THE SIGNIFICANCE OF SENSORIMOTOR RESPONSE COMPONENTS AND EMG SIGNALS DEPENDING ON STIMULI TYPE IN FENCING

Zbigniew Borysiuk

Faculty of Physical Education and Physiotherapy, Opole University of Technology, Opole, Poland

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The purpose of the present study was to examine reaction time, movement time (MT) and electromyography signals under conditions of tactile, acoustic and visual stimulation. Two groups of subjects took part in the study – one consisting of advanced fencers (n = 12, average age 22.3) having practiced fencing for an average of 8.3 years; and the other consisting of novice fencers (n = 15, average age 14.8) having practiced fencing for an average of 2.8 years. The research tool applied in the study was an innovative system of surface electromyography with peripheral equipment that enabled participants' reactions to tactile, audio and visual stimulation to be recorded. The system made it possible to record RT and MT separately. The subjects were exposed to forty five stimuli in a randomized manner for each type of stimulation. The tested fencers responded fastest to tactile stimuli, then to acoustic stimuli, and in a much slower way to visual stimuli ($p < 0.01$). The advanced fencers exhibited significantly lower values of RT, MT, and EMG in comparison with the novice fencers. Both groups exhibited a decrease in the EMG signal value during the tactile, acoustic and visual stimulation trials, supporting the hypothesis. A slight coincidence of EMG signal curves was also observed in the visual stimuli test. It can be concluded that visual perception lowers muscle tension in novice fencers ($p < 0.050$).

Keywords: Surface electromyography, fencing, reaction time, tactile stimuli.

INTRODUCTION

Apart from assessment of movement precision, another fundamental type of evaluation of motor behavior is measurement of sensor-motor responses, depending on the type of stimuli. It is assumed that an individual who processes information faster in the course of time is more efficient in many types of motor tasks. Reaction time (RT) and movement time (MT) are the basic measures (ms) of the speed of information processes (Schmidt, 1991).

In terms of the training process one needs to take account of the significance of the dominant stimuli characteristic of a particular sport, such as reactions to visual, tactile and acoustic stimuli (Czajkowski, 2001). Quick perception and prompt identification of acoustic stimuli play a significant role in athletic running events, swimming and skating (Starkes & Ericsson, 2003). Combat sports (such as fencing, boxing, and karate) feature a number of requirements as far as tactile and visual perception is concerned. In fencing in particular, apart from the obvious significance of reactions to visual stimuli, responses to the opponent's blade strikes (so called iron sensing) are also vital. What is more, acoustic effects are also important to some extent in fencing, as the fencer's step rhythm enables assessment of the distance between the contestants and determines the choice of footwork techniques (Lukovich, 1986).

RT can be defined as an interval between the appearance of a stimulus (e. g. visual stimulus) and the first bioelectrical muscle activity (Kelso, 1995). MT is an interval between the registered muscle activity and the completed movement. Thus it became necessary to design a device that could examine RT and MT separately along with the EMG signal. As we know, most movement reactions in real sport are made in a repetitive sequence manner, and thus a system able to register such movements was developed. For this purpose, the threshold of electromyography signal detection was established. This was necessary as empirical studies indicated that subjects often tensed their muscles excessively before testing, which caused a failure in the registration system (Borysiuk, 2000).

Studies of responses to stimulation in sport have been carried out by Williams and Grant (1999) and Abernethy (1996), who suggest that the RT to (receptive tactile) stimulation falls between 90 and 130 ms, to acoustic stimuli from 20 to 50 ms, and to light signals from 180 to 200 ms. Earlier studies examining different kinds of fencers' RT reached similar conclusions (Tyszler & Tyszler, 1995), and also there was also a finding that advanced athletes displayed a considerably shorter RT in their responses to visual stimuli. The Borysiuk's and Zmarzly's (2005) study of physically active students using the surface electromyography (sEMG) system showed that RT to tactile stimuli (RTT) was about

20 ms shorter than RT to acoustic stimuli (RTA), and about 80 ms shorter in RT to visual stimuli (RTV). An innovative system of information registration was used in this research, in conjunction with sEMG (De Luca, 1997). This new approach was motivated by the need to separate data about information processes taking place in the central nervous system (RT), from the movement itself (MT).

The following research questions were formulated:

1. Does the type of stimulation influence RT, MT and EMG signal values in advanced and novice fencers?
2. How significantly do the parameters of information processes differ in advanced and novice fencers?

The adopted hypothesis predicted that the RT, MT and EMG parameters differed considerably depending on the type of stimulation, and that they were significantly reduced in the advanced fencers.

Thanks to application of the beginner expert paradigm, certain proposals can be suggested to fencers. The differences in RT, MT and EMG can serve as a database for development of motor habits, understood as sensormotor responses to tactile, acoustic and visual stimuli.

METHODS

Participants

The participants were divided into two groups. The group of advanced fencers (n = 12, mean age 22.3) consisted of athletes who had been actively practicing fencing for a mean of 8.3 years. The group of novice fencers (n = 15, mean age 14.8) consisted of athletes who had been practicing fencing for a mean of 2.8 years.

The study was preceded by numerous piloting studies, which made it possible to choose the most optimal methods of measurement. The range and methodology of the experiment gained the approval of the lead author's institute's Bioethics commission of scientific research (13. 4. 2006).

Instrumentation

From the standpoint of physical culture sciences, i.e. muscle physiology and psychomotor reactions, the system of surface electromyography (sEMG) seems to be the most useful. Following De Luca (1997) three types of sEMG application can be distinguished:

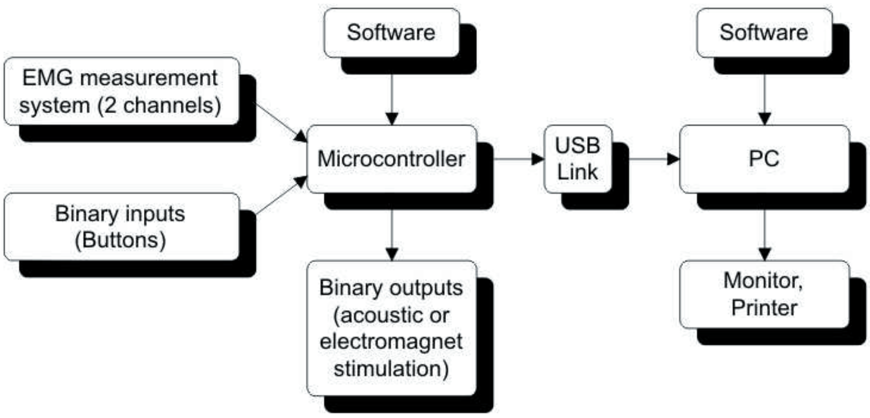
- establishment of the muscle activation time, i.e. the start and finish of muscle stimulation,
- assessment of muscle strength,
- establishment of the muscle fatigue index through analysis of the spectrum of signal frequency.

The first use of sEMG, i.e. setting the muscle activation time, can be also employed in diagnostics of information processes. This innovative application would necessitate a separate analysis of parameters of information processes in the central nervous system, interpreted as reaction time (RT) and movement time (MT). RT is the interval between the occurrence of the stimulus (e.g. visual) and the first bioelectrical activity of the muscle. MT is the interval between the registered muscle activity and the completion of movement. It would be necessary to design a device capable of calculating these parameters as well as the value of muscle activation (μV).

Measurement system

The measurement system consists of the analogue and digital parts (Borysiuk & Zmarzly, 2006). Fig. 1 presents the respective flow chart. The analogue part allows pre-amplification and filtering of the EMG signal. The signal is then digitalized and transmitted to the microprocessor. The microprocessor input is equipped with the switching circuit (buttons). The applied software allows synchronizing measurement samples, digital prefiltering and generation of data transfer protocol. The data is transferred with the aid of USB 2.0 (Universal

Fig. 1
Flow chart of the measurement system



Serial Bus). The digital signal representing the EMG voltage is sent to the PC. The software allows detection of the latency time, motor reaction time and synchronization with the visual impulses. Moreover, the PC collects data and studied parameters and the subject's characteristics and places them into a database.

PC software

The software consists of modules responsible for data acquisition, signal processing, setting the signal parameters and visualization and storage of measurement results. The data transfer module ensures the transfer of synchronic data representing the measured EMG signal. The data is processed, digitally filtered and buffered. A respective module determines the measurement sequence consisting of cyclic light impulses in a specific color. The number of impulses and intervals between them can be regulated in a wide spectrum. There is a possibility of random timing. Furthermore, the sequence may include interfering impulses in different colors and quantity. On the basis of the time difference between the occurrence of the light impulse in a specific color and the signal of muscle activation, the motor reaction time and latency time are detected. The time course of the EMG signal, respective time intervals and the voltage range during reaction are visualized during measurement. At the same time respective characteristics are being generated. After the measurement the results can be stored in a database or saved as graphic files (JPG).

Testing station with peripheral devices

The testing station consists of a PC and an electromyograph connected to two pairs of electrodes and the reference electrode through binary outlets. The electromyograph is operated from the control panel. Since the computer screen can emit only visual stimuli the testing station was also equipped with a loudspeaker emitting acoustic signals and an electromagnet generating tactile stimuli (Fig. 2).

Fig. 2
The subject is waiting for a tactile signal (an electromagnet bolt hits against the palm)

Procedures

The participants responded to singular tactile, acoustic and visual stimuli. Their responses were recorded as simple reactions classified into different types. During the study three test trials were carried out in which the sEMG system emitted 45 tactile, acoustic and visual stimuli. The three trials were separated by two ten minute breaks, where were used to avoid sensor-motor facilitation and thus to obtain more objective results. RT, MT and EMG were registered in all trials:

1. In the tactile stimuli test a computer assisted electromagnet was used. The electromagnet bolt was placed in the plate on which the subject's palm of his/her dominant hand rested. After the bolt hit against the palm, the subject pressed the button with his/her fingers, covering a distance of 35 mm.
2. The acoustic signal was emitted by a speaker connected to the EMG apparatus. The subject pressed the panel button following each stimulus in the same way as in the tactile stimuli test.
3. The visual stimulus was displayed on the computer screen as a red circle taking up about a quarter of the screen. Immediately after noticing the signal the participants had to press the button in the same way as in the previous tests.

In all the trials, time intervals in stimuli emission were set at random between 1 and 5 seconds (Fig. 3).

Statistical analysis

The conformity of results with the normal distribution was examined. Friedman's ANOVA was chosen as a nonparametric test as this criterion was not satisfied. A t-test for dependent variables was chosen for the analysis of the subjects' internal structure. The inter group analysis results were represented graphically by way of unweighted means.

RESULTS

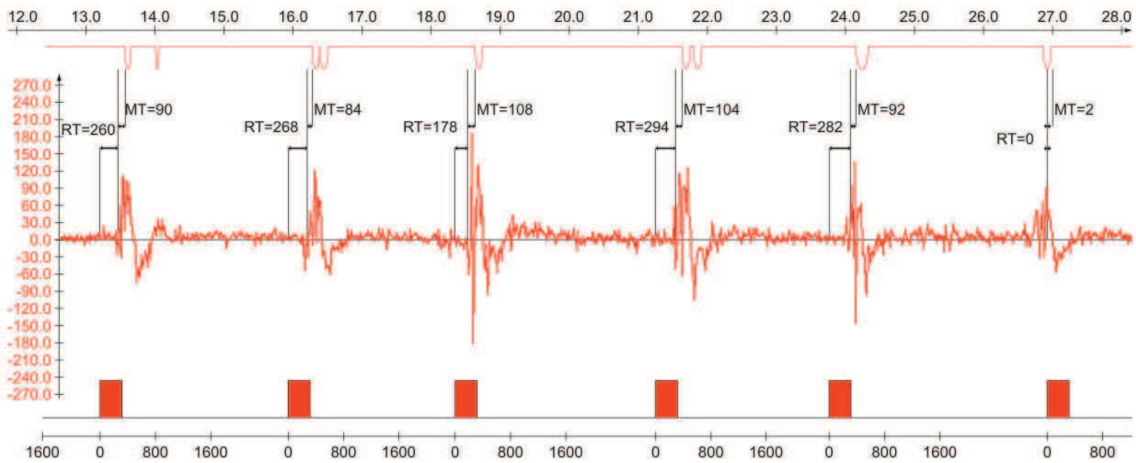
The system registered RT, MT and EMG to tactile stimuli (RTT, MTT, EMGT); acoustic stimuli (RTA, MTA, EMGA) and visual stimuli (RTV, MTV, EMGV).

Advanced fencers

The collected data confirmed the assumption that the fencers achieved the best results in reaction to tactile stimuli by reducing RT for about 21 ms in their responses to acoustic stimuli and 75 ms in their responses to visual stimuli (TABLE 1).

The t-test for dependent variables confirmed significant differences between the three indices of reaction time: RTV v. RTT ($p < 0.001$), RTV v. RTA ($p < 0.001$) and RTT v. RTA ($p < 0.021$). There were no significant

Fig. 3
EMG signal curve with RT and MT marked values



differences in the MT parameters between 214 and 221 ms. The level of statistical significance for MT of the three kinds of stimulation amounted to MTV v. MTT ($p < 0.819$), MTT v. MTA ($p < 0.698$), MTA v. MTV ($p < 0.601$), respectively. The obtained results were similar as the subjects had to cover the same distance (35 mm) using their fingers. The significant time differences in RT in the three trials had no influence on MT fluctuation.

The collected data point to a significant variability of EMG parameters (TABLE 2). The highest values concerned the differences between EMGA and EMGV ($p < 0.002$) and between EMGT and EMGV ($p < 0.003$). As far as the differences in EMG signals to tactile stimuli and acoustic stimuli are concerned, the level of significance was $p < 0.048$. The results showed that the tactile and acoustic stimulation caused a lower EMG signal. They indicate that the participants' response to visual signals causes a decrease of muscle tension without effective RT reduction.

TABLE 1
Variability indicators of RT, MT depending on the type of stimuli with advanced fencers

Variable	Average rank	Sum of ranks	Average	Standard deviation
RTT	1.250	15.000	125.250	24.110
MTT	4.833	58.000	219.833	33.108
RTA	2.1667	26.000	146.166	29.941
MTA	4.250	51.000	213.666	52.908
RTV	3.416	41.000	200.166	28.856
MTV	5.083	61.000	220.833	20.818

TABLE 2
Variability of EMG signal on tactile, acoustic and visual stimulation with advanced fencers

Variable	Average rank	Sum of ranks	Average	Standard deviation
EMGT	2.750	33.000	716.833	196.081
EMGA	2.000	24.000	585.167	52.958
EMGV	1.250	15.000	512.333	61.705

Novice fencers

The collected data confirmed the assumption that in reactions to different stimuli novice fencers achieved the best (the lowest) RT values, ie: RTT, RTA and RTV. The following differences were noted: RTV v. RTT ($p < 0.001$) and RTV v. RTA ($p < 0.001$). There were no significant differences between RTA and RTT ($p < 0.378$). An analysis of mutual dependencies for MT did not show any significant differences in particular trials (TABLE 3).

TABLE 3
Variability indicators of RT, MT depending on the type of stimuli with novice fencers

Variable	Average rank	Sum of ranks	Average	Standard deviation
RTT	1.733	26.000	149.067	28.255
MTT	4.400	66.000	225.733	31.263
RTA	1.600	24.000	164.267	45.731
MTA	3.533	53.000	217.333	55.068
RTV	5.467	82.000	243.733	42.568
MTV	4.267	64.000	232.067	51.149

Significant differences were noted in the value of the EMG signal for the three kinds of stimulation. A similar decrease in the EMG signal value was noticed in the novice fencers as well as in the advanced fencers (TABLE 4). Bioelectrical muscle tension expressed by a decreasing EMG value displayed a linear tendency: EMGT v. EMGA ($p < 0.001$), EMGT v. EMGV ($p < 0.001$) and EMGA v. EMGV ($p < 0.004$).

TABLE 4
Variability of EMG signal on tactile, acoustic and visual stimulation with novice fencers

Variable	Average rank	Sum of ranks	Average	Standard deviation
EMGT	2.933	44.000	904.600	153.677
EMGA	1.867	28.000	763.667	99.139
EMGV	1.200	18.000	603.600	142.931

EMG – electromyography
EMGA – electromyography acoustic
EMGT – electromyography tactile
EMGV – electromyography visual
MT – movement time
MTA – movement time acoustic
MTT – movement time tactile
MTV – movement time visual
RT – reaction time
RTA – reaction time acoustic
RTT – reaction time tactile
RTV – reaction time visual

Comparative analysis of parameters of different kinds of stimulation for advanced and novice fencers using a t-test with a separate variance assessment

In the cases of each of these three kinds of stimulation one can observe significant RT differences as far as tactile ($p < 0.029$) and visual ($p < 0.057$) indices between the tested groups were concerned. It is vital that the greatest differences concerned most RT to tactile stimuli; slight differences were recorded in responses to acoustic stimuli ($p < 0.249$). A characteristic tendency is the lack of significant differences concerning MT in the three trials. This suggests that novice athletes may compensate for delays in processing sensual information (expressed by RT) with their speed of movement (expressed by MT) (Fig. 4).

Both groups featured an expected drop in the EMG signal value in the tactile stimuli trial, acoustic stimuli trial and visual stimulation trial. A slight coincidence of EMG signal curves could also be observed in the visual stimuli test. This may suggest that visual perception lowers the novice fencers' muscle tension ($p < 0.050$) (Fig. 5).

DISCUSSION

The research was aimed at estimation of reaction time (RT) and movement time (MT) in fencing. According to fencing experts, some elite fencers feature instant RT and MT. There are, however, some elite fencers whose pace of information processing is very fast, but the performance of their movements is relatively slow albeit accurate (Lukovich, 2003). The study used three types of stimulation (tactile, acoustic, visual) considering the fact that success in fencing, unlike in many other combat sports, depends on the time of response to these three types of stimulation. An innovative EMG system not only allowed registration of muscle tone during the tests but also registration of information from any number of repeated movements.

The authors used experiments – considering the specificity of fencing responses – measuring simple reaction time. It was assumed that a number of motor habits in sport would appear in the form of single sensor-motor responses (Poulton, 1957), (Czajkowski, 2005). For instance, a simple reaction can be a response with a trained movement to a known stimulus. In fencing, simple reaction takes place when a fencer responds with a thrust or a parry to a familiar stimulus (coach's signal) (Borysiuk, 2006). What is unknown is when exactly the coach would make the movement. This model of simple reaction is the basis of one of the most widely applied training methods in combat sports, i. e. exercising a given action in response to the coach's signal (Salczenko, 1980). That is why the stimuli in the present study were emitted at random in the range between 1 and 5 seconds.

The analysis of the study results confirmed the initial hypothesis about different reaction times, depending on the type of stimulation (Kandel et al., 2000). The responses to tactile and acoustic stimuli were significantly faster than responses to visual stimuli. These differences were associated with neuronal transduction. It is commonly asserted that reaction to visual stimuli is associated with a considerable number of synaptic links with the retina. It can be assumed that significantly faster reactions to tactile stimuli are due to the large concentration of receptors in the finger pad (about 2000) as well as due to the system of conduction of impulses and the speed of stimulation of cortical areas of somatic sensation (Enoka, 2002). Finally, the efficiency of the auditory system depends on the receptors in the spiral organ of the middle ear cochlea. The impulses are conducted by sensory neurons in the auditory canal to the temporal lodes of cerebral cortex. According to Welford (1980) acoustic stimuli cover this distance in 10–15 ms.

Fig. 4
RT and MT profiles as dependent variables for advanced and novice fencers

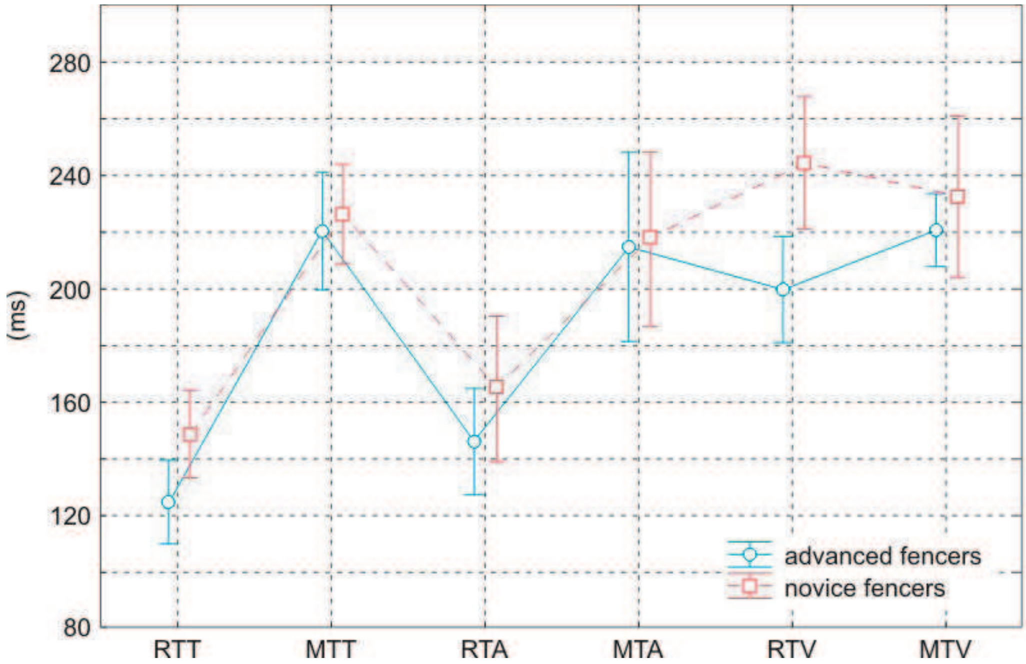
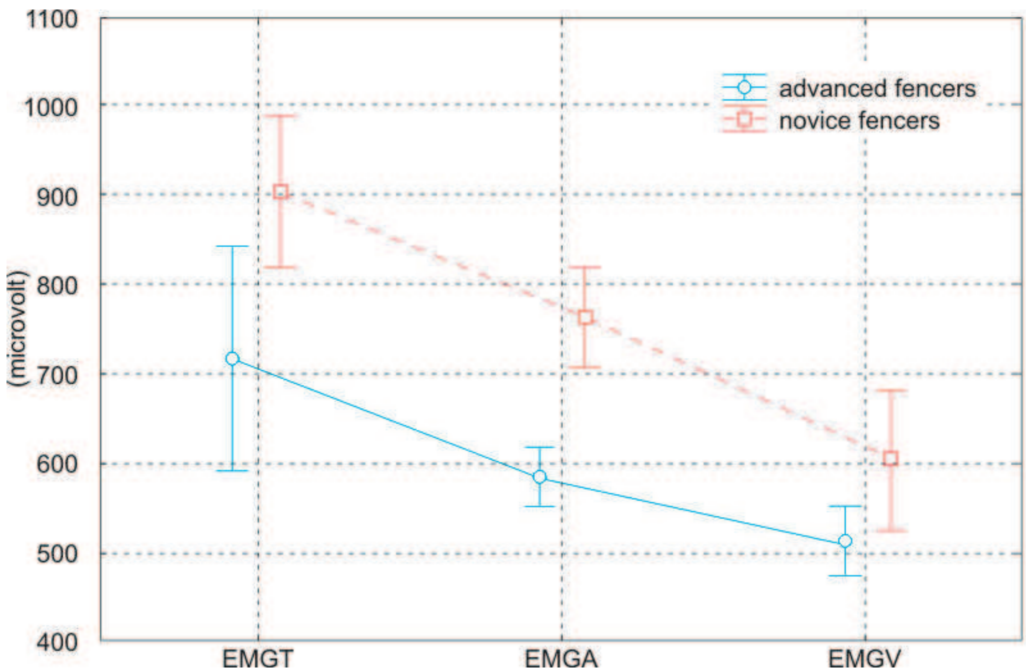


Fig. 5
EMG signal profiles as dependent variables for advanced and novice fencers



The obtained results are in accordance with the results of Abernethy, Woods and Parks (1999) of their study of athletes. However, they are slightly different from the data of Welford (1986) and Luce (1986), who studied young people featuring an average level of physical activity. According to their findings, RT to acoustic stimuli amounted from 140 to 160 ms, and it was shorter from 20 to 40 ms in comparison with responses to tactile stimuli. The aforementioned differences indicate that fencing training affects the speed of information processing in each kind of stimulation. At the same time, the use of a fencing weapon had a decisive influence on the improvement of reactions to tactile stimuli, which is of crucial significance in fencing.

The reaction time profiles of novice and expert fencers revealed significant differences in RT to acoustic, tactile and visual stimuli. Characteristically, the reactions to acoustic stimuli revealed no significant differences. One may, therefore, conclude that reactions to tactile and visual stimuli can be effectively exercised. A similar tendency was observed in movement times of sensor-motor reactions to the three types of stimuli. It shows that one's predispositions to perform fast movements appear at the early stages of training and can be further developed only to a limited extent. It can be claimed that the type of stimulation, as opposed to reaction time (RT), does not significantly affect the variability of movement time (MT) parameters. The greatest differences between RT and MT, between experts and beginners, were, however, noted in reactions to visual stimuli. This shows that fencing training greatly reduces the information processing time in reaction to visual stimulation. A long term fencing training program, held under conditions of permanent time shortage, greatly affects the speed of the constitutive information processes (identification of stimuli, choice of response and reaction programming) as attributes of the decision making speed. The effectiveness of the information processing speed is related to the development of cognitive processes such as analysis of initial signals, concentration and divisibility of attention. The advanced fencers' ability to produce a fast reaction conditions the feeling of pace, which is an important part of fencing shock tactics.

Significant differences were observed between EMG values, which were much higher in the novice fencers in their reactions to tactile, acoustic and visual stimuli. Thus, the higher capacity of expert fencers reduces the tension of muscles involved in performance of the test. This relationship has been confirmed by many combat sports experts, e. g. Czajkowski (2005), Sadowski (1999).

The tactile system delivers information gathered in tactile receptors (Meisner's and Rusffini corpuscles). Once the stimulation strength exceeds the threshold of activation of sensory nerves, the signals are activated and transmitted directly to the brain. In combat sports tactile perception plays a very important role next to visual perception. Eastern martial arts, boxing and fencing are contact sports in which the feedback about the strength and type of tactile stimuli determines the fighter's choice of sensor-motor responses. What is characteristic of the historical development of fencing technique is the fact that even the most basic fencing movements, including thrusts, in all kinds of fencing weapons, commence with the contact between the master's and student's blades. The master's release is a signal for action. Also acoustic stimulation is crucial for cognitive processes in fencing as anticipatory perception of other stimuli. Acoustic information consists of such components as perception of the rhythm of movements, their frequency, timing and sound pitch and amplitude. The importance of hearing in sports involving artistic expression has been widely discussed in literature. In fencing (Szabo, 1977), (Czajkowski, 2001) footwork training is based on the feeling of rhythm relative to the concept of fencing pace. Losing the proper rhythm during offensive actions in the use of conventional weapons (saber, foil) usually ends in relinquishing the right of way and exposes fencers to defeat in particular bouts.

Visual perception serves as a framework for sound signals. In other words, visual memory is like a map demonstrating auditory expression relative to motor proprioception. It can be concluded that visual information is complementary information in the process of making and adjusting decisions (Evangelista, 2000; Lukovich, 2003).

CONCLUSION

1. Assuming that a study of sport mastery development for several years from the novice to the master level is not practically feasible in longitudinal research, an informative beginner expert paradigm was adopted (Schack, 2003).
2. The obtained results confirm other reports concerning fast processing of tactile and acoustic information as opposed to visual information in athletes and sedentary and moderately physically active students (Starkes & Ericsson, 2003).
3. The research shows that novice and expert fencers differ significantly in their times of sensor-motor responses to tactile and visual stimulation. The expert fencers' sensor-motor responses were significantly reduced in reaction time (RT), whereas non significant differences were observed in movement time (MT). The acoustic stimuli did not display any variability. These results prove that fencing training consisting of the application of blade work (parries and binds) in individual sessions with a coach, affects the development of perception skills and processing of tactile stimuli. The greatest differences were observed in the processing of visual information, which was decisively faster in the expert fencers.
4. Important conclusions can be drawn concerning the EMG signal, which reveals lower bioelectrical tension in expert fencers' muscles in the cases of these three types of stimulation. The expert fencers responded faster, however more economically and sensibly, without generating unnecessary bioelectric tension. The similarity between the tests and real fencing actions made the expert fencers reproduce the motor patterns in the tests almost automatically.

5. The present research reveals differences in the quality, structure and organization of motor patterns in performing motor tasks among expert and novice fencers. These differences are associated with the formation of neuronal as well as central representations. At a high sports level their organization is multi-hierarchical allowing for the effectiveness and repeatability of responses which are determined by the spatial and temporal aspects of movement organization.

The research conclusions can be useful guidelines for coaches in their development of motor patterns during a long term perceptual training program, based on the concept of KR (knowledge of results) feedback which considers time as a variable affecting the organization of motor programs.

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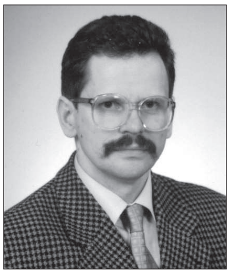
VÝZNAM KOMPONENTŮ SENZORIMOTORICKÉ RESPONZE A EMG SIGNÁLŮ V ZÁVISLOSTI NA TYPU STIMULŮ PŘI ŠERMU

(Souhrn anglického textu)

Cílem této studie bylo zkoumat reakční čas (RČ), pohybový čas (PČ) a elektromyografické signály za podmínek taktilní, akustické a vizuální stimulace. Studie se zúčastnily dvě skupiny osob – jedna zahrnovala pokročilé šermíře (n = 12, průměrný věk 22,3), kteří se šermu věnují průměrně 8,3 roku, druhá pak zahrnovala začínající šermíře (n = 15, průměrný věk 14,8), kteří se šermu věnují průměrně 2,8 roku. Výzkumným nástrojem užitým při této studii byl inovativní systém povrchové elektromyografie s periferním vybavením umožňujícím zaznamenat reakce účastníků na taktilní, akustickou a vizuální stimulaci. Systém umožňoval zaznamenávat zvlášť RČ a PČ. Účastníci byli vystaveni čtyřiceti pěti náhodně voleným stimulům pro každý typ stimulace. Testovaní šermíři reagovali nejrychleji na taktilní stimuly, dále na akustické stimuly a teprve mnohem pomaleji na stimuly vizuální ($p < 0{,}01$). Zkušenější šermíři vykazovali ve srovnání se začínajícími šermíři významně nižší hodnoty RČ, PČ a EMG. Obě skupiny vykazovaly při taktilních, akustických a vizuálních testech sníženou hodnotu signálu EMG, což podporuje hypotézu. Při vizuálním stimulačním testu byla také pozorována mírná shoda signálních křivek EMG. Lze formulovat závěr, že vizuální percepce snižuje u začínajících šermířů muskulární napětí ($p < 0{,}050$).

Klíčová slova: povrchová elektromyografie, šerm, reakční čas, taktilní stimuly.

Dr. Zbigniew Borisiuk



Opole University of Technology
Faculty of Physical Education and Physiotherapy
ul. Prószkowska 76
45 758 Opole
Poland

Education and previous work experience

Doctor of physical education science, graduated the Academy of Physical Education in Warsaw; doctor's dissertation at Academy of Physical Education in Katowice. Successfully links theory with practice as a coach of the National Polish fencing team. In 1993 he trained British fencers and gave lectures to instructors and coaches as a result of the agreement with the Scotish national fencing federation. His students have won the titles of the World Champion and European Champion of juniors. He conducted research in the human kinetics area and the influence of psychomotor factors on the effectiveness in combat sports. Member of European college of sport science and International association of sport kinetics. Close cooperation with Faculty of Human Kinetics at Technical University of Lisbon. The author of tens papers in motor control field, coaching and methodology of fencing published in Polish and foreign magazines and books.

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