Prevalence of Carpal Tunnel Syndrome (Cts) In Civil Shooters: Retrospective Neurophysiological Evaluation

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Research

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Abstract

Background: Shooting may impact the development of mononeuropathies in upper extremities nerves or cervical disc-root conflicts. The study aimed to assess whether shooting sports trained with a handgun by civilians are a risk factor of carpal tunnel syndrome (CTS) and other neuropathies of the upper extremity nerves.

Method: Neurophysiological studies utilising electromyography (at rest-rEMG, during maximal contraction-mcEMG), electroneurography (ENG) and motor evoked potential (MEP) were applied in nine shooters (rigorously screened as positive using clinical examination for carpal tunnel syndrome among the population of 42) to confirm pathologies.

Results: Increased muscle tension in rEMG and simultaneous decrease of motor units activity in mcEMG were recorded both in upper extremities of proximal and distal muscles in shooters than in healthy controls-volunteers, ENG examination confirmed CTS in shooting hand of four persons (4/42, 9,5%); all examined subjects suffered from brachial plexus pathologies on both sides (according to MEPs examinations) and two had ulnar neuropathy at the wrist on shooting side.

Conclusions: Shooting is a moderate risk factor for CTS and significant for brachial plexus neuropathies.

Trial registration: The Bioethics Committee of Poznan University of Medical Sciences approved the study (decision number 554/17 of 22 June 2017), performed following the Declaration of Helsinki.

Background

Shooting position enforces sustaining overloading at wrist, elbow and shoulder, which may cause dysfunction of neural signals transmission at these three locations within the anatomical passage of upper extremity nerve branches. Previous studies related to mentioned changes in sports and military disciplines like golf [1] and archery [2] showed with neurophysiological approach abnormalities of muscles motor units activity responsible for grasping and extending. Analysis of available literature does not provide neurophysiological proofs of similar pathologies except diagnosis of radial nerve palsy induced by military shooting training [3]. It should be expected that dysfunction of the motor system in shooters caused by both holding of a handgun and a recoil impact may contribute to the development of peripheral neuropathies or injuries of nerve fibers at levels of an arm or a spine what was presented by Zeman and Pitr [4]. However, they did not use the precise instrumental method to ascertain such dysfunctions and focused mainly on spine pathologies evaluated with clinical examinations. It can also be assumed that long-lasting history of shooting influences neuropathies' advancement like carpal tunnel syndrome (CTS), ulnar nerve neuropathies at wrist or elbow or changes in fibers of brachial plexus. The knowledge gap may lie in either low incidence of complications or using the low sensitive tools to evaluate pathologies. Modern clinical neurophysiological studies like electroneurography (ENG), electromyography (EMG) and recently motor evoked potential (MEP) studies provide precise evaluations of sensory and motor deficits; in our study we applied all mentioned techniques.

Methods

Aim

The study aimed to assess whether shooting sports trained with a handgun are a risk factor of CTS and other neuropathies of the upper extremity nerves. The zero hypothesis is that shooting does not cause peripheral mononeuropathy or predispose shooters for disc-root conflicts.

Study design

Figure 1 provides a visual presentation of the overall design and course/flow of the study. We recruited shooters meeting the inclusion criteria, who then underwent screening for CTS. Those who were screened positively were followed by a neurophysiological examination.

The preliminary sample included 50 members of local shooter club. Prior to the screening, subjects were required to: confirm the history of systematic training with a handgun (minimum 6 months) and sign written informed consent for participation in the study. Exclusion criteria included: severe spinal or head injury, history of stroke/other neurological and autoimmune diseases, recent pregnancy, the presence of a pacemaker or a cochlear implant. The Bioethics Committee of Poznan University of Medical Sciences approved the study (decision number 554/17 of 22 June 2017), performed following the Declaration of Helsinki. All procedures were performed following the Declaration of Helsinki, including studies on healthy people. Data on anthropometric properties and details concerning shooting practice of nine neurophysiologically examined shooters were collected (Table 1). As a control population we recruited a group of healthy volunteers (N = 9; equal to number of neurophysiologically examined subjects) with the similar age, BMI and prevalence of dominant hand (right). They have been examined with the same neurophysiological methods as applied for shooters to obtain recorded parameters' reference values. Among clinical methods of evaluation, we used three subtests: 1) von Frey's filaments test (vFf) (towards changes in sensory perception [5, 6]; 2) Tinel-Hoffman sign – (towards pathologies of median nerve [7], 3) history of CTS specific symptoms. When at least one positive result was achieved a shooter was enrolled into neuropsychological examinations. The final sample included two females and seven males whose anthropometric properties are described in Table 1. In general, they practised for seven years with almost five shooting sessions per month.

Table 1

Anthropometric properties and clinical studies results in healthy subjects (N = 9) and shooters (N = 9). Median or mean values with standard deviations are presented.

Variable	Control (N = 9)	Shooters (N = 9)	p
Age [years]	41,6 ± 13,0	43,4 ± 14,1	NS
Weight [kg]	76,2 ± 11,8	82,4 ± 16,1	NS
Height [cm]	172,8 ± 6,5	174,7 ± 10,1	NS
BMI	25,4 ± 2,9	27,0 ± 4,8	NS
Shooting hand/Dominant hand	Right = 9	Right = 8 Left = 1	NS
Practice [years]	NA	7,1 ± 36,0	NA
Frequency of training [x/month]	NA	4,8 ± 3.4	NA
Pain VAS [0–10]	0	1	NS
vfF filaments, 2nd fingertip (C6-C7)	1	2	0,02
vfF filaments, 5th fingertip (C8-T1)	1	2	0,02
vfF filaments, area over biceps muscle (C5)	1	2	0,05
Abbreviations: vfF filaments – von Frey's filaments of superficial sensory perception studies (0 – analgesia, 1 – normal, 2 – hyperesthesia), NA – not applicable, NS – not significant; $p \leq 0,05$			

Neurophysiological testing

All tests were performed once with four-channel Keypoint System (Medtronic A/S, Skovlunde, Denmark) in the prone position (Fig. 2).

Surface electromyographical recordings (sEMG, Fig. 2A) were performed bilaterally at rest (rEMG) and during maximal muscle contraction (mcEMG) from deltoideus (DEL), biceps brachi (BB), abductor digiti minimi (ADM) and abductor pollicis brevis (APB) lasting 5 seconds. Parameters of amplitudes (in μV) in rEMG and mcEMG recordings and additionally frequencies (in Hz) of recruiting motor units action potentials were analysed and indexed from normal (3) to severe pathological (1). Methodological principles of sEMG are described elsewhere [8].

Electroneurographic (ENG, Fig. 2B) examinations included evaluating neural transmission in motor and sensory fibres of median and ulnar nerves bilaterally following stimulation with electrical pulses over the anatomical passage at the wrist, cubital fossa or ulnar sulcus, arm and Erb's point [6, 8]. To ascertain peripheral or ventral roots neural transmissions at cervical spine, recordings of M-wave and F-wave evoked potentials were recorded from APB and ADM muscles, respectively. Parameters of amplitudes (μV) and latencies (ms) of potentials were compared between results obtained from shooters and healthy volunteers.

All subjects have undergone sensory conduction studies (SCV) (Fig. 2B) in the median and ulnar nerves following stimulation of fingertips with recordings from pre-wrist areas.

Motor evoked potentials (MEP, Fig. 2C) were recorded bilaterally from DEL, BB, APB, and ADM muscles with sEMG electrodes following excitation of motor neurons and spinal roots C5-C8 levels with magnetic stimulus. It was delivered via C-100 circular coil by MagPro R30 stimulator with 70% of maximal strength (1,7T). The evaluation method from the spinal center directly to the effector has been described elsewhere [9] where amplitudes and latencies parameters were analysed.

Statistical analysis

Data were analysed with Statistica software version 13.1 (StatSoft, Poland). Descriptive statistics were reported as minimal and maximal values (range), mean or median and standard deviations (SD). The Shapiro-Wilk test was used to assess the normality of distributions in the test score. The Friedman test was used to determine whether there were any differences between the measurements performed in shooters and healthy subjects. P-values of less than 0.05 were considered statistically significant.

The statistical software was used to determine the required sample size using the primary outcome variable of sEMG amplitude recorded from APB and BIC muscles during maximal contraction with a power of 80% and a significance level of 0.05 (two-tailed). The mean and standard deviation (SD) were calculated using the data from the first five subjects. The sample size software estimated that at least 9 subjects were needed for this study.

Results

We screened thirteen shooters positively for CTS in clinical examination (Fig. 1). Interestingly, in ten, the symptoms were present in the shooting hand while in three, this side was not affected. Moreover, we found two positive Froment's signs towards ulnar neuropathy. Quantitatively, neurophysiological examination confirmed CTS in shooting hand of four shooters (4/42, 9,5%); all examined subjects suffered from brachial plexus pathologies in both sides and two had ulnar neuropathy at the wrist on shooting side.

The population of nine shooters did not report significant pain symptoms (VAS – scale 1) but in all participants, vFf testing revealed the hyperesthesia (Table 1).

In the qualitative approach (Table 2), statistical analysis showed a significant increase in muscle tension of all examined muscle groups in both the proximal and distal parts of the firing extremity, expressed in increased amplitude parameters in rEMG recordings (Fig. 3, uppermost traces). A simultaneous decrease in the motor units' activity examined during maximal contraction was displayed in shooters as the diminishing of the amplitude parameter in mcEMG recordings (comparing to normative healthy volunteers' results).

Table 2

Comparison of results from neurophysiological studies in healthy subjects (N = 9) and subjects (N = 9). Median or mean values with standard deviations are presented.

Recording site		Measured parameter	Control		Shooters		p	
			Right	Left	Right	Left	Right	Left
sEMG	DEL	rEMG (μ V)	13,3 $\pm$ 4,3	15,0 $\pm$ 3,5	18,9 $\pm$ 5,4	18,3 $\pm$ 4,3	0,05	0,06
		mcEMG (μ V)	1522,2 $\pm$ 198,6	1567,0 $\pm$ 163,6	1211,1 $\pm$ 1326,1	1522,0 $\pm$ 443,8	0,03	0,13
		FE	2,3 $\pm$ 0,5	2,3 $\pm$ 0,5	2,7 $\pm$ 0,4	2,3 $\pm$ 0,5	0,06	0,12
	BB	rEMG (μ V)	13,8 $\pm$ 3,3	16,1 $\pm$ 3,3	22,2 $\pm$ 6,6	18,3 $\pm$ 6,6	0,02	0,07
		mcEMG (μ V)	1522,2 $\pm$ 454	1577,7 $\pm$ 484,1	1422,2 $\pm$ 840,8	1344,4 $\pm$ 769,9	0,09	0,1
		FE	2,7 $\pm$ 0,4	2,7 $\pm$ 0,4	2,3 $\pm$ 0,5	2,2 $\pm$ 0,4	0,05	0,04
	APB	rEMG (μ V)	13,9 $\pm$ 3,3	16,1 $\pm$ 3,3	18,9 $\pm$ 6,0	17,2 $\pm$ 7,5	0,02	0,1
		mcEMG (μ V)	1588,9 $\pm$ 459,4	1611,1 $\pm$ 428,4	1600,0 $\pm$ 1072,3	1677,8 $\pm$ 902,4	0,1	0,12
		FE	2,8 $\pm$ 0,3	2,9 $\pm$ 0,3	2,6 $\pm$ 0,5	2,5 $\pm$ 0,5	0,12	0,11
	ADM	rEMG (μ V)	14,9 $\pm$ 2,5	15,0 $\pm$ 3,5	18,3 $\pm$ 5,6	17,7 $\pm$ 6,6	0,04	0,06
		mcEMG (μ V)	1922,2 $\pm$ 1204,9	2355,5 $\pm$ 1117,0	1511,1 $\pm$ 459,4	1688,8 $\pm$ 348,0	0,02	0,03
		FE	2,8 $\pm$ 0,3	2,7 $\pm$ 0,4	2,7 $\pm$ 0,4	2,5 $\pm$ 0,5	0,07	0,07
ENG – median nerve	M-wave Wrist	Amplitude (μ V)	11111,1 $\pm$ 2204,7	11111,2 $\pm$ 2227,6	8833,3 $\pm$ 3142,4	9888,9 $\pm$ 2027,6	0,02	0,03
		Latency (ms)	3,0 $\pm$ 0,3	3,1 $\pm$ 0,2	3,6 $\pm$ 1,2	3,5 $\pm$ 0,9	0,02	0,05
	M-wave	Amplitude (μ V)	977,7 $\pm$ 1487,3	972,8 $\pm$ 1394,4	7833,3 $\pm$ 3500,0	8333,3 $\pm$ 2397,9	0,02	0,05
	FOC	Latency (ms)	6,4 $\pm$ 0,6	6,5 $\pm$ 0,5	7,1 $\pm$ 0,8	7,2 $\pm$ 0,6	0,06	0,07

Abbreviations: rEMG-amplitude at rest, mcEMG - amplitude during maximal contraction, FE- modified frequency index (3 – 0) – frequency of motor units action potentials recruitment during maximal contraction sEMG recording: (3–95-70Hz, 2–65-40Hz. 1–35-10Hz, 0 – no contraction); DEL –deltoid muscle, BB – biceps brachii muscle, APB – abductor pollicis brevis, ADM –abductor digiti minimi muscle; sEMG – surface electromyography; ENG - electroneuronography; SCV – sensory conduction studies; MEP – motor evoked potential induced oververtebrally at cervical level

	M-wave	Amplitude (μV)	11222,0 ± 1986,1	11111,0 ± 1900,3	9444,4 ± 4245,9	11278,0 ± 2796,3	0,02	0,06
	Arm	Latency (ms)	8,3 ± 0,4	8,4 ± 0,4	8,5 ± 1,0	9,0 ± 0,8	0,06	0,07
	M-wave	Amplitude (μV)	11122,0 ± 1986,1	11000,0 ± 2000,0	10111,1 ± 669,8	12811,1 ± 3206,0	0,07	0,06
	Erb	Latency (ms)	10,7 ± 1,7	10,5 ± 1,0	13,5 ± 0,7	13,4 ± 0,9	0,02	0,03
	SCV - wrist	Amplitude (μV)	16,2 ± 6,8	14,7 ± 7,7	14,0 ± 10,0	11,5 ± 5,3	0,05	0,03
		Latency (ms)	2,9 ± 0,1	2,9 ± 0,2	3,2 ± 0,6	3,3 ± 0,4	0,06	0,07
	F wave [x/20]		17,8 ± 1,8	17,3 ± 2,0	15,6 ± 3,4	16,1 ± 3,4	0,05	0,13
	M-F latency [ms]		22,7 ± 2,0	23,9 ± 2,7	23,8 ± 2,7	24,6 ± 1,9	0,07	0,06
ENG – ulnar nerve	M-wave Wrist	Amplitude (μV)	10556,0 ± 1130,4	10888,9 ± 1763,8	9777,8 ± 322,1	10111,1 ± 2204,8	0,05	0,06
		Latency (ms)	3,1 ± 0,3	3,1 ± 0,1	2,7 ± 0,5	2,7 ± 0,2	0,06	0,07
	M-wave	Amplitude (μV)	9000 ± 866,3	9666,7 ± 866,0	7477,8 ± 3362,2	8666,7 ± 1145,6	0,05	0,06
	Sulcus uln.	Latency (ms)	6,4 ± 0,4	6,5 ± 0,4	6,7 ± 0,5	6,5 ± 0,6	0,1	0,1
	M-wave Arm	Amplitude (μV)	9888,9 ± 21453,0	9777,8 ± 1201,9	9666,7 ± 3741,7	9000,0 ± 1500,0	0,1	0,05
		Latency (ms)	8,2 ± 0,5	8,3 ± 0,3	8,8 ± 0,9	8,9 ± 0,9	0,1	0,1
	M-wave	Amplitude (μV)	10556,0 ± 1130,4	10889,0 ± 1763,8	4844,4 ± 3644,4	3644,4 ± 3178,1	0,03	0,02
	Erb	Latency (ms)	10,5 ± 1,6	10,4 ± 1,2	13,1 ± 1,2	12,9 ± 0,7	0,03	0,02
	SCV - wrist	Amplitude (μV)	16,7 ± 4,3	16,1 ± 6,4	10,9 ± 4,6	10,8 ± 4,3	0,02	0,02

Abbreviations: rEMG-amplitude at rest, mcEMG - amplitude during maximal contraction, FE- modified frequency index (3 – 0) – frequency of motor units action potentials recruitment during maximal contraction sEMG recording: (3–95-70Hz, 2–65-40Hz. 1–35-10Hz, 0 – no contraction); DEL –deltoid muscle, BB – biceps brachii muscle, APB – abductor pollicis brevis, ADM –abductor digiti minimi muscle; sEMG – surface electromyography; ENG - electroneuronography; SCV – sensory conduction studies; MEP – motor evoked potential induced oververtebrally at cervical level

		Latency (ms)	2,9 ± 0,2	2,9 ± 0,1	2,7 ± 0,3	3,0 ± 0,5	0,07	0,06
	F wave [x/20]		18,1 ± 1,5	18,1 ± 1,5	17,3 ± 2,6	16,7 ± 2,4	0,06	0,07
	M-F latency [ms]		25,3 ± 0,7	25,5 ± 0,8	23,9 ± 2,2	25,0 ± 2,1	0,06	0,07
MEP	DEL	Amplitude (μV)	1188,9 ± 169,1	1177,8 ± 120,1	477,8 ± 192,2	700,0 ± 531,1	0,02	0,03
		Latency (ms)	4,9 ± 0,3	5,1 ± 0,3	4,9 ± 0,3	5,1 ± 0,3	0,1	0,1
	BB	Amplitude (μV)	1166,7 ± 122,5	1188,9 ± 161,6	1066,7 ± 878,9	1311,1 ± 873,9	0,1	0,07
		Latency (ms)	5,5 ± 0,4	5,6 ± 0,4	5,9 ± 0,8	6,1 ± 0,6	0,02	0,03
	APB	Amplitude (μV)	1200,0 ± 165,8	1200,0 ± 200,0	866,6 ± 878,9	511,1 ± 275,8	0,03	0,02
		Latency (ms)	13,6 ± 0,3	13,5 ± 0,4	14,1 ± 1,1	14,0 ± 0,9	0,1	0,1
	ADM	Amplitude (μV)	1211,1 ± 161,5	1155,6 ± 113,4	677,8 ± 108,3	644,4 ± 339,5	0,03	0,02
		Latency (ms)	13,2 ± 0,5	13,4 ± 0,5	14,2 ± 1,6	14,5 ± 0,9	0,09	0,1
Abbreviations: rEMG-amplitude at rest, mcEMG - amplitude during maximal contraction, FE- modified frequency index (3 - 0) – frequency of motor units action potentials recruitment during maximal contraction sEMG recording: (3–95-70Hz, 2–65-40Hz. 1–35-10Hz, 0 – no contraction); DEL –deltoid muscle, BB – biceps brachii muscle, APB – abductor pollicis brevis, ADM –abductor digiti minimi muscle; sEMG – surface electromyography; ENG - electroneuronography; SCV – sensory conduction studies; MEP – motor evoked potential induced oververtebrally at cervical level								

Electroneurographic recordings of the transmission of nerve impulses in sensory and motor nerve fibers showed a decrease of amplitude parameter in M-wave and SCV recordings of median nerve potentials. It indicated the consequences of carpal tunnel syndrome and the generalised neuropathy of the motor fibers in the ulnar nerve along its entire length with a predilection to the wrist's level (Fig. 3, ENG results). The F-wave study results indicated slight abnormalities in the transmission of nerve impulses in the motor fibers of the C6-C7 ventral roots on the shooting side (decrease of F-wave frequency potential following median nerve stimulation).

The highest sensitivity in detecting sequence of abnormalities caused by shooting was demonstrated by MEP efferent transmission studies from the level of C4-C8 motor cervical neuromers to effectors on the shooting side; it was expressed by a decrease in amplitude and latency (Fig. 3, lowermost recordings).

Discussion

Interestingly, two shooters developed CTS in both hands, and all suffered from brachial plexus neuropathies at both sides, which implies that impact at the wrist of recoil is not the only cause. Maintaining the shooting position for a prolonged period likely leads to such results. This statement may be reinforced by the results of a study finding shooters to suffer from lower back pains as frequent as weight lifters proving this discipline to impact tissues at spine levels [10] significantly. Moreover, Ojanen et al., [11] found shooting scores achieved in a standing position to be positively correlated with abnormalities of muscles' strength in the lower extremities and the upper body. These results were displayed on military field training; however, it can also be assumed that sport shooters to obtain high accuracy need to increase their posture muscles strength and overload tissues at spine levels.

However, we cannot exclude that extended arm can transfer enough force of recoil into the upper extremity's proximal levels and impact nerves also on the opposite side. There is also a possibility of long-lasting influence of inorganic lead fumes produced on shot to impact neuropathies' development due to its neurotoxic properties [12]. The most plausible explanation of our results includes the combined impact of all the mentioned factors. However, the last one is least probable, since club members' shooting range seemed to be adequately ventilated.

We are aware of the limitations of our study: 1) examined group was relatively small and heterogeneous; therefore our results may to some degree originate from differences in anthropologic properties or lifestyle; 2) shooters used handguns predominantly, our results are not fully applicable to users of longer firearms; 3) shooters used handguns with different weight, handles, calibres and types of ammunition (rimfire and centerfire), which may affect their impact on the body.

The knowledge provided by this study can be applied in clinical practice by sports and military physician as well as the general practitioners to detect neuropathies before they lead to severe complications and hence a decrease in quality of life. Understanding that shooters are more likely to develop these types of injuries, it would be sensible to find ways to alleviate some impact on nerves associated with this sport: it should be promoted to create the ergonomic workspaces and reinforce the healthy posture in their daily life. Moreover, it is possible that different types of handles in handguns differ in how they impact their user, and so creating the most ergonomic one may be beneficial in the context of prevention of neuropathies in the upper extremity. Interestingly, during military field training, standing shooting score achieved with a rifle was decreased in mid-training measurements, while the one scored in the prone position was not affected [11]. Standing position may exert significant stress on a body, and thus alleviation of this effect should be achieved by training shooting sports in the prone position. The abovementioned study did not assess neurophysiological properties in upper extremities, and therefore its application is limited with regard to our paper.

Conclusion

An increased prevalence of CTS and brachial plexus pathologies accompanied by statistically significant abnormalities in presented results of neurophysiological studies on shooters indicates that this activity is a risk factor for their development. A greater understanding of distinct risk factors associated with shooting sports will be achieved by conducting the future large, multicenter study on homogenous population in terms of their equipment, training, BMI, age and sex.

Abbreviations

sEMG – surface electromyography

rEMG – electromyography at rest,

mcEMG – electromyography during maximal contraction,

ENG – Electroneurography,

SCV – sensory conduction studies,

MEP – Motor evoked potential,

CTS – Carpal tunnel syndrome,

vFf – von Frey's filaments test ,

SD – Standard deviations,

BB – biceps brachii muscle,

DEL – deltoideus,

APB – abductor pollicis brevis,

ADM –abductor digiti minimi muscle.

Declarations

Ethics approval and consent to participate

The Bioethics Committee of Poznan University of Medical Sciences approved the study (decision number 554/17 of 22 June 2017), performed following the Declaration of Helsinki. Each subject was informed about the study's aim and gave written consent for examinations and data publication.

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests

Funding

The authors declare that they have no funding.

Authors' contributions

AR and JH were responsible for: study design, collection of data, conducting research, statistical analysis, interpretation of data and manuscript preparation. JH additionally supervised the entire study protocol.

MK, AF and BK were responsible for: collection of data, conducting research, interpretation of data and manuscript preparation. All authors read and approved the final manuscript.

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Figures

Figure 1

Study design.

Figure 2

Photographs of experimental setup applied during neurophysiological recordings. A – sites of bilateral placements bipolar surface electrodes over muscles in proximal (a) and distal (b) parts of upper extremities when sEMG recordings at rest and during maximal contraction were performed. B – sites of bilateral electrical stimulation of motor nerve fibres in the median and ulnar nerves at Erb's point (a), arm, cubital fossa or ulnar sulcus (not shown) and wrist (b) during ENG studies of M wave recordings from

hand muscles. The methodology of sensory conduction studies (SCV) (c) in the median and ulnar nerves (not shown) following stimulation of fingertips with recordings from pre-wrist areas. C – principles of multiple motors evoked potential recordings from upper extremity muscles (MEP) after oververtebral magnetic stimulation of motor centers at C5-C8 spinal neuromers. Abbreviations: r-recording, s-stimulation

Figure 3

Examples of sEMG, ENG, MEP recordings in healthy volunteer and shooter for comparison. Note different amplification of MEP recordings, four times more amplified in case of shooter. Abbreviations: rEMG- amplitude at rest, mcEMG - amplitude during maximal contraction; ENG - electroneuronography; MEP – motor evoked potential induced oververtebrally at cervical level

Figure 4

Summary of the main results in the presented study