquez G, Serrano JA, *et al.* The effect of tennis participation on bone mass is better retained in male than female master tennis players. In:Lees A, Kahn JF, Maynard IW, editors. *Science and racket sports III.* London: Routledge Press, 2004:76–81.
64 **Etherington J**, Harris PA, Nandra D, *et al.* The effect of weight-bearing exercise on bone mineral density: a study of female ex-elite athletes and the general population. *J Bone Miner Res* 1996;**11**:1333–8.
65 **Moysi JS**, Dorado C, Vicente-Rodriquez G, *et al.* Inter-arm asymmetry in bone mineral content and bone area in postmenopausal recreational tennis players. *Eur Menopause J* 2004;**48**:289–98.
66 **Iacoboni**. M. Playing tennis with the cerebellum. *Nat Neurosci* 2001;**4**:555–6.
67 **Kerr JH**, Fauiyama H, Campano J. Emotion and stress in serious and hedonistic leisure sport activities. *J Leisure Res* 2002;**34**:272–89.
68 **Rotella RJ**, Bunker KL. Field dependence and reaction time in senior tennis players (65 and over). *Percept Motor Skills* 1978;**46**:585–6.
69 **Spiriduso W**, Clifford P. Replication of age and physical activity effects on reaction and movement time. *J Gerontol* 1978;**33**:26–30.
70 **Cupini LM**, Matteis M, Troisi E, *et al.* Bilateral simultaneous transcranial Doppler monitoring of flow velocity changes during visuospatial and verbal working memory tasks. *Brain* 1996;**119**:1249–53.
71 **Gur, RC, Ragland JD, Resnick SM, et al**. Effects of memory processing on regional brain activation: cerebral blood flow in normal subjects. *Int J Neurosci* 1993;**72**:31–44.
72 **Orlandi G**, Murri L. Transcranial Doppler assessment of cerebral flow velocity at rest and during voluntary movements in young and elderly subjects. *Int J Neurosci* 1996;**84**:45–53.
73 **Marks BL**, Katz LM, Nunley DC, *et al.* Cerebral blood flow and cognitive function is maintained in aerobically active older adults. *Circulation* 2000;**102**(suppl 18):II–875.
74 **Satoh T**, Sakurai I, Miyagi K, *et al.* Walking exercise and improved neuro-psychological functioning in elderly patients with cardiac disease. *J Intern Med* 1995;**238**:423–8.
75 **Moul JL**, Goldman B, Warren B. Physical activity and cognitive performance in the older population. *J Aging Phys Activity* 1995;**3**:135–45.
76 **Colcombe SJ**, Kramer AF, Erickson KI, *et al.* Cardiovascular fitness, cortical plasticity, and aging. *Proc Natl Acad Sci USA* 2004;**101**:3316–21.
77 **Chockalingam A**, Venkatesan S, Dorairajan S, *et al.* Estimation of subjective stress in acute myocardial infarction. *J Postgrad Med* 2003;**49**:207–10.
78 **Bailey M**, McLaren S. Physical activity alone and with others as predictors of sense of belonging and mental health in retirees. *Aging Mental Health* 2005;**9**:82–90.
79 **Kolt GS**, Driver RP, Giles LC. Why older Australians participate in exercise and sport. *J Aging Phys Act* 2004;**12**:185–98.
80 **Roetert EP**, Brody H, Dillman CH, *et al.* The biomechanics of tennis elbow. *Clin Sports Med* 1995;**14**:47–57.
81 **Brasseur J-L**, Lucidarme OL, Tardieu M, *et al.* Ultrasonographic rotator-cuff changes in veteran tennis players: the effect of hand dominance and comparison with clinical findings. *Eur Radiol* 2004;**14**:857–64.
82 **Spector, TD, Harris PA, Hart DJ, et al**. Risk of osteoarthritis associated with long-term weight-bearing sports: a radiologic survey of the hips and knees in female ex-athletes and population controls. *Arthritis Rheum* 1996;**39**:988–95.
83 **Leach RE**, Abramowitz A. The senior tennis player. *Clin Sports Med* 1991;**10**:283–90.
84 **Shepard RJ**. Cardiac risks of racquet sports. *Can J Sport Sci* 1991;**6**:6–7.
85 **Comfort SR**, Curry R, Roberts WC. Sudden death while playing tennis due to a tear in ascending aorta (without dissection) and probable transient compression of the left main coronary artery. *Am J Cardiol* 1996;**78**:493–5.
86 **Sonnery-Cottet B**, Edwards B, Noel E, *et al.* Rotator cuff tears in middle-aged tennis players: results of surgical treatment. *Am J Sports Med* 2002;**30**:558–64.
87 **Mont MA**, Rajadhyaksha AD, Marxen JL, *et al.* Tennis after total knee arthroplasty. *Am J Sports Med* 2002;**30**:163–6.
88 **Mont MA**, LaPorte DM, Mullick T, *et al.* Tennis after total hip arthroplasty. *Am J Sports Med* 1999;**27**:60–4.
89 **Seeman TE**, Berkman LF, Charpentier PA, *et al.* Behavioral and psychosocial predictors of physical performance: MacArthur studies of successful aging. *J Geron Med Sci* 1995;**50A**:M177–83.
90 **Rikli RE**, Jones CJ. Assessing physical performance in independent older adults: issues and guidelines. *J Aging Phys Activity* 1997;**5**:244–61.
91 **Laukkanen P**, Kauppinen M, Heikkinen E. Physical activity as a predictor of health and disability in 75- and 80-year-old men and women: A five-year longitudinal study. *J Aging Phys Activity* 1998;**6**:141–56.
92 **Jokl P**. The masters (50 years and older) tennis player. *Med Sci Tennis* 2005;**10**(NR2):3.

COMMENTARY

Research on the physiological effects, both short and long term, of tennis is limited and scattered. Unlike the runner or cyclist, the tennis player is hard to quantify in a laboratory situation. This review addresses some of the issues and starts to take perceived health attributes of tennis for older players from hearsay into proven fact, while maintaining a critical approach to the areas which remain far from clear, such as the effect of modern equipment, and the generally limited application of current sports science principles by veteran players.

S R Parsonage
Food for Performance, Sarasota, Florida, USA;
srparsonage@yahoo.com