ACTA UNIVERSITATIS CAROLINAE
KINANTHROPOLOGICA Vol. 50, 2 – 2014 Pag. 98–107

CHARLES UNIVERSITY IN PRAGUE,
FACULTY OF PHYSICAL EDUCATION AND SPORT,
DEPARTMENT OF ANATOMY AND BIOMECHANICS[1]
DEPARTMENT OF MILITARY SCIENCE[2]

EFFECT OF MAXIMUM HEART RATE ON ACCURACY OF FIRE

RICHARD BILLICH[1], ERIK BARTÁK[1,2], JIŘÍ BENEŠ[2], PETR MAJERČÍK[2], KAREL JELEN[1]

ABSTRACT

In today's world, when many offenders are well-equipped with firearms and ready to use them to avoid their apprehension, when the threat of a terrorist attack is high, when war conflicts are increasingly conducted within city borders (urban warfare), the skill of precise and quick elimination of an enemy is vital for members of law enforcement agencies operating in physically demanding situations.

The goal of this paper is to examine the effect of maximum heart rate on the pistol shooting performance by analyzing precision target shooting data of a set of 8 participants all coming from the ranks of the Police of the Czech Republic. This paper represents an empirical descriptive study. In order to find out statistical significance, we used the statistical method of a paired two-sample t-test. We organized the collected data by comparing arithmetic means. For grouping and interpretation of target shooting data, we utilized the method of finding the central point of shots at a target. The *Sport tester*, a monitoring device, helped provide the values of maximum heart rate. Based on the data collected, we conclude that maximum heart rate has a statistically significant effect on precision of target shooting. This precision was defined by the average distance of individual shots at a target from the central point of impact. We also found that the size of this distance before and after intense physical activity can be influenced sport activities that respondents perform as their hobbies.

Keywords: shooting; physical activity; resting heart rate; relaxed state heart rate; maximum heart rate

INTRODUCTION

In today's world, when many offenders are well-equipped with firearms and ready to use them to avoid their arrests, when the threat of a terrorist attack is high, when war conflicts are increasingly conducted within city borders (urban warfare), the skill of precise and

quick elimination of an enemy is vital for members of law enforcement agencies operating in physically demanding situations.

In the Czech Republic, this phenomenon relates to troops of the Czech Armed Forces operating in foreign deployments and specialized units concerned with fighting organized crime, terrorism and arresting dangerous individuals within the borders of the Czech Republic. These units include local municipal police departments, the Rapid reaction unit – an elite Anti-Terrorist Unit of the Czech Police, and specialized bodies such as Customs Service of the Czech Republic and Prison Service of the Czech Republic.

To carry out their work, these specialized units are quite flexible in operations and utilize the element of surprise in their tactics. The surprise aspect is significantly related to a quick approach to the target which with weapons and additional equipment can be compared to a moderate-intensity endurance performance such as a 400 m sprinting event or one lineup change in ice hockey. However, if we take into account that this kind of performance is concluded with point shooting, in other words "target focused shooting", it is necessary to pose the following question: Will the shooting be executed precisely enough? In this aspect we have to consider that shooting which follows intense physical activity can present a certain level of variance from shooting in relaxed state. This variance can be attributed to a short-term physical fatigue impairing the brain's motor centers and hence effecting fine motor skills necessary for the upcoming shot.

The aforementioned conditions for shooting will be simulated by physical activity during which the heart rate of tested individuals will be reaching maximum values. We then assess their shooting performance for preciseness during a normal resting heart rate (phase 1 of the trial) and the maximum heart rate (phase 2 of the trial).

The findings of this analysis can find application within the framework of developing firearms skills in the context of physical training not only in the Czech Army but also in the above mentioned law enforcement units of the Czech Republic.

METHODS

Research participants

The research group (Table 1) consists of 8 participants with the mean age of **30.3 ± 3.5**. As members of the Rapid reaction unit of the Czech Police operating in Prague, they all participate in a minimum of 6 intensive rounds of shooting practice each month. The ammunition used starts with the minimum of 2000 bullets per person per month.

Table 1. Participant characteristics

	Participant No. 1	Participant No. 2	Participant No. 3	Participant No. 4	Participant No. 5	Participant No. 6	Participant No. 7	Participant No. 8
Age	31	34	35	28	26	31	33	25
Height [cm]	186	191	187	179	186	163	177	184
Weight [kg]	81	98	92	81	88	70	83	84
Expected max heart rate [min]	189	186	185	192	194	189	187	195
Physical fitness back-ground	Crossfit Climbing Shooting Cycling	Martial Arts Crossfit	Boxing Crossfit Power-lifting	Triathlon Collective sports	Martial Arts Athletics Cross Country Skiing Cycling	Crossfit Martial Arts	Climbing Tenis	Athletics Martial Arts Cycling

Legend: Physical fitness background – physical activity which participants engage in in their free time

Measuring

The measurement was conducted by using a modified physical stress test to achieve maximum heart rate as published in Macek and Radvansky (2011) and Shephard (1987). The observation took place in an indoor shooting range STVS MO in Praha-Ruzyne on April 19, 2013 at 11:00 a.m. The subjects were introduced to and familiarized with the Czech Army's official safety rules for using firearms as well as the facility safety rules and regulations of the shooting range. Because of limited capacity, the group of 8 subjects was divided into two groups – each group consisting of 4 participants. The first phase of measuring started with the first group of 4 firing at a target during a normal resting heart rate at 11:08 a.m. The same group was then exposed to physical exertion which was followed by the second phase of shooting at 11:15 a.m. The last participant finished his shooting round at 12:15 a.m. Each trial was in compliance with the official legislation of the Czech Armed Forces related to firearms (Vsevojsk 4–2) and the facility safety rules and regulations of the shooting range STVS MO Praha-Ruzyne. The medical emergency personnel from Medical Emergency Service were on site at the time.

Shooting test

The standard distance from the firing line to the target was shortened in our test to the distance of 15 m. Each subject used 10 bullets. The time limit for each shot fired was 2 s. The total time for each round was 20 s. The schematic diagram of the shooting test can be seen in Figure 1. For our test, we chose the Glock 17 pistol which is a standard weapon used by the Rapid reaction units in all Regional Directories of the Police of the Czech

Republic. In order to remove another research variable represented by weapon modification, we consciously decided to use only one type of a handgun design.

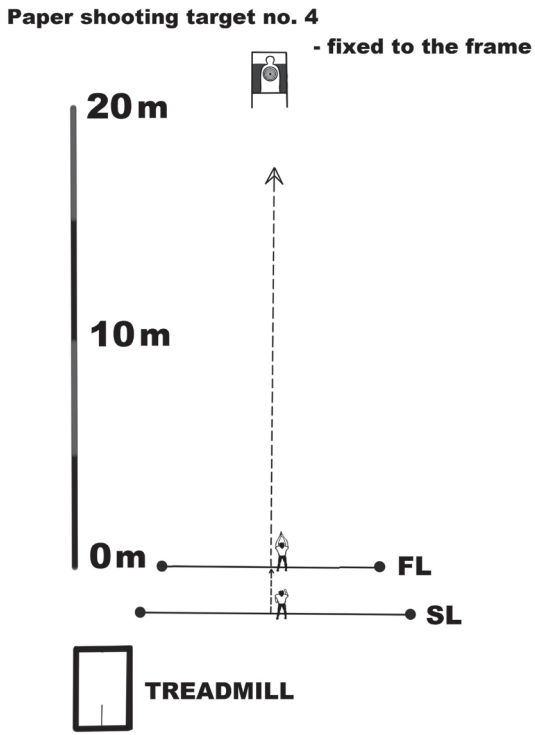

Figure 1. Schematic diagram of test
Legend: SL – starting line; FL – firing line

As Table 2 shows, we utilized the 9 × 19 mm Luger Parabellum cartridge which has also been adopted as standard ammunition by the Police of the Czech Republic and the Czech Army. The bullet is of FMJ (full metal jacket) type which means that a lead core is jacketed with an alloy of copper and zinc content.

Table 2. Technical data of LUGER 9 mm ammunition

Ammunition	Bullet type	Cartridge length [mm]	Cartridge weight [g]	Bullet weight [g]	Muzzle velocity [m*s^{-1}]	Muzzle energy [J]
9 mm Luger	FMJ	29.69	12.15	7.5	390	**570**

Figure 2 represents the shooting target selected for our study. We chose a standard bullseye shooting target No. 4 also used for developing handgun skills based on the Czech Army's Vsevojsk 4–2 regulations.

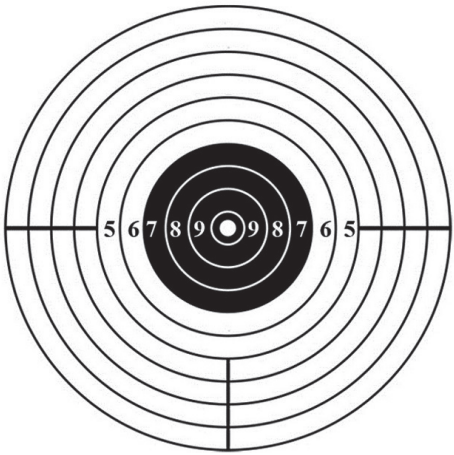

Figure 2. Shooting target number No. 4

Physical stress test

For reaching the maximum heart rate, we used the means of a modified version of the physical stress test which is described both in the Czech and foreign research literature Macek and Radvansky (2011) and Shephard (1987). In accordance with Macek and Radvansky (2011), we decided to take advantage of a treadmill ergometer which engages more muscle groups of its user as opposed to the cycle ergometer. Hence, the treadmill exercise better simulates the real-life physical intensity tested in our study.

The physical stress test began with a treadmill warm-up of light intensity, at the speed of 5.5 km/h. Conditions were changed after 2 minutes and speed went up to 10 km/h. The intensity of exercise was then continuously increased by +2 km/h every minute until each participant refused to continue. Each physical activity took on average 7.5 ± 0.58 min. The test administrators used Garmin Forrunner 310XT Sport tester to monitor reaching the maximum heart rate of each participant.

Data analysis

All shots were recorded and their values analyzed based on the distance of each hit from the centre of the hit and their mean was calculated. The collected data of both sets – before the physical stress test (relaxed state) and after the physical stress test (maximum heart rate) – was statistically compared by means of calculating the arithmetic mean, then the standard deviation, statistical dispersion, and finally evaluating the level of statistical significance using a paired two-sample t-test. In the test, we use the pairwise differences of measured values for the comparison of variational series. We test the hypothesis that the mean value of the measurements before and after the experiment is equal to 0 (difference in mean value of pairwise measurements is equal zero.) The sample was tested for normal distribution by statistical program as part of the

t-test. All statistical calculations were performed using adequate functions of Microsoft Excel 2010 program.

RESULTS

Using the statistical method of a paired two-sample t-test, we apply the collected data to tests our *null hypothesis* **H0 : μ1 = μ2** with an alternative hypothess **H1 : μ1 < μ2**. The level of significance for our data is set at 5%. The value $\alpha = 1.95471783903802 \times 10^{-6}$ ($p < 0.05$) is statistically significant (see Table 5). So, we reject the null hypothesis (H0 : μ1 = μ2: The results of shooting before and after physical activity are the same. We accept the alternative hypothesis (H1 : μ1 < μ2): The results before and after physical activity are different. The distance between hits before and after physical activity has significantly **increased from the mean of 3.211 cm** from the target's centre to **5.560 cm**.

The representation of data in Table 3 and 4 shows that physical activity intensity reaching maximum heart rate has negatively affected the results of shooting of each study participant in the form of increased distance average of hits from the centre point.

The greatest average drop is demonstrated among the participants who performed best i.e. had the lowest average distance in the first phase of measuring that is before the physical test (participants 1, 2, 6). Participant No. 1 shows the exact difference of 2.53 cm, participant No. 2 shows the difference of 2.83 cm, and the participant No. 3 the difference of 2.85 cm. Participants No. 1 and 2 each exhibit more than 100% increase of average distance.

Despite this relatively significant drop, the average results before and after physical activity is still the lowest of the entire set. By analyzing the subject's physical fitness background, we found that participant No. 1, who achieved the best results, engages in firearm shooting in his spare time. Based on the same analysis, we can also speculate that the rest of the participants No. 3–8 who mainly engage in power training rather than aerobic exercises did not adapt well to shooting after physical activity.

On the hand, the lowest difference is found with participant No. 5, specifically 1.499 cm. These participant's hobbies range from power training to endurance activities which can positively effect his adaptation to anaerobic exercise with lactate threshold reaching the maximum heart rate. The second lowest difference of 1.96 cm was achieved by participant No. 8. This participant, just as participant No. 5, is interested in power training and endurance training. As mentioned above, these activities can effect one's adaptation to moderate intensity physical activity for reaching the maximum heart rate. Participant No. 3 achieved the greatest average distance of hits before and after physical activity. Specifically, the average before was 3.86 and after 6.27. This participant is also involved in power training which can influence his poor results after physical activity. When interviewed, this participant revealed that he is quite new at the Rapid reaction unit. Therefore, it is likely that his handgun skills are worse than those of the rest of the study participants.

Table 3. Arithmetic mean distance ($\bar{x}$) from the target centre values [cm] hit [x1 – x10] shooting in relaxed state

HIT	Participant No. 1	Participant No. 2	Participant No. 3	Participant No. 4	Participant No. 5	Participant No. 6	Participant No. 7	Participant No. 8
x1 [cm]	2.9	4.0	3.3	1.4	0.9	3.2	0.6	4.0
x2 [cm]	0.7	0.6	3.7	1.3	1.2	2.7	2.1	3.4
x3 [cm]	1.2	1.3	1.4	5.2	4.6	2.7	4.4	4.2
x4 [cm]	2.4	3.3	2.3	3.7	5.7	3.4	3.2	0.8
x5 [cm]	3.5	1.6	5.1	5.0	3.2	3.3	5.1	4.8
x6 [cm]	4.3	3.0	5.5	4.3	4.4	2.4	4.2	3.5
x7 [cm]	1.8	2.3	4.7	3.9	4.7	1.5	4.6	1.3
x8 [cm]	1.6	1.8	3.3	5.1	5.4	4.3	3.9	1.9
x9 [cm]	1.3	2.4	3.6	4.5	4.1	1.8	2.8	3.7
x10 [cm]	1.7	4.0	5.7	4.0	3.5	4.6	3.2	4.9
$\bar{x}$ [cm]	**2.14**	**2.43**	**3.86**	**3.84**	**3.77**	**2.99**	**3.41**	**3.25**

Table 4. Arithmetic mean distance ($\bar{x}$) from the target centre values [cm] hit [x1 – x10] shooting after physical activity

HIT	Participant No. 1	Participant No. 2	Participant No. 3	Participant No. 4	Participant No. 5	Participant No. 6	Participant No. 7	Participant No. 8
x1 [cm]	4.6	0.9	2.5	2.1	1.2	2.4	3.2	0.6
x2 [cm]	5.7	4.6	1.6	4.2	3.4	2.3	2.7	1.8
x3 [cm]	4.4	7.2	6.8	3.3	5.4	5.2	2.2	5.6
x4 [cm]	4.8	6.4	7.4	3.8	7.2	5.3	6.1	3.8
x5 [cm]	2.4	6.8	5.0	7.6	6.1	7.3	9.8	5.4
x6 [cm]	3.3	5.2	8.2	5.8	9.3	8.5	9.7	1.1
x7 [cm]	4.5	3.2	7.6	6.5	7.6	5.7	1.0	4.8
x8 [cm]	6.7	4.3	8.2	10.1	6.1	4.8	6.1	7.3
x9 [cm]	5.2	6.2	7.1	8.3	5.3	9.8	8.3	10.3
x10 [cm]	5.1	7.8	8.3	9.2	1.09	8.1	8.6	11.4
$\bar{x}$ [cm]	**4.67**	**5.26**	**6.27**	**6.09**	**5.269**	**5.94**	**5.77**	**5.21**

Table 5. T-test calculation ($\bar{x}$ X arithmetic mean values in relaxed state, $\bar{x}$ Y arithmetic mean values after physical activity)

SUBJECT	$\bar{x}$ X [cm]	$\bar{x}$ Y [cm]
1	2.14	4.67
2	2.43	5.26
3	3.86	6.27
4	3.84	6.09
5	3.77	5.269
6	2.99	5.94
7	3.41	5.77
8	3.25	5.21
$\bar{x}$	**3.21125**	**5.559875**
STANDARD DEVIATION	0.609947487	0.507786972
T-TEST	**$1.95471783903802 \times 10^{-6}$**	
SIGNIFICANCE	$p < 0.05$	

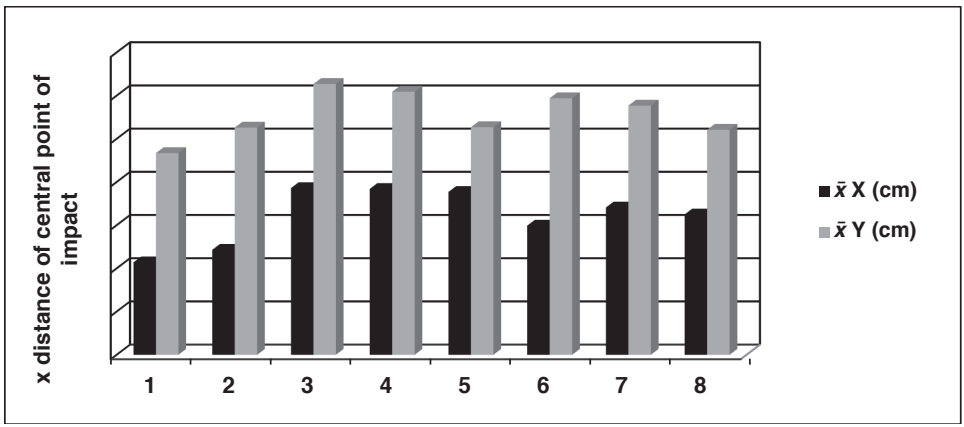

Figure 3. Comparison of arithmetic mean values of distance from the target centre in relaxed state ($\bar{x}$ X) and after physical activity ($\bar{x}$ Y).

DISCUSSION

The goal of this paper was to assess the effect of physical activity which reaches the values of maximum heart rate and which is simulated by a physical stress test using gradually increasing levels of speed on a treadmill ergometer until voluntarily aborting the exercise. For our research we selected from the members of the Rapid reaction unit of the Czech Police operating in Prague who have handgun shooting experience. The intended output of the test was to find statistical differences and statistical significance between

values measured before and after physical activity. To evaluate the statistical difference between shots fired, we took advantage of a ballistics method of ***determine the central point of impact*** which is a point surrounded by evenly scattered points of impact (hits) executed under the same conditions. (Plihal et al., 2011; Kneubüehl et al., 2008). We then determined and compared the arithmetic means of distances of each shot at a target. The method of a paired two-sample t-test allowed us to calculate the statistical significance of the phase 1 and 2 measurements (Navaro, 2007). ***Student's t-test*** is a commonly used and popular parametric test used to test if two sets of data have significantly different mean values μ. The concept of statistical significance testing the difference of mean values helps us consider the effect of the experimental intervention (Brainina, 2013; Chrázka, 2007). The test confirms that the probability that observed differences occur by chance alone is less that 5%. In other words, ***it works with a 95% certainty***. In our study, we tested the null hypothesis **H0 : μ1 = μ2** and the alternative hypothesis **H1 : μ1 < μ2** at the 0.05 level of significance. The value $\alpha = 1.95471783903802 \times 10^{-6}$ ($p < 0.05$) was statistically significant (see Table 5).

In this case we have to reject the null hypothesis (H0 : μ1 = μ2): The results of target shooting before and after physical activity are the same. **We accept the alternative hypothesis (H1 : μ1 < μ2):** The results of target shooting before and after physical activity are different. We then conclude that physical activity which reaches the values of maximum heart rate has an effect on the precision of target shooting.

The negative effect of physical exertion demonstrated in all 8 participants a greater average distance of fired hits from the central point. Second participants whose hobbies range from power training to endurance activities posted the lowest difference of values. One participant who has less firearms experience than others in the group, posted poor results although they were not significantly worse. The best result was registered by a participant who practices his firearms skills outside of work as well.

Our hypothesis assumed that the average distance of shots around the central point would increase after a level of physical exertion. Having conferred our measured data and results, we come to the conclusion that our hypothesis confirms with all participants.

In conclusion, we would like to point out that the highest average distance was 6.27 which is enough to hit a 12.5 diameter circle from a 15 m distance. Also the values of dispersion from the central point of shots was insignificant in comparison to values measured before physical activity. Although statistically significant, the value differences will most likely not influence the factual success of eliminating the target. The shooting ability of all members of the Rapid reaction unit was in all cases correct and clustered. For the next steps of this research, the administrators should measure the values of less and more experienced shooters and compare problematic areas and their causes should be analyzed, and evaluated for their elimination.

CONCLUSION

Based on the data collected from the members of the Rapid reaction unit of the Czech Police operating in Prague and its statistical analysis, we can make the following conclusion. The measuring output was statistically significant. This means that physical exertion

which reaches the values of maximum heart rate has an effect on the precision of target shooting. The null hypothesis of the t-test was rejected and our alternative hypothesis was accepted. We also found worse results for all participants, in other words, the increase in the average distance of shots around the central point after a level of physical exertion. We also noted that for some participants, different kind of physical movement had a level of influence on their shooting performance. Those who do power training and endurance activities of cyclical character registered the lowest difference in comparison to the rest. The same thing happened in one participant which is dedicated in firearms skill training outside of work (better results) and another participant without shooting experience (worse results).

Nevertheless, it is necessary to note that our participant sample size was too small to make generalizations about the population. However, this paper offers certain trends related to further research in this area.

ACKNOWLEDGEMENTS

This paper was supported by grants GAUK 364811, PRVOUK 38 and SVV 2014-260115.

REFERENCES

ANDĚL, J. (2007). *Základy matematické statistiky*. 2nd ed. Praha: Matfyzpress.

BRAININA, S. I. (2013). *Probability Characteristics of Random Processes. Application of Random Process Excursion Analysis.* Elsevier.

ČELIKOVSKÝ, S., et al. (1979). *ANTROPOMOTORIKA pro studující tělesnou výchovu*. 3rd ed. Praha: SPN.

DOVALIL, J., et al. (2002). *Výkon a trénink ve sportu*. Praha: Olympia.

HELLER, J., VODIČKA, P. (2011). *Praktická cvičení z fyziologie tělesná zátěže*. Praha: Karolinum.

HENDL, J. (2004). *Přehled statistických metod*. Praha: Portál.

HYNOUŠ, J. (1980). *Teorie střelby*. Praha: Univerzita Karlova.

CHRÁSKA, M. (2007) *Metody pedagogického výzkumu*. Praha: Grada.

KITTNAR, O., et al. (2011). *Lékařská fyziologie*. Praha: Grada.

KNEUBÜEHL, B. P., COUPLAND, R. M., MARKUS, A. R., MICHAEL, J. T. (2008). *Wound Ballistics, Basic and Application*. Berlin Heldelberg: Springer.

KRUTECKIJ, V. A. (1972). Problema formirovanija i razvitija sposobnostej. *Voprosy psychologii* 2, 3–13.

KRYL, L. (1979). *Fyziologie sportovní střelby*. Praha: ÚV Svazarmu.

MARQUES, J. P. (2007). *Applied Statistics Using SPSS, STATISTICA, MATLAB and R*. 2nd ed. Berlin: Springer.

MORAVEC, R., et al. (2004). *Teórie a didaktika športu*. Bratislava: Fakulta tělesnej výchovy a športu Univerzity Komenského Bratislava.

NAVARO, M. (2007). *Pravděpodobnost a matematická statistika*. 1st ed. Praha: Nakladatelství ČVUT.

PERIČ, T., DOVALIL, J. (2010). *Sportovní trénink*. Praha: Grada Publishing.

PLÍHAL, B., et al. (2011). *Balistika*. Brno: Univerzita obrany.

SCHMIDT, R. A. (1991). *Motor learning and performance. From principles to practice*. 2nd ed. Champaign (IL): Human Kinetics.

SCHNABEL, G., THIES, G. (1993). *Lexikon Sportwissenschaft. Leistung, Training, Wettkampf*. Berlin: Sportverlag.

SHEPHARD, R. J. (1987). *Exercise Physiology.* B.C. Decker INC.

Richard Billich
richard.billich@gmail.com