The science of fencing: implications for performance and injury prevention

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The Science of Fencing

Implications for Performance and Injury Prevention

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Contents

Abstract

In this review we analyse the data from the literature on fencing with the aim of creating a psychobiological and multi-factorial model of fencing performance.

Fencing is an open-skilled combat sport that was admitted to the first modern Olympic Games in Athens (1896). It is mainly practised indoors, with three different weapons: the foil, the sabre and the épée, each contested with different rules. A fencing international tournament may last between 9 and 11 hours. Bouts represent only 18% of total competition time, with an effective fight time of between 17 and 48 minutes.

The physical demands of fencing competitions are high, involving the aerobic and anaerobic alactic and lactic metabolisms, and are also affected by age, sex, level of training and technical and tactical models utilized in relation to the adversary.

The anthropometrical characteristics of fencers show a typical asymmetry of the limbs as a result of the practice of an asymmetrical sport activity. Fencing produces typical functional asymmetries that emphasize the very high level of specific function, strength and control required in this sport.

Moreover, the physical demands of fencing are closely linked to the perceptual and psychological ones, and all are subjected to a continuous succession of changes during the bouts based on the behaviour of the opponent. For this reason it is difficult to identify a significant relationship between any one physiological characteristic and performance, and performance is more likely to be influenced by perceptual and neuro-physiological characteristics. Fencers need to anticipate the opponent and to mask their true intentions with a game of feints and counter-feints, which must be supported by an adequate psycho-physical condition to prevent central and peripheral fatigue.

Fencing is not particularly dangerous; however, there is a fine line between a fatal lesion and a simple wound from a broken blade. The suggestions for injury prevention fall into three primary areas: (i) actions that can be taken by participants; (ii) improvements in equipment and facilities; and (iii) administration of fencing competitions. As in every other sport, the prevention of accidents must be accomplished at various levels and above all must involve the institutions that are responsible for safety in sports.

Fencing is one of the oldest sports, having been practised in ancient Egypt from at least 1200 BC. It has constantly evolved with the development of new techniques for fusing metals and with the influence of different cultures and their fighting traditions. In Europe, the rise in wearing swords as part of civilian dress and the increase in duelling contributed to the wide diffusion of fencing and led to an increasing demand for training.

Throughout history, fencing has been conceived of and practised as an art form,[1,2] and has also been presented as a science formally since 1604.[3] In 1896, fencing as a sporting activity was admitted to the first modern Olympic Games in Athens.

In this review, we analyse the data presented in the literature and attempt to highlight factors that may influence performance and may predispose fencers to injuries. We used information from articles published in peer-reviewed journals. These sources of information were supplemented with other descriptive data from national publications, technical journals, university theses and congress abstracts and also with personal unpublished data.

Taken together, all these papers must be put into a broad multi-dimensional perspective, so the main objective of this review is to draw a psychobiological and multi-factorial model of fencing performance.

1. Characteristics of Fencing

Fencing is an open-skilled combat sport mainly practised indoors, in which two athletes fight indirectly, through their weapons, and physical contact is forbidden. Fencing is practised by men and women, with three different weapons; the foil, the sabre and the épée, each contested with different rules (table I). For protective purposes, fencers must wear specific fencing dress, mask, gloves and plastrons, that may decrease their cardiopulmonary performance and increase the loss of water.[4,5]

In fencing, the competition field is 14 m long and between 1.5 and 2 m wide. A referee presides over the bout with the aid of an electrical scoring apparatus connected with the targets of the fencers. Epée was electrified in 1936, foil in 1956, and sabre in 1988, and these modernizations made some changes to fencing techniques.

Table I. Characteristics of fencing weapons and targets

	Foil	Epée	Sabre
Mass (g)	<500	<770	<500
Total length (cm)	110	110	105
Blade length (cm)	90	90	88
Shape of the blade	Quadrangular	Triangular	Triangular
Valid targets	Trunk	All the body	Head, trunk, upper arms, glove
How to hit the target	Tip	Tip	Blade (cutting) and tip
Force for detecting (N)	>4.90	>7.36	Only contact
Priority	Yes	No	Yes

Nowadays, competitions are organised into preliminary pool bouts (of 5 touches), and in direct elimination bouts (of 15 touches) with a maximum time allowed. The first fencer to score either 5 or 15 touches is declared the winner. In foil and sabre, the game is played by a system of priority. When two touches are scored at the same time, regardless of who is touched first, only the fencer with the priority scores the touch. A touch which lands on an invalid target stops the bout, but no point is scored.

2. Physical Demands of Fencing

A fencing international tournament may last between 9 and 11 hours. Bouts represent only 18% of total competition time,[6] with an effective fight time of between 17 and 48 minutes (table II).[7] During a bout, the fencer covers a total distance of 250–1000 m.[8] The duration of every action may be very short and intensive (<1 second), or it may last >60 seconds (submaximal performance). On average, an action lasts 5 seconds in foil and 15 seconds in épée, with a ratio for action : interruption of 1 : 1 in men's épée, 1 : 3 in men's foil and 2 : 1 in women's épée.[7,8]

In every bout there are preparatory movements that are generally of longer duration and of submaximal intensity, followed by some very intensive movement of shorter duration, associated with the final attempt to touch the opponent (figure 1).

The heart rate (HR) during a fencing bout is clearly intensity dependent. It was first recorded telemetrically by Rittel and Waterloh[9] in 1975. They reported that males have a lower HR than females. During the sabre competitions, the HR is higher and some ectopic beats may be recorded during the most intense phases of the bout. During training sessions of the Italian National Team before the 1982 World Championships, it was observed that HR is dependent on the intensity of the bout and frequently the winner has the lowest HR.[10]

During a women's épée competition, HR ranged from 167 to 191 beats/min, i.e. 70% of maximal HR, for about 60% of the fight duration.[11] HRs were above the anaerobic threshold for 41 ± 34% of the fight time.[6] In competitive bouts, the estimated

Table II. Time-motion characteristics of an international competition involving 64 fencers competing in direct elimination bouts (range) calculated for the winner (personal unpublished data, 1998, 2007)

	Women's épée	Men's épée	Men's foil
Number of bouts	6	6	6
Total competition time (h)	9–11	9–11	9–11
Resting time between bouts (min)	15–300	15–300	15–300
Total bout time (min)	47–81	48–98	77–122
Effective fight time (min)	28–48	22–39	17–34
Effective interruption time (min)	19–33	26–59	60–89
Interruptions (n)	126–150	96–180	246–318
Attacks (n)	66–138	96–180	138–210
Changes of direction (n)	210–582	102–294	120–180

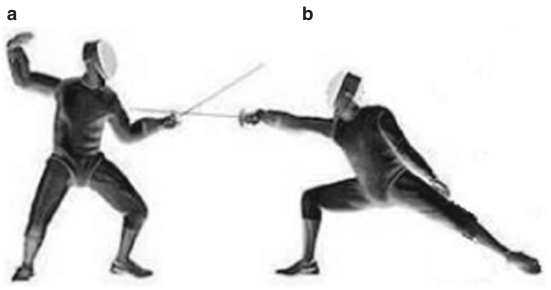

Fig. 1. The on-guarde starting position (**a**) and the attack (lunge; **b**) in fencing.

oxygen uptake averaged 39.6 mL/kg/min and 53.9 mL/kg/min for Spanish female and male fencers, respectively.[6]

During a regional men's foil competition, blood lactate concentrations ([La]) assessed 5 minutes after the end of the bout were between 1.4 and 3.9 mmol/L (2.5 ± 1.1 mmol/L) during the preliminary pool bouts of the tournament, while during the direct elimination bouts and in the finals [La] was always higher than 4 mmol/L, and the highest value was found in the winner (15.3 mmol/L) at the end of the competition.[12] On the contrary, during training, the contribution of the lactic metabolism is almost always lower than the anaerobic threshold.[13] The higher lactate values in competitions, compared with training, might also be caused by an additional adrenaline (epinephrine) stimulation of the anaerobic muscular glycolysis.[13]

During competitions, the muscular involvement may be considered relevant, as pointed out by Li et al.,[11] showing a significant increase ($p < 0.05$) in plasma creatine kinase activity in women's épée fencers the day after a competition at national level. The daily energy intake of ten men's épée fencers at international level (3868 ± 954 kcal) was significantly higher than that of 11 men's foil (3176 ± 467 kcal) and 11 men's sabre (3127 ± 640 kcal) fencers of a similar level.[14]

There are other studies on fencing that demonstrate: an increase in bone mineral density,[15] deficiencies of water soluble B_1, B_2 and B_3 vitamins because of perspiration in training and competitions,[16-18] and internally desynchronized circadian rhythms (in some French sabre fencers during the 1984 Olympic Games in Los Angeles), where the physiological synchronization of circadian rhythms would be a predictor of good performance.[19]

Taken together, all these data emphasize the variability of the physiological response during fencing. In fencing, the physical demand is affected by different factors, of which age, sex, level of training and the technical and tactical models utilized in relation to the adversary are of particular importance. Generally, when the technico-tactical abilities of the fencer are better than those of the adversary, the metabolic involvement is high, but always submaximal.[10,13,20] With an increase of the technico-tactical involvement of both fencers, the metabolic and muscular involvement increase at the same time, and the involvement of the lactic metabolism becomes more and more important.

3. Physiological Characteristics

3.1 Anthropometrical Characteristics

The anthropometrical characteristics of some groups of fencers reported in literature are summarized in table III. Based on the calculation of body mass index (BMI), most of the fencers are classified as being of normal weight, but they show a different percentage of body fat, as a result of different training and/or testing protocols. A relative high level of body fat as well as lower values of lean body mass in female fencers may have a negative effect on performance compared with males, and may also reflect their training status.[21]

Fencers show a greater cross-sectional area (CSA) of the dominant forearm, arm,[21,27] thigh[24,27-29] and calf,[24] which are independent of technical level and years of training. Tsolakis et al.,[21] reported a low, but significant, common variance (R^2 = 0.09–0.12) between arm asymmetries and years of training providing some support for a possible influence of training on the magnitude of asymmetry, but the lack of a control group makes a complete interpretation of this trend difficult.[21]

CT scanning showed the medial extensor muscles in both legs of a group of fencers had a larger CSA than the same muscles of a control group of

Table III. Anthropometrical characteristics of fencers (mean ± SD)[a]

Study	Age (y)	Mass (kg)	Height (cm)	BMI (kg/m^2)	Fat (%)	n	Weapon
Tsolakis et al.[21]	11.7 ± 1.1	44.4 ± 11.3	155 ± 11	18.4 ± 3.7	25.1 ± 1.1	16	W
Tsolakis et al.[21]	11.7 ± 1.2	46.5 ± 12.1	152 ± 11	19.3 ± 3.1	22.7 ± 1.2	22	M
Tsolakis et al.[21]	15.3 ± 1.1	64.4 ± 9.1	176 ± 7	20.9 ± 2.3	18.0 ± 0.1	31	M
Tsolakis et al.[21]	15.5 ± 1.1	57.7 ± 8.5	166 ± 7	21.1 ± 2.8	26.7 ± 0.7	27	W
Rivera et al.[22]	17.4 ± 2.3	58.1 ± 4.4	160 ± 4	22.7	22.1 ± 4.7	11	W
Tsolakis et al.[21]	18.7 ± 0.9	60.0 ± 9.9	167 ± 9	21.4 ± 3.3	27.3 ± 1.7	10	W
Tsolakis et al.[21]	19.0 ± 0.8	73.7 ± 9.1	182 ± 6	22.2 ± 1.9	14.3 ± 1.4	8	M
Rivera et al.[22]	19.4 ± 4.4	69.5 ± 15.1	174 ± 5	23.0	14.1 ± 4.8	8	M
Caldarone et al.[14]	19.7 ± 1.6	71.8 ± 6.4	179 ± 6	22.4 ± 1.1	9.6 ± 1.2	10	ME
Caldarone et al.[14]	20.0 ± 2.8	76.0 ± 10.8	179 ± 7	23.6 ± 2.2	12.1 ± 3.2	11	MF
Vander et al.[23]	20.4 ± 2.0	68.0 ± 8.1	175 ± 2	22.2 ± 0.8	12.2 ± 5.1	7	
Roi and Mognoni[24]	21.5 ± 3.4	71.7 ± 6.0	178 ± 4	22.6 ± 1.6	10.1 ± 2.3	33	ME
Harmenberg et al.[25]	21–30	77.0 ± 4.2	184 ± 5	22.7 ± 1.0		10	ME
Caldarone et al.[14]	22.1 ± 4.7	73.1 ± 8.1	177 ± 4	23.2 ± 1.9	12.6 ± 2.9	11	MS
Hoch et al.[13]	23.4 ± 3.5	81.9 ± 9.9	184 ± 8	24.2 ± 2.2		10	
Tsolakis et al.[21]	23.4 ± 4.1	58.8 ± 8.8	166 ± 6	19.9 ± 3.3	22.1 ± 1.1	15	W
Tsolakis et al.[21]	24.4 ± 4.2	74.2 ± 6.2	180 ± 7	22.9 ± 1.3	15.3 ± 0.7	23	M
Koutedakis et al.[26]	25.6 ± 3.7	73.4 ± 3.5	181 ± 4	22.4 ± 0.9	15.3 ± 3.9	7	ME

a Note that all these data are presented mainly for descriptive reasons in the related papers.

BMI = body mass index; **M** = men; **ME** = men's épée; **MF** = men's foil; **MS** = men's sabre; **W** = women.

students and of body builders.[28] This finding reflects the bouncing movements performed in the on-guard position, where the knee joint is flexed by 20–30°, a technique which is popular in modern fencing.[28]

The differences of fat-free CSA of the dominant and non-dominant forearm are always significant (table IV) and female fencers show significantly smaller CSA than males.[30]

Similar asymmetries may be found for the arm (men's foil −9%; women's foil −8%; men's épée −8%; women's épée −10%), the thigh (men's foil −11%; women's foil −13%; men's épée −9%; women's épée −8%) and the calf (men's épée +2%).[30]

Arm asymmetries were evident from an early age (10–13 years), while leg asymmetries were first observed in the 14- to 17-year-old group.[21]

The somatotype assessed according to the Heath-Carter method[31] in the fencers participating in the 2004 Greek championships, was characterized as a central type for men (n = 84, mean endomorphy 3.1, mesomorphy 2.6, ectomorphy 3.2) and as endo-ectomorph for women (n = 68, mean endomorphy 3.8, mesomorphy 1.8, ectomorphy 3.3).[21] Male fencers showed a significant decrease in endomorphy between 10 and 13 years and in subsequent age groups, accompanied by relative stability of mesomorphy and ectomorphy across all age groups. For female fencers, the somatotype components were

Table IV. Fat-free cross-sectional area of dominant and non-dominant forearm of fencers

	Dominant (cm^2) [mean ± SD]	Non-dominant (cm^2) [mean ± SD]	Difference (%)
Men's foil	53.9 ± 4.8	47.6 ± 4.3	−12*
Women's foil	37.7 ± 3.6	33.6 ± 4.0	−11*
Men's épée	58.3 ± 3.9	51.8 ± 3.5	−12*
Women's épée	36.6 ± 2.0	32.2 ± 2.5	−10*

* $p < 0.05$.

not different between 10 year-olds and those over 20 years.[21]

Taken together, the anthropometrical characteristics of fencers show a typical asymmetry of the limbs as a result of the practise of an asymmetrical sporting activity, but they do not seem to reveal an *a priori* predisposal to success. Although some morphological factors may play a role in fencing success, their influence is small when physiological and tactical factors are accounted for.[32]

The fairly new field of kinanthropometry explores the relationships between sports performance and the length ratio of the second digit (2D, index finger) to the fourth digit (4D, ring finger).[33] The 2D : 4D ratio is considered a promising biomarker for the magnitude of prenatal androgen exposure, with effects on the structure and function of the body and the morphology and the neural organization of the brain.[34] For male fencers, the directional asymmetry in digit ratios (i.e. right minus left 2D : 4D), was found to be inversely related to national rankings, and this effect was independent of training intensity and fencing experience.[35]

3.2 Static Strength

Several authors[8,27,28] reported significantly stronger isometric handgrip strength in the weapon hand of about 10%, but endurance strength did not differ significantly.[28] On the contrary, the maximal isometric finger strength was not significantly different between the two hands.[28] Also, the maximal isometric strength of the knee extensors at fixed angles of 30°, 60° and 90° did not show any significant difference between limbs. This is probably dependent on the on-guard position of the fencers, where the muscular activity of both limbs has been shown to be similar.[28]

The handgrip strength asymmetries are the result of asymmetric sport training at sub-maximal intensities. Despite this, the force/CSA ratio (namely stress) of fencers assessed by handgrip does not show any significant difference between the two limbs and between fencers and controls, suggesting that stress is independent of years of training and it is a physiological characteristic of human skeletal muscle (table V).[27]

3.3 Dynamic Strength and Anaerobic Power

Isokinetic assessment of maximal peak torque (MPT) of the knee showed a significant difference between the forward and the backward leg. Both knee extensors and flexors MPT of the forward limb were significantly higher at 60° and 180° per second,[24,28,36] while at lower (30° per second) or higher (300° per second) angular speeds the differences were not always significant. These findings are contradicted by Koutedakis et al.,[26] who reported a lack of statistical differences of MPT between limbs, and stated that their results may be explained by differences in performance levels of their British sword fencers, and also with differences in test protocols.

Functional differences were emphasized considering that the forward knee extensor muscles produce an eccentric action in every lunge for decelerating the body, while the muscles of the rear limb have a more powerful concentric action.[24] A significant difference was also reported between the electromyographic (EMG) activity of the forward quadriceps that was more static, while the EMG activity

Table V. Force and anatomical cross-sectional area (CSA) of the forearm in fencers of different technical levels and in control subjects[27]

	Subjects (n)	Dominant	Non-dominant	Difference (%)
CSA (cm^2)	Fencers (58)	51.7 ± 8.2	45.8 ± 7.8***	−11
	Controls (17)	47.3 ± 2.7*	45.3 ± 3.5**	−4
Force (N)	Fencers (58)	502 ± 126	449 ± 115***	−11
	Controls (17)	469 ± 45*	444 ± 54***	−5
Stress (N/cm^2)	Fencers (58)	9.6 ± 1.6	9.8 ± 1.7	+2
	Controls (17)	9.9 ± 0.7	9.8 ± 1.0	−1

* Significant difference between fencers and controls ($p < 0.001$); *** significant difference between non-dominant and dominant limb ($p < 0.001$; ** $p < 0.005$).

of the backward quadriceps was faster.[37] Peak torques of both knee extensors and flexors were significantly lower during the in-season than the off-season assessments,[26] probably as a consequence of different training programmes during the season.

The long-term effect of a combined physical conditioning and fencing training programme was studied in nine members of the Greek Olympic team over a period of three mesocycles (120 days).[29] The performances in the squatting and countermovement jumps increased non-significantly at the end of the first mesocycle (pre-competitive training phase), while the contact time in the drop jump significantly decreased by about 30% ($p < 0.05$), without significant changes in the jump height. The exercise-related gains were maintained after 20 days of reduced volume that followed the pre-competitive training phase, and in the third mesocycle (maintenance period). The authors concluded that the application of a training period repeated twice (lasting 40 days each) of different strength training methods combined with a typical fencing training programme, followed by 40 days of maintenance period was useful for influencing the neuromuscular performance of elite fencers.[29]

In a group of eight prepubescent males with a fencing training background of 1 year, a successive fencing training programme of one more year was inadequate to alter the normal growth process, assessed by variations in serum testosterone, sex hormone binding globulin, growth hormone and leptin.[38] As a consequence, the changes in arm CSA, handgrip strength and vertical jump performance were not significantly different from those of an age-matched control group.[38]

Maximal anaerobic alactic power (W) was studied by jumping on a force platform. In a sample of 11 top level épée fencers, W was 56.0 ± 6.6 W/kg, with insignificant differences between control subjects and different levels of fencers.[24] A 20-second Wingate-type test performed by British épée fencers of international level showed a peak power of 809 ± 38 W, which was not significantly higher during the in-season compared with the off-season.[36] Even the correlations between dominant/non-dominant leg CSA and jumping performances were absent over a training period of 120 days.[29]

The symmetric tests are not sufficiently specific for an asymmetric sport. Indeed, the segmentary strength assessment carried out with the isokinetic dynamometer, and with EMG measurements, evidenced functional asymmetries that are in relation to typical anthropometrical asymmetries. On the other hand, the data collected in the field through asymmetric tests specific for fencing indicate that the velocity of a technical gesture (forward cross, step, lunge) is a crucial characteristic of high-level fencers[25,39] that tends to constantly increase throughout a training cycle over a number of years.[40]

3.4 Muscular Biopsies

Muscular biopsy specimens were taken from the quadriceps of both legs of four épée fencers. The percentage of type I fibres was 56 ± 12 in forward and 48 ± 12 in the backward legs with differences between +31% and −13% in the percentage of type I fibres between limbs.[28]

3.5 Aerobic Power

A moderate aerobic power is necessary to support the sub-maximal changes of direction of the fencer to achieve the control of the game and to refuel the anaerobic mechanisms during the repeated interruptions occurring through the fencing bouts.

The data of maximum oxygen uptake of fencers ($\dot{V}O_{2max}$) [table VI] show greater values than those reported for sedentary subjects, but are always meaningfully lower than those of subjects practising endurance activities. Only Nyström et al.[28] reported very high values of $\dot{V}O_{2max}$ compared with the other data in the literature, but such differences can be due to various methods of training and do not seem to be strongly related to the level of performance.

Indeed, there are no studies yet conceived for assessing the relationship between $\dot{V}O_{2max}$ and level of fencing performance, and the conclusions of the published studies are contrasting: in one of our papers we have not found meaningful differences of $\dot{V}O_{2max}$ between the four categories of Italian épée

Table VI. Maximal oxygen uptake of fencers

Study	$\dot{V}O_{2max}$ (mL/kg/min) [mean ± SD]	n	Country	Gender and weapon
Nyström et al.[28]	67.3 ± 3.7	6	Sweden	Men's épée
Astrand and Rodhal[41]	61.0	NS	Sweden	NS
Daya et al.[5]	59.3 ± 2.0	9	Ireland	NS
Lavoie et al.[8]	59.0 ± 5.0	5	Canada	Men's épée international level
Iglesias and Reig[6]	58.4 ± 5.3	NS	Spain	NS
Rivera et al.[22]	58.2 ± 6.3	8	Puerto Rico	Men, weapon NS
Koutedakis et al.[26]	58.0 ± 2.6	7	UK	Men's épée international level
Iglesias and Reig[6]	56.5	28	Spain	Men, weapon NS
Stewart et al.[32]	55.5	14	USA	Male college, weapon NS
Lavoie et al.[8]	54.0 ± 5.0	11	Canada	Men's épée provincial level
Vander et al.[23]	50.2 ± 5.3	7	USA	Men's épée NCAA
Roi and Mognoni[24]	48.8 ± 4.0	10	Italy	Men's épée
Di Prampero et al.[42]	47.3 ± 2.5	11	Different	NS
Macarez[43]	46.3 ± 0.9	3	France	Young women, weapon NS
Rivera et al.[22]	45.7 ± 6.2	11	Puerto Rico	Women, weapon NS
Macarez[43]	40.1 ± 2.3	7	France	Young men, weapon NS
Vander et al.[23]	34.2 ± 2.6	7	USA	Men's épée NCAA[a]

a Upper limbs assessment.

NCAA = National Collegiate Athletic Association; **NS** = not stated; **$\dot{V}O_{2max}$** = maximum oxygen uptake/consumption.

fencers,[24] while Stewart et al.[32] found a significant correlation of fencing scores to $\dot{V}O_{2max}$ and Lavoie et al.[8] found significant differences between fencers of international and provincial levels.

The absence of the important role of $\dot{V}O_{2max}$ in fencing performance would be confirmed by the absence of a resting bradycardia that is a typical adaptation to chronic endurance exercise.

In 25 Iranian junior fencers (18.2 ± 1.4 years) the inter-ventricular septum was thicker than in controls (9.55 vs 7.55 mm; $p < 0.05$), but there were no differences in left ventricular end diastolic and end systolic diameter.[44] In contrast, elite modern pentathletes demonstrated significantly increased left ventricular wall thickness ($p < 0.05$) with an insignificant increase in left ventricular internal diameter compared with controls.[45] Besides the completely different aerobic adaptations, these athletes experience a reduced endurance component in comparison to triathletes, combined with a high isometric component associated with fencing during the basic on-guard position, but this endurance component is always lower in individuals who practise fencing only.

4. Psychological Characteristics

The personality traits of 30 national-level women's foil fencers were investigated by Williams et al.[46] These fencers were ambitious, had a desire to succeed, scored highly on abstract thinking, were imaginative and creative. They were fast learners, independent, had a below-average desire to affiliate, were loners, not followers, were aggressive, had a low desire to lead or dominate, but were dominant in personality. The fencers showed average scores on stability and anxiety, were reserved rather than outgoing, and had a low desire to need or be needed. The main difference between high- and low-level competitors was in the area of dominance.

The influence of the emotional strain was evaluated by Hoch et al.,[13] who considered the ratio between noradrenaline (norepinephrine) and adrenaline as indicative of the proportion of physical to psychical strain. In the course of the training fights the physical effort was dominant, whereas an additional strain exists during national championships, where victory or defeat is essential and where adrenaline increased by 525%. Higher cortisol and renin levels were explained by the strong central stimulation and the direct peripheral effect of adrenaline, respectively. The correlations between systolic blood pressure and catecholamines attained statistical significance only during competition.

5. Acquisition of Fencing Skills

5.1 Age

In a study of 58 Italian fencers of international level, the mean age of taking up the sport was 8.4 ± 0.9 years (personal unpublished data). Caldarone and Berlutti[47] observed that the neuro-motor learning capacities are maximal between 6 and 12 years: at this age a good technical execution of the gesture can be rapidly acquired and the coordinative capacities and the tactico-strategic competence finds a fertile training ground in young people of prepubertal age. The young beginners enter their first competitions when they are around 10 years old, then may extend their participation until reaching the Master categories (>60 years).

The mean age of the fencers of the Italian National Team participating in the Olympic Games in Sydney (2000) was 29.1 ± 4.6 years. Colombo and De Ambroggi[48] found that the 415 participants of the 1982 World Championships had a mean age of 24.9 ± 4.7 years (table VII) with no significant age differences between fencers practising different weapons. A similar trend was observed for the 2006 World Championships, except for women's sabre, where the fencers were significantly younger ($p < 0.001$) because women's sabre is a fairly new discipline, introduced only in 1989. Also, the mean age of the winners was lower in 2006 than in 1982. Further studies are necessary for a better understanding of the relationship between age and fencing success.

5.2 Left-Handedness

Left-handers are a minority of the population and they are accustomed to right-handed opponents, so they have a strategic advantage over right-handers. As a consequence, left-handers appear to have advantages in certain sports, including fencing, and so these sports display a disproportionate number of left-handers relative to their incidence in the general population, especially for elite performance.[35] For instance, among the 32 finalists of the World Championships, 13 (41%) were left-handers in 1981[49] and 14 (44%) in 1982,[50] and among the 24 medallists of the 2006 World Championships, 12 were left-handers (50%), but there was only one left-hander (17%) among the six winners.

Left-handed fencers are known to be highly skilled, but is this due to some disorientation of right-handed people facing a left-handed opponent, or are there some differences in competence? To answer this question, Bisiacchi et al.[51] constructed an attentional task for 24 skilled fencers, and found that an advantage for the left hand in the left-handed fencers was found only for the unattended situation. This advantage was related to some anatomical evidence of right-hemispheric control of attention.

Therefore, left-handedness involves a neuro-functional advantage, but it does not seem to be a determining factor for actual top level performance

Table VII. Mean ± SD ages (years) of the participants in the World Championships (WC) of 1982 (Rome, 415 participants, without women's épée and sabre)[48] and 2006 (Turin, 716 participants)

	WC Rome 1982	WC Turin 2006
All the participants	24.9 ± 4.7	25.6 ± 5.1*
Men's foil (8 finalists)	25.3 ± 4.1	24.1 ± 2.7
Women's foil (8 finalists)	25.5 ± 3.5	27.5 ± 5.3
Men's épée (8 finalists)	28.5 ± 3.0	27.7 ± 6.8
Women's épée (8 finalists)		26.8 ± 5.8
Men's sabre (8 finalists)	28.1 ± 5.4	27.5 ± 3.4
Women's sabre (8 finalists)		20.7 ± 3.1*
Winners	30.7 ± 2.1	27.0 ± 6.9

* $p < 0.001$

in fencing. In fact, although left-handed fencers have some strategic advantage at a low level, at a high level, left-handed fencers appeared not to have strategic advantages.[38] Thus, left-handed fencers may be advantaged within lower ranking levels where technique, considered as velocity of execution, is more important than tactical aspects.

Generally, the phenomenon of asymmetry and laterality in fencing needs future multidimensional experimental procedures, as the dominancy in fencing research determined only from the armed hand and not from other specific neurophysiological tests may produce contradictive results.

5.3 Technique

In fencing, the relationships between the performance or the skill and the physical and physiological characteristics are difficult to assess. Notwithstanding this, the analysis of different fencing styles can discriminate between advanced and novice fencers. For instance, skilled fencers initiate a lunge by an extension of the arm rather than with a movement of the foot and they hit the target before the lead foot strikes the floor.[52] Different styles result in different technical solutions, that involve different velocity, acceleration, forces, powers and internal and external work, therefore different energy expenditure. These technical aspects were studied by biomechanical analysis.

One of the first studies in this field[53] demonstrated that fencers were able to reach the target fastest from a deep on-guard starting position. The lunge speed was inversely related to the vertical impulse originated by the rear leg and directly proportional to the horizontal impulse, indicating that drive of the rear leg is a major factor in developing speed and power in the lunge, contributing to success in fencing attacks (lunge and flèche).[52] Cronin et al.[54] showed that time to peak force was the best single predictor of lunge performance, and concluded that one strength measure cannot accurately explain functional performance because other factors, such as body mass, flexibility and leg length, have diverse effects on the adopted statistical models.

An experiment with several different handle angles was conducted to analyse the effect on performance.[55] The optimal handle angle of the fencing foil to provide the best overall performance and avoid wrist injury was found to be between 18 and 21°. A kinematics and dynamic simulation programme was constructed to analyse actual movements and to simulate the effect of variation in fencing style.[56] Five right-handed male fencers of different levels of skill were examined. The results of the study showed that the potential energy was monotonic for the more skilled fencers, while a maximum was present in the less skilled, suggesting a link between coordination and technique. Furthermore, the skilled athletes required less power to hit the target and were faster when hitting the target.

Finally, from analysing speed peaks, trunk and front leg angles, it was found that skilled sabre fencers are capable of performing in a reproducible manner a complex movement which belongs to their specific repertory.[57]

5.4 Perceptual and Psychomotor Characteristics

Fencing coaches frequently affirm that the most important characteristic of fencers is perhaps the quickness of their movements in response to the opponent's actions. Before the start of his or her action, a fencer must analyse and select the visual information provided by the opponent. After recording the eye movements, and considering the number of fixations for every site and their mean duration, Bard et al.[58] demonstrated that: (i) fencing masters and experts have shorter fixation times than beginners; (ii) all subjects have shorter fixation times during the assaults than during the practice with masters; (iii) for all the fencers, the hand guard is the most informative element; and (iv) most ocular movements take place between neighbouring elements.

Once the fencer has clarified from where the information must be taken, it is important to react readily, and for this, good coordination is required to achieve both speed and accuracy. The reaction times of fencers in performances requiring simple and complex responses were the subject of several studies.[59-61] These studies pointed out that with the increase in the difficulty in recognizing a stimulus and choosing the best response, both the nervous and the motor reaction times increase. Pierson,[59] as early as 1956, assumed that reaction time rather than movement time would be a discriminating factor for fencers. Furthermore, fencers were faster than non-fencers in movements of the upper limbs[59] and fencers who had greatest success during the competitive season showed the greatest power during visual rather than auditory conditions.[52] However, it is fairly difficult to find meaningful differences between fencers of various ranking levels when the tests that are utilized are not specific or start from a stationary position.

More recently, Williams and Walmsley[62] introduced recordings of EMG activity during measurement of response times. They affirm that with this method it is possible to study the differences in technical skills of fencers. They suggest that different movement contexts can lead to different levels of coordination between the system controlling posture and that controlling movement. In fact, elite fencers showed more coherent muscle synergies and more consistent pattern of muscle coordination than novice subjects.[63]

Do and You[64] examined whether the maximal speed of the foil is affected by anticipatory postural adjustments (APAs) preceding a voluntary lunge. They found that the maximal foil velocity decreases with the temporal progression of the APAs and reaches its minimal value when initiated at the time of voluntary lunge execution. The centrally programmed APAs elicited in the stepping forward movement induce a refractory period that affects performance of the pointing task. The negative effect on performance of the refractory period may be inhibited with the intensive practice of fencing.[65]

5.5 Tactics

Although movement speed is important, a key factor is the ability of the fencer to recognize the best time for starting an attack in response to the opponent's actions.[64] In other words, an important factor in determining a successful performance is the reaction time in response to a specific stimulus. Harmenberg et al.[25] proposed a test designed to mimic real competitive fencing where the fencer was moving backwards keeping the natural fencing distance and the forward motion was initiated by the extension of the forward arm of the master. In this test, where the stimulus was constant and pre-determined, world-class fencers (including a Swedish Olympic medallist) could be differentiated from beginners and there was correlation between reaction time (but not the movement time) and success within the group of top fencers.

In fencing, the distance between opponents is very close and the crucial problem to solve for hitting a score is to surprise the opponent with an unexpected movement. So in all the combat sports, athletes are trained for deception (feints) and also for preventing deception (tactics).[66] This intriguing aspect is the topic of most discussions between fencers and trainers, but is very rarely studied from a scientific point of view. In a time-motion analysis of 42 women's sword fencers involved in 21 fights during competitions,[7] a significantly higher number of changes of direction (forward-backward and vice versa) was found in each match between fencers of high technical ability than in matches between those with low technical level (133 ± 62 vs 85 ± 25, $p < 0.025$). This finding was claimed to be indicative of the different tactical levels of the two groups.

Di Russo et al.[67] recorded the event-related potentials in simple and discriminative reaction tasks to visual stimuli of 12 fencers with at least 4 years of international championships experience. They found that the ability of the fencers to cope with the opponent's feint is due to switching quickly from an intended action to a new, more appropriate action. This is likely due to a faster stimulus discrimination facilitated by higher attention and a stronger inhibition activity in the prefrontal cortex.

The above cited studies on technical and tactical skill of fencers indicate that there is an evident increased interest in the complex interactions between stimuli and responses involving multiple perceptual and motor processing stages, and also cognitive aspects (for instance, timing, sense of distance, balance and mental readiness against surprise). Further studies are needed to better understand fencing from this neuro-psycho-physiological point of view.

6. Injuries

The reports of fencing injuries are very scarce in the literature and epidemiological large-scale and prospective studies are lacking. As a consequence, it is difficult to draw a reliable panorama of fencing injures and their prevention based on objective data. The most comprehensive review was published by Zemper and Harmer in 1996.[68]

6.1 Epidemiology

The definition of injury is one of the most debated arguments in epidemiology. In fencing studies, an ‘injury’ was considered as a request for medical attention related to injury, and the exposure was calculated from the number of fights during competitions.

The injury rate during 47 regional competitions, involving 1365 fencers, was 3.7 per 100 male participants and 5.6 per 100 female participants, meaning an athlete exposure of 3.7 per 1000 and 5.5 per 1000, respectively.[69] Slightly higher injury rates were found for national and international competitions (11.7 per 100 male participants; 7.8 per 100 female participants; 7.7 per 1000 and 5.1 per 1000 athlete exposure, respectively) involving 1030 fencers.[68] During a Junior International Championship involving 205 athletes, an injury rate of 21.5 per 100 participants, or 51.8 per 1000 exposures, was observed.[70,71] Lanese et al.[72] reported the injury rate during 1 year of fencing training and competitions at a large university for 18 males (27.8 per 100 participants) and 6 females (50.0 per 100 participants) that is 0.10 and 0.18 injuries per 100 person-hours of exposure, respectively.

6.2 Specific Injury Sites

In four studies, the lower extremity was the most frequent location for fencing injuries (table VIII), followed by the upper extremity. Ligament sprains and muscle strains are the predominant injuries.[73] Tendon ruptures were also reported: tibialis anterior in a veteran fencer,[74] and the Achilles tendon of one of the authors of the present paper (DB, during the Olympic Games in Atlanta, 1996). The frequency of these injuries is unknown, but they need surgical treatment and may keep the fencer out of training and competitions for many months.

6.3 Mechanisms of Injury

The injuries caused by the opponent’s weapon (wounds and bruises) are reported to be 48% of those in regional competitions,[69] 55% in the youth categories[78] and 66% during Junior International Championships.[70,71] Anecdotal reports of wounds due to broken weapons are recorded for sabre, which is the weapon with the thinner blade, affecting the dominant hand and the carotid area of the neck.[70]

Contusions accounted for at least one-quarter of all recorded injuries, but non-contact injuries, such as ligament sprains and muscle strains are the predominant types of injury.[68] Heat illness and heat exhaustion caused by the protective gear, especially in hot environments, are also reported.[69,76]

Table VIII. Location and frequency of fencing injuries

	Participants (n)	Injuries (n)	Head	Spine/trunk	Upper extremity	Lower extremity	Other
Roi and Fascì[69]	1365	58	10.3	3.4	55.2	27.6	3.4
Muller-Strum and Biener[75]	105	148	2.0	23.0	20.0	55.0	0.0
Moyer and Konin[76]	NS	322	5.9	9.0	32.9	40.7	1.6
Carter et al.[77]	1603	842	0.6	13.8	30.4	54.6	0.6
Zemper and Harmer[68]	1031	107	2.8	9.3	41.1	46.7	0.0

NS = not stated.

From the 1992 United States Fencing Association survey,[77] the factors contributing to fencing injuries were divided into four categories: (i) personal (48%; mainly inadequate warm-up; poor technique, fatigue); (ii) equipment and facilities (28%; mainly fencing strip, shoes); (iii) behaviour of others (13%; mainly dangerous tactics by opponent); (iv) no identifiable contributing factors (11%).

6.4 Severity of the Injuries

Most of the injuries can be managed with RICE (rest, ice, compression, elevation), and rarely are fencers unable to complete the competition (about 5% withdraw from the tournaments).[68,69] The time loss rate from injury was calculated to be 0.33 per 100 participants and 0.27 per 1000 athlete exposure.[68]

The most dangerous injuries are those caused by the sharp end of a broken weapon. These injuries are defined as rare,[70] although the rate we calculated was 0.6 per 100 male participants (0.2 per 1000 exposures) and may account for at least 10% of the injuries.[68] In most cases these injuries do not preclude the participation to the competition. Unfortunately there are no data on the severity of injuries during practice and training.

6.5 Fatal Injuries

Penetrating injuries are rarely fatal. From 1930 to 1980 only three deaths occurred, but there were four deaths from 1980 to 1994.[68] From 1994 to 2006 there were another four deaths (two during training and two during competitions), suggesting a probable increase of the risk of fatal injury (Harmer, 2006 unpublished data) that needs further investigation.

Most of the fatal injuries have occurred in highly skilled competitors during elite competition. Blade breakage and force of penetration may contribute either singly or in combination with other factors, such as a right-handed fencer opposing a left-handed fencer, the use of orthopaedic grips, and the propensity to make counterattacks. Each of these characteristics was present in a majority of the fatalities, although in different combinations. Further research is needed to determine if modifying one or more of these factors would decrease the risk of fatal injury.

6.6 Prevention

Fencing is characterized by a real risk of numerous minor injuries that may be preventable. After the fatal injury occurred to the famous Soviet foilist Vladimir Smirnov during the 1982 World Championship in Rome, where the opponent's broken blade pierced the mask, the safety standard for blades, masks and clothing were improved, and nowadays they must be certified by the Federation Internationale Escrime (FIE). The protective clothing is made of tough cotton or nylon, with Kevlar fibres. For national and international competitions, dress and plastrons must resist a force of 800 N and mask bib to 1600 N. Blades must be made with Maraging steel. Fencers' equipment is controlled and must be approved by the equipment control before the start of every competition. Because penetration by a broken blade is the most likely cause of serious fencing injury, it is mandatory for every fencer to reduce the risk of blade breakage by checking their weapons regularly in the course of training and competitions and to discard soft and severely bent blades.

It is necessary to remember that penetrating injuries into the orbital region may also be caused by unbroken blades, when the fencers practice without the protective mask. Calvo-Rubal et al.[79] published a very unusual report of this kind of injury that occurred to a fencing instructor. The tip of the foil penetrated into the skull without eye lesions, but with delayed development of an intracranial haematoma requiring surgical evacuation, after which the fencer had a full functional recovery within 2 months.

Considering all the abovementioned observations, the suggestions for injury prevention in fencing fall into three primary areas (table IX):[68] (i) actions that can be taken by participants; (ii) improvements in equipment and facilities; and (iii) administration of fencing competitions. More detailed suggestions for injury prevention in fencing are available from the website *www.britishfencing.com*.[80] In this document, prevention is accom-

Table IX. The three primary areas for injury prevention in fencing

Participants
Warming up
Stretching
Physical conditioning[81,82]
Technique
Mental training
Equipment and facilities
Cushioning of the surfaces
Anti-slipping and cleaned surfaces
Height and width of strips
Strips firmly anchored
Avoid any potential hazard including officials
Fencing shoes
Quality of the blades
Clothing
Administration of competitions
Minimum standard for fencing strips
Rules against dangerous, overly aggressive and inappropriate conduct or tactics
Prevent HIV and hepatitis B virus infections
Medical coverage

plished mainly against traumatic injuries caused by the opponent's weapon and it is underlined that for effective prevention of these kind of injuries, fencers should apply the guidelines, children must be protected by adult fencers, coaches or officials, coaches have the responsibility for safety during training and referees are the guardians of safety in competitions.

It is interesting to note that nearly half of the factors contributing to the fencing injuries were personal (intrinsic) factors under direct control of the fencer, therefore implying that these injuries are preventable.[68] These factors are: inadequate warm-up, poor fencing technique, dangerous tactics, lack of adequate general conditioning, fatigue, overtraining and repetitive movements leading to overuse injuries.

Especially because fencing is an asymmetrical sport, overuse injuries are more common in the shoulder, the back and the pelvic girdle, so it is necessary that primary and secondary prevention be integrated into the daily training schedule of fencers.[83]

As a consequence, successful prevention must involve several steps and several people who carry out specific interventions in terms of structural and educational measures. These interventions need to be closely integrated with the planning of the sports activity itself, going from injury prevention to safety promotion.[84]

7. Conclusions and Recommendations

The scientific literature on fencing is not particularly abundant, but is sufficient to contribute to our understanding of the many aspects of this ancient sport.

Fencing is an asymmetric combat sport that produces typical anthropometrical and functional asymmetries that emphasize the very high level of specific function, strength and control required.

The physical demands of fencing are closely linked to the perceptual and psychological ones, and all are subjected to a continuous succession of changes during the fights based on the behaviour of the opponent. For this reason, it is difficult to identify a significant relationship between a single physiological characteristic and performance. On the other hand, performance is more likely to be linked with perceptual and neuro-physiological characteristics. In fact, the particular stimulus-response situation in fencing is enriched by the need to anticipate the opponent and to mask the true intention with a thin game of feints and counter-feints that must be supported by an adequate psycho-physical condition to prevent central and peripheral fatigue.

Therefore, the study of the tactical aspects of fencing has become more and more vital, and the multi-dimensional model of performance must include the opponent, who is a rather dominant 'signal provider', and must be considered in a dynamic way. Further studies are necessary for a better understanding of this fundamental aspect of all the open skilled sports, but this will necessarily involve many investigators with various competences, as performance in fencing is evidently a multivariate psychobiological phenomenon. Moreover, it is important to find the indicators of tactical abilities, which must be easily measurable so that information can be supplied for training and performance improvements.

Fencing as a sport is not particularly dangerous; however, there is a fine line between a fatal lesion and a simple wound from a broken blade. Regarding the epidemiology, it is necessary to find agreement on the definition of injury, considering not only the type, but also the consequences in terms of duration of absence from training and competitions. Moreover, more prospective studies are necessary for broadening the proposed multi-dimensional model of fencing, with a more precise computation of training time leading to precise information on the incidence of injuries, pathologies and re-injuries. As in every other sport, the prevention of accidents in fencing must be accomplished at various levels and above all must involve the institutions that are responsible for safety in sports.

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