Movement patterns and sensorimotor responses: comparison of men and women in wheelchair fencing based on the Polish Paralympic team

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Abstract

Background and Study Aim: Wheelchair fencing is defined as a psychomotor sport in which coordination predispositions (reaction speed, movements speed, kinaesthetic sensation, and focus of attention) have to go hand in hand with strength and explosiveness in the exercise capacity. The aim of the study was knowledge about the movement patterns among women and men in wheelchair fencing with a particular emphasis on postural muscles.

Material and Methods: The research involved 16 subjects, members of the Olympic team of fencers in wheelchairs (8 women and 8 men). The group of fencers represents international level because they are medal-winners and champions of the Paralympic Games. The task of the subjects was to perform a lunge on the coach's torso at the command given by the coach. Two research alternatives were investigated: in response to visual signal and sensory stimulation. The order of muscle stimulation was recorded using EMG and the movement pattern of the individual muscle activation was registered by application of an accelerometer. In the study, the electrodes were attached to six muscles: on the forearm (ECR RT, FCR RT) and upper arm (DEL RT, TRI RT and BC RT) as well as on the torso muscles: back (EAO RT and LT, LD RT and LT) and oblique abdominals.

Results: As a result of the study, statistically insignificant decrease of sensorimotor response time was recorded in men in comparison to women. The study, however, demonstrated significant differences in the initial phase of the movement pattern in the group of women and men in relation to the torso muscles, as the investigated women subjects activated extensor muscles, whereas men activated flexors. This demonstrates significant differences in the body posture assumed in the initial phase of the attack. A significantly lower bioelectric signal was recorded in the performance of the task response in response to sensory stimulation in men – TRI RT (triceps brachii) %MVC, $p = 0.0005$ and LD (latissimus dorsi) RT, $p = 0.016$.

Conclusions: In the light of the conducted research, it seems necessary to extend the scope of the training process to include postural muscle training with the purpose of strength and explosive power development. The recruitment of additional motor units should promote greater coordination and therefore enhance the speed of movement, both for women and men in wheelchair fencing.

Key words: neuromuscular activity • surface electromyography

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Épée – is the heaviest of the three modern fencing weapons (foil, épée, and sabre), each a separate event, épée is the only one in which the entire body is the valid target area. Épée is the heaviest of the three modern fencing weapons.

Neuromuscular – *adjective* referring to both nerves and muscles [20].

Motor – *adjective* relating to muscle activity, especially voluntary muscle activity, and the consequent body movements [20].

Psychomotor – *adjective* relating to bodily movement triggered by mental activity, especially voluntary muscle action [20].

Motor skill – a skill for which the primary determinant of success is the quality of the movement that the performer produces [21].

Motor skills – *plural noun* the ability of a person to make movements to achieve a goal, with stages including processing the information in the brain, transmitting neural signals and coordinating the relevant muscles to achieve the desired effect [20].

Reaction time – *noun* the interval of time between the application of a stimulus and The first indication of a response [20].

Response time – *noun* the time that it takes for someone to respond to a stimulus [20].

Strength – *noun* the fact of being strong [20].

Paralympic Games, Paralympics – *plural noun* an international sports competition for athletes with disabilities, held every four years in the same year as the Olympic Games [20].

Training session – *noun* a period of time during which an athlete trains, either alone, with a trainer or with their team [20].

INTRODUCTION

Wheelchair fencing as a Paralympic sport offer unique values, as it is capable of the integration of disabled athletes with the community of Olympians without disabilities. At the initial stage of training, it also performs a significant psychosocial role, as it can help of young people regain physical activity after dramatic trauma by enabling them to participate in the activity of the society, including involvement in sports competition at various levels. Just as in the fencing performed in with people without disabilities, the competition is held in three weapons: foil, epée and saber.

In professional competitions such as World Cups, World Championships and Paralympic Games as well as championships of individual countries, the competition is held separately for men and women. However, competition rules stipulate identical rules without differentiation with regard to the gender of fencers. Both men and women compete in the elimination round – competition in this round stops after 5 touches over a bout lasting 3 min. The competition held in a cup system (direct eliminations up to the final include matches comprising three rounds) with 15-touch bout with three-minute intervals [1].

In the practice of fencing, many training elements such as parry practice or individual training sessions performed one-on-one with the coach and exercises are applied so as to imitate the activation of postural muscles performed together without differentiation between women and men. The essence of the matter lies in the identification and individual selection of fencing techniques, practiced throughout practice session with the coach and technical and tactical tasks implemented in the course of the so-called free bouts with partners.

The need to adopt and follow an individual approach to the training process involves the need to follow the development of fencing technique in terms of the structure of muscle tensions registered by EMG. The second important element involves the assessment of the time intervals of technical activities in response to various types of stimulation: sensory and visual. Coaching practice indicates that there may be gender diversity in EMG indicators as well as different responses to visual and sensory stimulation in women compared to men. The literature on the subject does not indicate numerous research reports in the discussed issues. Most research conducted with regard to wheelchair fencing has focused on the issues of trauma and injury, physiological and kinematic aspects of the fencing technique.

An important starting element of the present study is concerned with the classification of disability and assigning categories to particular type of impairment. The researchers of this issue refer to the objectivity of the adopted criteria [2, 3].

In wheelchair fencing, we have to do with the classification of fencers into three categories: A, B, C. Category A includes fencers with the relatively smallest degree of disability, e.g. one after amputation or athletes with limited paralysis within the lower limbs who are free to move their trunk and arms. Category B fencers includes ones who have suffered spinal cord injury and paresis of legs and arms (paraplegics), while category C includes the tetraplegic athletes with four-limb paralysis [4]. This study included fencers classified into categories A and B. Disabled fencers have to train and demonstrate particular dynamics involving many muscles, primarily in the arms in the and forearms, as well as in the torso on the back and in the abdomen. Wheelchair fencing is defined as a psychomotor sport in which coordination predispositions (reaction speed, movements speed, kinaesthetic sensation, and focus of attention) have to go hand in hand with strength and explosiveness in the exercise capacity.

The design of the wheelchairs provides extraordinary dynamic-indicators of motion in the torso together with an arm holing the weapon, which determines the motor skills during a fencing bout. Numerous studies of fencers without disabilities have proved the role of the footwork in the structure of movement patterns playing important postural functions. In relation to wheelchair fencing, an important role is assumed by selected abdominal and torso muscles [5-7].

The research procedure adopted a classification of subjects into women and men representing categories A and B of disability. The essence of the study was to perform a straight lunge on the coach's torso. The role of the coach who participated in the study was concerned with initiating two types of reactions in the subjects, i.e. attacks in response to the visual stimuli and to sensory stimuli.

The aim of the study was knowledge about the movement patterns among women and men in wheelchair fencing with a particular emphasis on postural muscles.

We have verified the following hypotheses:

• the structure of the movement pattern (order of bioelectric muscle activation) represented by the straight lunge on the torso significantly differentiates the group of women and men, in particular in terms of the order of postural muscle activation;
• just as in the case of fencers without disabilities, the decrease of the complex response time (CRT) should be higher in the group of men subjects;
• the group of men should present higher EMG values (%MVC) as an expression of increased movement dynamic characteristics associated with the activation of additional motor units.

MATERIAL AND METHODS

Participants

The experimental group comprised 16 competitors (8 women and 8 men) of the Olympic team in wheelchairs fencing (Table 1). Athletes represent the international level as they include multiple medal winners at the Paralympics Games.

The research was carried out in accordance with a decision of the Bioethics Committee of the Medical Chamber (Resolution No. 237 of 13 December 2016), based on the applicable criterion shown in the Helsinki Declaration regarding the conduct of clinical trials in humans.

Procedures

For the purposes of this study, a 16-channel NORAXON sEMG measurement system (DTS, Desktop Direct Transmission System, Scottsdale, brand) was applied whose accuracy is 16 peaks at 1500 HzDTS Noraxon system – MyoResearch XP Master Edition software was applied to analyze the EMG system tests. In order to standardize the EMG system with the channels (sensors) an accelerometer was used) a wireless unit recording and transferring the EMG signal directly to the PC system (indicators: three-axis wireless DTS 3D accelerometer sensor with following specifications: nominal output range: +/− 6g, sensitivity +/− 0.67 V/g, bandwidth 5Hz to 1.8kHz)

The research procedure was conducted in accordance with the principles of the SENIAM project. Of the 3 tests performed by the competitors in a series of activities (on a visual and sensory stimuli), sample 2 was most often subjected to detailed analysis.

EMG signals have been subjected to smoothing pre-processing involving the estimation of a square root mean over a period of **100 ms**.

Table 1. Summary of information on subjects participating in the study.

Fencer	Age (years)	Body height (m)	Body mass (kg)	Training experience (years)
		Women		
KD	24	1.71	68	13
MF	29	1.74	69	20
PH	28	1.56	48	7
JP	38	1.62	56	6
JW.	17	1.50	50	3
KK	25	1.53	50	4
AS	29	1.45	40	3
RB	36	1.72	70	11
Mean	28.25	1.60	56.38	8.38
SD	6.24	0.10	10.61	5.57
		Men		
G	52	1.80	69	6
AG	17	1.69	60	3
AC	29	1.67	67	11
KR	34	2.00	73	7
DP	44	1.82	74	23
NC	32	1.82	70	18
RT	32	1.81	82	7
SL	29	1.69	55	3,5
Mean	33.63	1.79	68.75	9.81
SD	9.81	0.10	7.84	6.70

Technique– *noun* a way of performing an action [20].

Tactics – *plural noun* the art of finding and implementing means to achieve immediate or short-term aims [20].

Electromyogram *noun* a chart showing the electric currents in active muscles. Abbreviation **EMG** [20].

One of the EMG indicators involves the determination of the maximum value. This phase was also carried out in the MyoResearch XP Mater Edition package. On the basis of the normalization of data over 3 tests, the maximum EMG signal was obtained. The MVC reference value was shown at **50 ms**, for which the mean EMG signal value was the highest. All signals have been normalized to these values and expressed in %.

Complex reaction time (CRT) was another indicator that was subjected to a broader analysis in a given activity. The data with regard to the response times was derived on the basis of the interval between the first significant change of the transmitter signal and the highest value of EMG signal.

The study was preceded by a 20 to 25 minute individual training session held with a coach. Following a standard technical lesson with the coach, the fencer was considered to be prepared for the test procedure. In the study, the electrodes were placed on 9 muscle channels: on the forearm (ECR RT, FCR RT) and arm muscle (DEL RT, TRI RT and BC RT) as well as on the trunk muscles: at the back (EAO RT and LT, LD RT and LT) and oblique abdominals. The index list with muscle names is shown below.

Index with muscle names: RT right side; LT left side; DEL deltoideus middle head; TRI triceps brachii; biceps brachii.

Before initiating the tests, the fencing platform with the wheelchair was set up and the distance from the end of the weapon to the bent arm of the coach was measured (Figure 1 illustrates the manner in which the distance between the tip of the fencer weapon to the coach's elbow was determined – an accelerometer was installed on the guard of the coach's weapon). Throughout the research, the coach initiated the subjects to perform three series of lunge attacks in response to the visual stimulus (movement of the coach's blade from parry quarte to parry sixte and to the sensory stimulus – lunge performed by the fencer at the coach's command marked by detaching their weapon from the one held by the fencer. Figure 2 illustrates attack performed in response to visual stimulus in female fencer.

The present research involved the determination of the characteristics of the movement pattern on the basis of the initiation of muscle activation. Figure 3 and Figure 4 present the order of muscle activation in response to visual stimulus.

Statistical analysis

The research material has been analysed in the program Statistica 13.1 (StatSoft, Inc., USA). The assumption about the normal distribution of the analysed statistical features was tested using the Shapiro-Wilk test. All the hypothesis considered in the paper were verified at significance level $p \leq 0.05$.

Due to the fact that not all the features have met the assumptions of normal distribution, to test. Interdependence of it nonparametric tool was verified by application of the nonparametric Wald-Wolfowitz Runs Test.

The movement patterns were primarily distinct in terms of the initial and final stages, in the other phases significant differences were registered

Figure 1. Adjustment of the position of fencing platform applied for testing.

Figure 2. Attack performed in response to visual stimulus in female fencer.

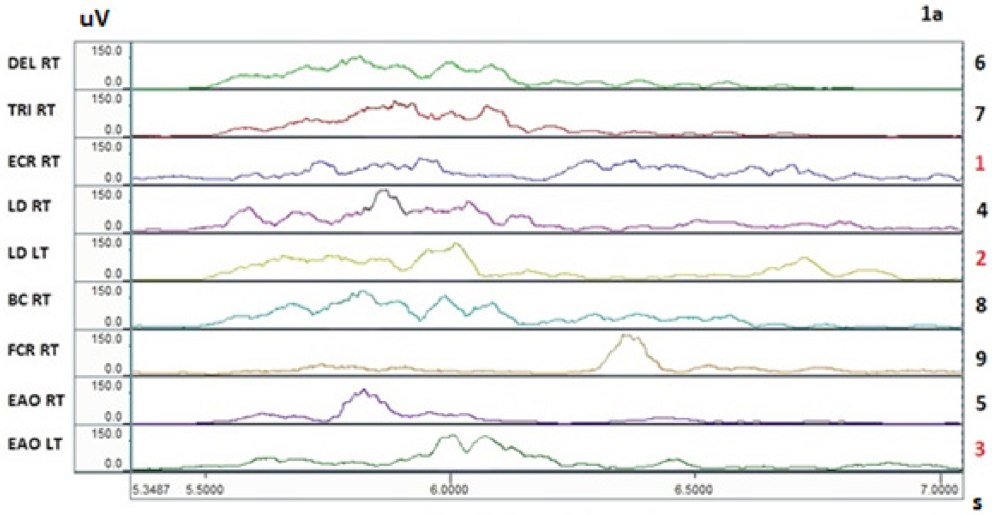

Figure 3. Charts representing muscle activation in response to visual stimulus in women.

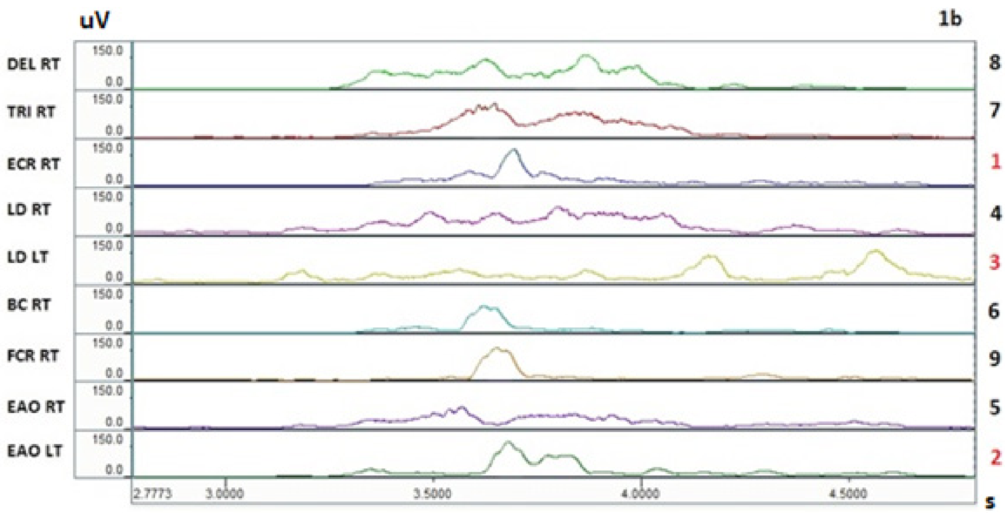

Figure 4. Charts representing muscle activation in response to visual stimulus in men.

with regard to the order of muscle activation. In the women's group, the movement pattern began by initiation of the extensor carpi radialis longus muscle (right), followed by the latissimus dorsi muscle on the opposite (left) side. In the final phase of the pattern, the arm muscles (triceps and biceps brachii) were activated. In the men's group, just as for the case of women extensor carpi radialis longus (right) muscle was activated at the initial stage, followed by the external abdominal oblique muscle on the (left) side, whereas in the final phase no significant differences were observed with the pattern performed by women.

The comparative analysis carried out with relation to the gender of fencers demonstrated significant differences in terms of the values of sEMG signal of the analysed muscle groups. These values were calculated as (%) MVC, in terms of two types of sensorimotor reaction: to visual stimulation (Table 2) and to sensorimotor stimulus (Table 3).

On the basis of the statistical analysis (Table 2) applying the non-parametric test for two independent samples – Wald–Wolfowitz Runs Test – it was found that the time values represented by the mean of 3 tests did not demonstrate significant differences. In contrast, the values of MVC derived from three tests imply that the activation of DEL RT muscle played a statistically significant role ($p = 0.038$, $Z = -2.070$) and EAO RT ($p = 0.010$, $Z = -2.588$) in response to the visual stimulus in both groups. This appears to

Table 2. Statistical analysis (Wald-Wolfowitz Runs Test) applied for analysis of the relations between the mean time taken to perform three trials and values of EMG signal (%MVC) of selected muscles in the group of men and women – visual stimulus.

Muscle	Variable	Wald-Wolfowitz Runs Test			
		Mean Time Women (ms)	Mean Time Men (ms)	Z	p-value
DEL RT	Time (ms)	0.5694	0.49325	–0.5175	0.604773
TRI RT		0.5878	0.55525	0.00000	1.000000
ECR RT		0.5590	0.45350	0.51755	0.604773
LD RT		0.5170	0.47604	0.00000	1.000000
LD LT		0.5668	0.42618	0.51755	0.604773
BC RT		0.5641	0.49956	–0.5175	0.604773
FCR RT		0.6882	0.58524	0.00000	1.000000
EAO RT		0.5285	0.47566	0.0000	1.000000
EAO LT		0.5512	0.42725	–1.5526	0.120508
DEL RT	MVC (%)	116.4395	61.58459	–1.5526	0.120508
TRI RT		114.6910	73.44100	–0.5175	0.604773
ECR RT		115.5005	72.22900	0.5175	0.604773
LD RT		108.3003	78.29338	–1.0351	0.300624
LD LT		105.1589	50.11000	1.5526	0.120508
BC RT		110.8830	72.65520	0.5175	0.604773
FCR RT		122.1163	63.21963	–2.5877	0.009661
EAO RT		100.7880	90.46638	1.0351	0.300624
EAO LT		0.5694	0.49325	–0.5175	0.604773

definitely coincide with the results of muscle activation (% MVC) of both categories and confirms the hypothesis adopted at the initial stage of the present study.

Significant differences were recorded in response to the sensory stimulation in the following muscles (Table 3): triceps ($p = 0.0005$), biceps brachii ($p = 0.016$), flexor carpi radialis ($p = 0.016166$), latissimus dorsi on both sides ($p = 0.016$), external abdominal oblique on the right ($p = 0.016$).

DISCUSSION

On the basis of the analysis, significant differences were established in the initial phase of the movement pattern in the groups of women and men with regard to the torso muscles, as the group of investigated women subjects initially activated extensor muscles, whereas in the men's group, flexor were activated. This indicates differences in the body position taken in the initial phase of the movement pattern.

The results may indicate the need to focus on the initial position of opponents in a wheelchair fencing bout, which may depend on the fencer's height (taller fencers have to perform a bend, whereas lower ones keep an upright position, which seems to be more economical, as it provides an easier defence) due to the ability to balance the body backwards more quickly. These changes may also result from visual control, because higher height fencers are able to easier control the aim of the attack in a slight forward leaning position.

The authors' research on motor patterns of the upper limbs in people with hemiparesis demonstrated the occurrence of motor disorders in both limbs, i.e. also in the limb without disability. Motor skills disabilities were recorded in the areas related to in the coordination of movement, and trunk compensation [8, 9]. On this basis, it can be concluded that fencers in both categories A and B, neuromuscular activation undergoes significant changes even in the elements of the body that are not affected by disability. Therefore, the skills acquired and developed by an athlete

Table 3. Statistical analysis (Wald-Wolfowitz Runs Test) applied for analysis of the relations between the mean time taken to perform three attempts in the test and values of EMG signal (%MVC) of selected muscles in the group of men and women – sensory stimulus.

Muscle	Variable	Wald-Wolfowitz Runs Test			
		Mean Time women (ms)	Mean Time men (ms)	Z	p-value
DEL RT	Time (ms)	0.5015	0.46359	1.36412	0.172531
TRI RT		0.5970	0.57618	1.36412	0.172531
ECR RT		0.6180	0.47610	−1.32822	0.184106
LD RT		0.5131	0.45276	−0.78975	0.429672
LD LT		0.4814	0.32750	−0.25129	0.801594
BC RT		0.5810	0.46151	−1.32822	0.184106
FCR RT		0.6325	0.48841	−0.78975	0.429672
EAO RT		0.5180	0.35216	−0.78975	0.429672
EAO LT		0.4986	0.35816	0.28718	0.773972
DEL RT	MVC (%)	116.5814	97.58438	−1.86669	0.061946
TRI RT		119.3809	86.99154	−3.48210	0.000498
ECR RT		96.7882	83.69278	−0.78975	0.429672
LD RT		118.5470	66.12555	−2.40516	0.016166
LD LT		106.9551	67.14698	−2.40516	0.016166
BC RT		108.6566	65.59269	−2.40516	0.016166
FCR RT		97.9053	47.47259	−2.40516	0.016166
EAO RT		120.3581	78.92070	−2.40516	0.016166
EAO LT		105.6427	90.90730	−0.25129	0.801594

are determined by his individual motility, which is a response to the existing motor dysfunction and results primarily from the individual functional state of the athlete [10]. Therefore, compensation and adaptation associated with individual functional conditions is certain to play an invaluable role in the acquisition of motors patterns in wheelchairs fencing. The compensation system quickly adjusts posture imbalances through muscle synergies, and the anticipatory system provides posture adjustment for voluntary movements to minimize posture disorders [11, 12].

We can emphasized the significant role taken by the torso and abdominal muscles, which perform postural functions and activate in the first place in opposition to the arm muscles [13, 14]. In order to maintain a stable body posture, the central nervous system initiates an anticipatory mechanism that activates postural muscles [15, 16].

Interesting results are provided by the analysis of EMG bioelectrical voltage expressed in terms of %MVC, which illustrates the tendency to generate higher EMG voltage values of most muscles in the group of women in comparison to men. In addition, slightly lower sensorimotor response (CRT) times were recorded in men, in response to both sensory and visual stimuli. The explanation of this phenomenon should be sought in the longer training experience of the fencers, which results in adoption of an economic movement pattern involving the selecting of key muscles that are relevant to the model of a specific movement pattern. This can be associated with the activity of the abdominal muscles in the initial phase in men and therefore leading to the decrease of the initial phase of the movement pattern, which enhances the performance of an attack. However, to minimize the risk of unsuccessful attack, men generate lower tensions throughout an attack, so as to be able to quickly switch to defence by application of the antagonistic muscles group. In this respect, valuable guidelines are provided in the research by [17], whose study demonstrates that slower arm extension in wheelchair fencing was associated with greater energy expenditure and greater problems in maintaining a stable posture in a sitting position.

CONCLUSIONS

As a summary, we can state that the psychomotor response pattern described in this research (a simple lunge at the trainer's torso in response to a visual and sensory signal) forms an original contribution to the assessment of technique in wheelchair fencing. Although selected components of wheelchair fencing technique were previously evaluated in other studies, the present results indicate the movement pattern described by the complex reaction time representing muscle activation and the level of bioelectric signals expressed in terms of EMG. The new approach places an emphasis on the important role assumed by postural muscles: back and abdomen and their effect on the effectiveness of fencing attack [18, 19]. Observations of wheelchair fencing training demonstrate that it is mainly based on individual classes with coaches and free bouts (duels with teammates). In the light of the research it seems necessary to complement the course by training by adding postural muscle training in it for the purposes of strength and explosive power development. The activation of additional motor units should contribute to greater coordination and therefore enhance movement speed.

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