

# Measuring the effect of physiological tremor on accuracy in competitive pistol shooting

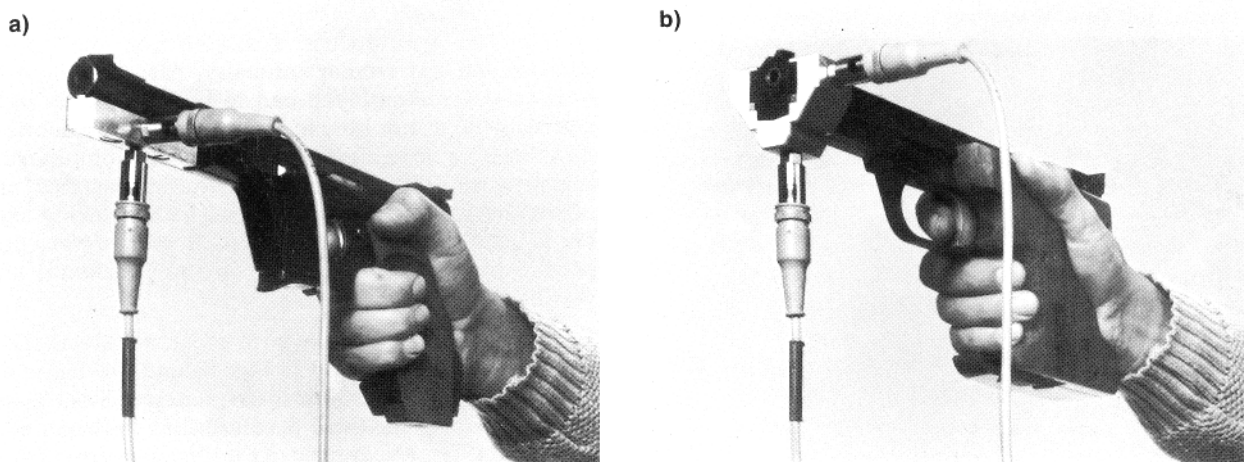
by Bernd Nickel

Even perfectly healthy people suffer from a slight, uncontrollable shaking of their extremities. Such shaking is known as physiological tremor and is a normal involuntary side effect of muscle contraction. Tremor makes difficult the execution of precise body movements, for example in the aiming of a pistol. This article describes one method of measuring tremor to determine its effect on an individual's shooting performance. Tremor was measured by attaching accelerometers to the barrel of the pistol. The investigation provided quantitative data on the effects of various types of stress on hand tremor in different competitors. Results show a clear relationship between tremor intensity and shooting performance.

In assessing skill in any competitive sport, it is the so-called "athletic efficiency" that is of utmost interest. Efficiency in this context means the optimization of athletic performance by combining a competitor's skill and the unavoidable psychological/physical stress of competition to maximum benefit. The goal is to achieve an optimum balance between both factors whereby performance is maximized and psychological/physical stress is minimized. Attainment of this optimum requires an understanding of proper athletic and psychological motivation as well as of the psychobiological impairment which can be caused by overstress. Of course, any scientific attempt at studying the interplay between stress and athletic performance requires quantitative data acquired from actual participants in the sport and quantitative data on psychological/physical stress in athletic competition in general.

A valuable aid in the assessment of athletic performance and efficiency is the measurement and recording of physiological parameters during competition. Observation and analysis of these parameters reveal their variation under increasing psychological/physical stress, give clues to individual differences, and provide information on stress limits and the existing energy reserves of athletes. There can be no doubt that the sport of target shooting in particular requires participants who are emotionally well-balanced. Competition places enormous psychological stress on the individuals, caused by ambition and the desire for success combined with the fear of failure.

The aim of this experiment was to obtain quantitative data on psychological/physical stress by measuring hand tremor in competitive pistol shooters. The goal



**Fig. 1: Two pistol types require different transducer attachment methods: a) original balance weight is supplanted with accelerometers; b) accelerometers are held by adaptor made out of aluminum or plexiglas**

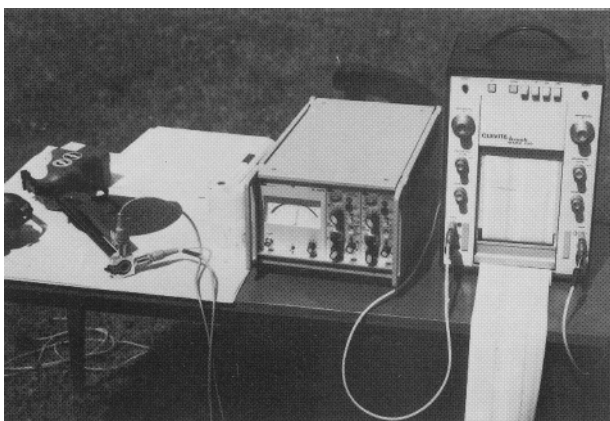
was to see to what extent the hand tremors of different individuals affect shooting performance. Another area of interest was how the tremors of individual competitors change under different levels of psychological/ physical stress, and whether there is a relationship between tremor amplitude and shooting accuracy.

## Tremor: Amplitude varies, not frequency

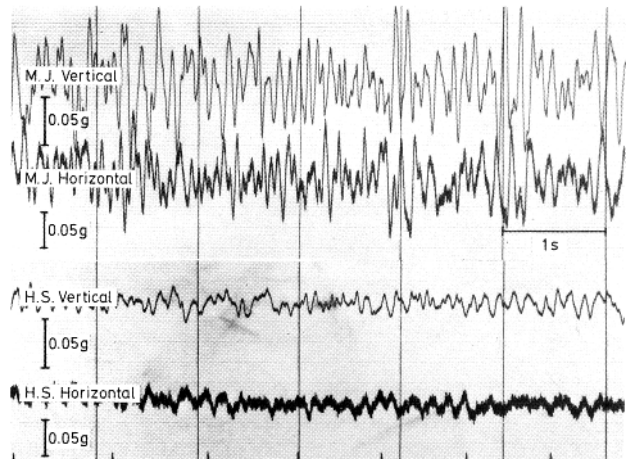
Small, precise movements of the hand requiring practice and skill, such as the threading of a needle, are often made difficult by a slight, uncontrollable shaking. In a normal healthy individual, the shaking is an involuntary side effect of muscle contraction and is known medically as physiological tremor. Tremor prevents the hand or finger from being brought into the required position and varies in strength in the same individual at different times of the day and also from person to person. Tremor sets natural limits to precise movements and exact muscle contraction.

Generally speaking, physiological tremors — that is, those with no relation to illness — can be viewed as the muscular-mechanical consequence of normal activity in the motor elements of a muscle. Tremor is intensified considerably by excitement or physical exertion. Recordings show that there is no qualitative difference between a tremor which is only discernible by sensitive measuring equipment and a visible tremor caused by great excitement. For example, competitive pistol shooters with a very steady hand and those with a visible tremor differ only in tremor amplitude, not frequency. The dominant tremor frequency of around 6 Hz is also independent of the strength of the particular muscle contraction or the muscle whose contraction has caused the tremor.

The tremor measurements in connection with pistol shooting described in this article were taken with the assistance of athletes in training for the modern pentathlon and free-pistol shooting, both olympic events. In the modern pentathlon, athletes shoot 20 shots in four series of five at a range of 25 meters (82 ft). The pivoting bulls-eye target is in view for only three seconds, after which it disappears for seven seconds. In the three



**Fig. 2: Measuring system consisted of pistol with accelerometers, twin-channel 5-kHz carrier-frequency amplifier, and twin-channel strip-chart recorder**



**Fig. 3: Tremor intensities from two competitors may show wide variation, but experiments prove that maximum tremor frequency always lies within the 5 to 8 Hz range**

seconds that the target is in view, the competitor must raise his arm from the rest position—which must not be above 45 degrees to the horizontal-aim, and fire. Surprisingly enough, scores of 197 to 199 out of a possible 200 are no rarity in this particular discipline. Free-pistol shooting is quite different. Here, marksmen fire 60 shots at a range of 50 meters (164 ft) with the target continuously in view and without a time limit. When one considers however, that a displacement of only 2 mm (0.08 in.) to the muzzle of a pistol 25 cm (10 in.) long can result in a miss of about 400 mm (16 in.), it becomes clear what an important role an individual's physiological tremor plays in the sport of pistol shooting.

## Accelerometers detect tremor intensity

In order to measure the movement of the hand before, during, and after pulling the pistol trigger, two accelerometers were attached directly to the pistol barrel. Accelerometers were used because there were no suitable transducers available for the direct measurement of tremor intensity. Also, the type of sensing device employed had to be sufficiently light and small so as not interfere with the act of shooting. By using a computer it is a simple matter to obtain from the measured accelerations all the values that are necessary for evaluating tremor. The measuring axes of the accelerometers attached to the barrel were perpendicular to the barrel axis in the horizontal and vertical directions.

Two different pistols fitted with accelerometers (HBM Type B 12;500) are shown in **Fig. 1a and 1b**. These accelerometers have a natural frequency of 500 Hz and are designed to measure accelerations between zero and 250 Hz. The upper limit of their measuring range is  $1000 \text{ m/s}^2$  ( $3281 \text{ ft/s}^2$ ) which is narrow enough to pick up tremor, yet broad enough to insure that they can safely withstand the high accelerations which occur when the pistol fires.

The sensing element of the accelerometer comprises a spring-mass system operating below resonance whose deflection is converted into an electrical signal by an inductance-bridge reluctance transducer. Each weighs only 17 g (0.6 oz) and is cylindrical; 12.6 mm (0.5 in.) in diameter and 26 mm (1.1 in.) long.

Two 22-caliber automatic pistols were used in the test, a Haemmerli 232 and a Walther OSP. In the case of the Walther OSP as shown in Fig. 1 a, the weight normally attached to the muzzle was replaced by the accelerometers and a balance weight. The weapon, therefore, retained its normal competition weight (1045 g or 2.3 lb) and balance after the fitting of the transducer system. According to the competitors, shooting was not adversely affected by the mounted accelerometers. The same was said about the attachment of accelerometers to the barrel of the Haemmerli pistol, which was done by means of an aluminum adapter as shown in Fig. 1 b. Such adapters can be made to fit any type of pistol.

Because the signals produced by the accelerometers had to be measured simultaneously, two amplifier channels (HBM Type KWS 273.A7 two-channel amplifier) were necessary. The inductive measurement principle of the accelerometers necessitated a 5-kHz carrier-frequency amplifier. Both amplifier channels possess analog outputs from which the amplified signals can be used in an analog recording instrument. Recording of the signals was performed with an Ampex analog tape recorder, a light-beam oscillograph, an oscilloscope, and a continuous-line recorder which were used either singly or in parallel according to requirements. It was possible, for example, to observe the signals on the oscilloscope at the same time as they were being recorded. Digitalizing of the taperecorded

signals by means of a PDP 12 process computer was followed by a fast Fourier transform, which transferred signals from the time range to the frequency range and calculated the energy spectra.

Fig. 2 shows the test setup which can be used at the shooting range and is easy to operate. It includes a pistol fitted with two accelerometers, two-channel amplifier, and two-channel recorder. This system provides immediate traces of tremor frequency and intensity from the participating competitors.

Before any measurements were taken, each participant fired 50 shots from 25 meters (82 ft) at a stationary ten-point bulls-eye target in order to ascertain skill level. Once this was determined, each competitor performed a special test program using the tremor measuring system described. The procedure comprised of three drills:

- 30-second aim. Four times without firing, with a one-minute pause between each.
- Fire. Five shots six times, with a pause after each five. Examination of target score during the pause.
- 120-second aim. Four times without firing with a one-minute pause between each.

This test program was performed by the participants ten or twelve times in all, on different days but under as similar conditions as possible.

## Results: Tremor-accuracy link confirmed

The measurements, which were recorded directly and also evaluated immediately with the computer, revealed great variation in the intensity of the physiological tremors among different participants. In the most extreme case, variation among individuals differed by a factor of eight. In all cases, as expected, the maximum intensity of tremor lay in the frequency range 5 to 8 Hz, and overall in the range 0.5 to 25 Hz. Fig. 3 shows the results from tremor measurements in the vertical and horizontal directions recorded from two different participants.

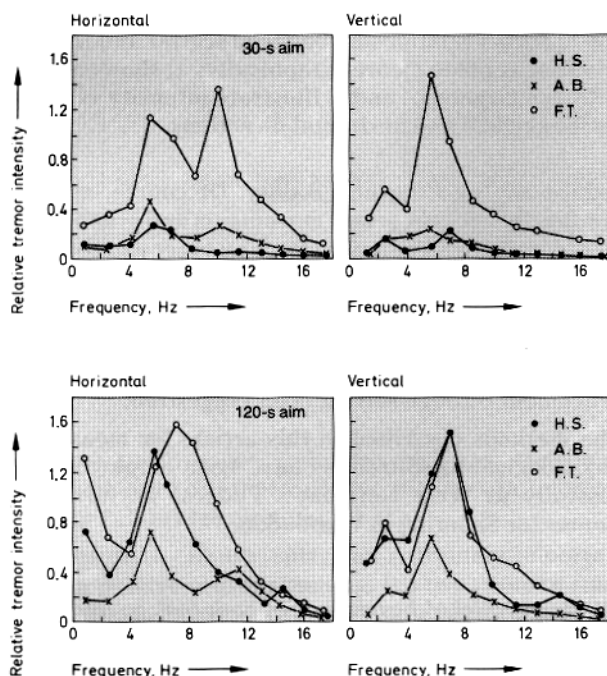


Fig. 4: Relative tremor intensity is plotted against frequency for three participants in the 30-s-aim and 120-s-aim drills. Note maxima at 2.5 Hz and 6 to 8 Hz

For nearly every athlete, a comparison of the tremor spectra obtained from the 30-s-aim and 120-s-aim drills shows a significant increase in tremor intensity for the latter. The increase in intensity varies from individual to individual. For certain individuals, the maximum intensity for the 120-s aim was as much as eight times the value recorded for the 30-s aim, whereas others experienced only a very slight increase in tremor during the longer period of aiming.

Fig. 4 shows the relative tremor intensity ascertained from individuals' results plotted against tremor frequency for the 30-s-aim and 120-s-aim drills. In each case, there are two maxima at approximately 2.5 Hz and between 6 and 8 Hz respectively. Moreover, it can be seen that there is an enormous difference between the results achieved by participants F.T. and H.S. for the 30-s aim. Whereas the poorer shot F.T. showed only a slight increase for the 120-s aim, the better shot H.S. showed a sharp increase. This fact makes it quite clear that the ability of someone to hold the pistol relatively

still for more than 30-s is no indication of the accuracy of their shooting. The different tremor intensities measured for the 30-s aim and fire are a more reliable means of determining an individual's skill level.

The relative tremor intensity ascertained from the firing drill is illustrated in Fig. 5. There are only slight differences from the results obtained from the 30-s-aim and 120-s-aim drills. With all participants, the mean intensity levels from the firing drill are higher than for the 30-s aim in both the horizontal and vertical directions. In contrast, the mean value for fire is lower than for the 120-s aim.

It is interesting to note that H. S., the most accurate and consistent of all the participants, shows only a slight increase in tremor intensity when firing. With all the others, the necessity to shoot causes a clear increase in tremor intensity. This difference makes it easy to distinguish between a good shot and a poorer shot.

When the tremor intensity of each individual is compared with their score pattern on the target, it becomes clear that there is a direct relationship between the scatter and the tremor—the greater the tremor intensity, the greater the scatter. This relationship is made clearer in Fig. 6. Plotted in sections 6b and 6c are the rms values of tremor intensity versus mean target scatter for the vertical and horizontal directions. The actual targets are also shown in section 6a to illustrate accuracies more graphically.

Results revealed the deviation of tremor intensity in individuals under relatively controlled conditions to be approximately 10 % whereas the maximum deviation among various competitors was as high as 900 %. From these results it is possible to conclude that physiological tremor can be regarded as a personal characteristic. Also, since the tests show a definite relationship between target scatter and physiological tremor, it is possible to utilize tremor measurements to select people who are especially suited to certain skills, such as high-level athletic competition which may require a very steady hand.

Since it is known that excitement—which is always accompanied by a rise in pulse rate, unsteadiness, and reduced muscular strength—increases tremor intensity, the obvious course of action is to adopt countermeasures to reduce it. Exercises are normally prescribed for strengthening the arm muscles, and unsteadiness can be eliminated with practice.

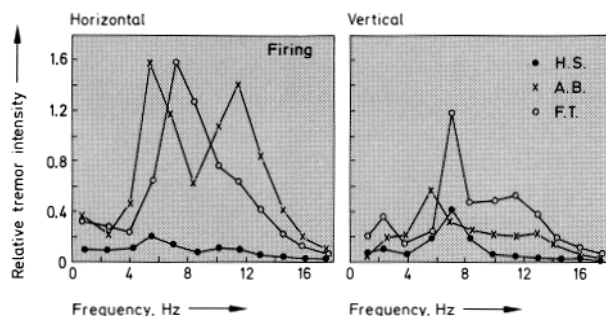


Fig. 5: Relative tremor intensity is plotted against frequency for three participants in firing drill. Note that levels are usually higher than 30-s-aim drill

Every opportunity must be taken to produce harmony and familiarity with the action to be performed. This is the only way in which activities requiring a steady hand can become automatic and be absorbed into the subconscious. This helps to raise self-confidence and

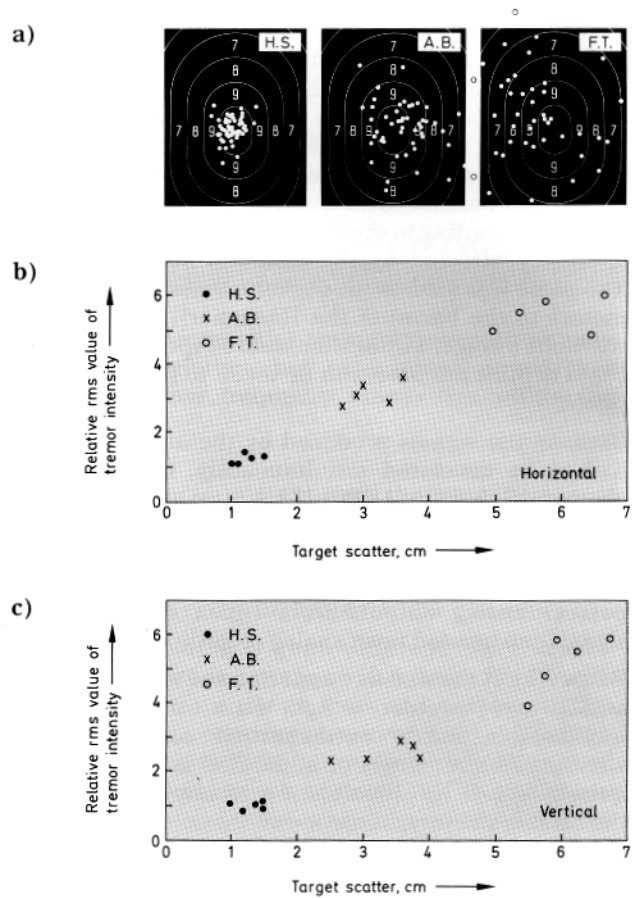


Fig. 6: Direct relationship between scatter and tremor intensity is made clearer graphically: a) shows actual bulls-eye targets; b) and c) illustrate intensity vs. scatter for vertical and horizontal directions

reduce any existing uncertainty. Of course, greater familiarity with necessary movements and greater self confidence have a calming effect on inner excitement. Other effective training methods especially suited for pistol and rifle shooting are autogenic training and, as a preliminary to this difficult-to-master relaxation technique, autosuggestion, which is encourages improvement through self-induced suggestion.

The methods described in this article for measuring physiological hand tremors have been employed successfully at West Germany's Federal Performance Center for Shooting in Wiesbaden.

Dr. Bernd Nickel has degrees in both biology and theoretical medicine and is currently involved in biological research with the firm Chemiewerk Homburg, Degussa Pharma Gruppe, Frankfurt am Main. The work described in this article was carried out while the author was with the Physiological Center of the Neurophysiology Department, Johann Wolfgang Goethe University, Frankfurt.