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Ergonomic Analysis of a Firearm According to the Anthropometric Dimension

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Abstract

The paper summarizes the results of an ergonomic analysis of firearms with regard to anthropometric dimensions of selected populations. For evaluation 3D digital human models, which represent currently the best technology, have been used. Analyses are performed for three major population groups (Americans, Europeans and Asians). Ranges to controls (e.g. lock, trigger, etc.) are critically evaluated. The grip of the firearm according to the position of shooters wrist is also a subject to critical analysis. At the end of the paper the deficiencies found are discussed as well as a bad situation regarding the availability and timeliness of anthropometric dimensions of Czech population. Further work that is described will be focused on the creation of national anthropometric database. The database shall include the dimensions of the hand and will be created according to the rules of EN ISO 15535. The data will be suitable for the design of other hand tools from various sectors.

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Keywords: firearms; ergonomic analyses; anthropometric dimensions; digital human models; ranges

1. Introduction

Ergonomics as a multidisciplinary science extends to many fields of human activities. In the last years the division stabilized on product and process ergonomics. Product ergonomics primarily focuses on the product and how this product should comply specific parameters of friendliness to human. Process ergonomics is focuses by contrast on production method of product. This process should be design regard to human demands. This article is mainly focuses on the field of product ergonomics. The subject of our study is relatively unusual product, which is a

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firearm. Mainly armed forces (army, police, etc.) come into contact with guns nearly every day. For this reason these weapons must be adapted to fit in the hand in the best way. Thus the weapons must be maximally reliable during shooting.

Creation of universal product which would fit to all users on global market is absolutely impossible. The aim must always be to ensure friendliness for the largest possible group. The differences between various populations throughout the world are significant if we compare statures of Asians and Europeans or Americans. It is important to use anthropometric databases to design concrete product. These databases allow usage of the physical dimensions of different populations so that the final product can be tailored to certain group of users.

Today the information technologies are perceived as an indispensable tool in the design of a new product. Possibility to verify product parameters and suitability for user in computer virtual reality before functional prototype is absolutely undeniable. For this purpose the digital human models (DHM) are used. These DHM are fully customizable, so that results of studies carried out are perhaps the most realistic. If we talk about customization of a DHM, we mean setting its gender, nationality, percentile or specific body measurements, so that our digital human as much as possible corresponds to specific user. With user defined like this we then have the possibility to perform a variety of ergonomic analysis. We can find out how users (from different population size) will perform a given task, analyze the risk of injury, needed power, reach, grips and many other factors.

2. Methodology

For analysis and development of new weapons within Czech Republic we used the ergonomic software Tecnomatix Jack and digital human model included in this software ranks among the best in its category[1]. Tecnomatix Jack (Tx Jack) contains several anthropometric databases and it is possible to compare weapon models for different populations. Based on these results we can say, what suits and what is appropriate to change.

Ergonomic analysis of firearms related mainly to the suitability of the location of the controls and the way of the weapon grip. The aim was to ensure maximum comfort during weapon using and also elimination of adverse effects on the user which related to safety use. Each weapon should be suitable for the widest number of users. Therefore three populations were chosen for analysis. It is database ANSUR ANSUR [2] (U.S. Army Anthropometry Survey) which represents American population, GERMAN [3] which represents European population and KOREAN [4] which represents Asian population. For each population analyses were carried out for three different sizes of statures, namely for 5th, 50th and 95th percentile.

The first step was to compare available anthropometric databases and databases contained in Tx Jack (Table 1, Table 2 and Table 3). The tables show the comparison only for men, but the comparison and subsequent analysis were conducted also for women, which was one of the requirements of the assignment. Within this comparison we verified that the database differences are minimal and therefore it is possible to fully utilized software Tx Jack for subsequent analyses. The largest deviation in compared dimensions amounted to 6 mm in length of hand for 95th percentile of Korean population. Generally, it can be argued that in fact the majority of dimensions for the 95th percentile greatest differences were achieved.

Table 1. Comparison of hand anthropometry according to Hand Anthropometry of U.S. Army Personnel [2] and ANSUR Population Tx Jack.

MEN	Percentile	Hand Anthropometry of U.S. Army Personnel	ANSUR Population Tx Jack
Hand length [cm]	5	17,85	18,3
	50	19,35	19,3
	95	21,09	20,6
Hand breadth [cm]	5	8,36	8,6
	50	9,02	9,1
	95	9,76	9,5

Table 2. Comparison of hand anthropometry according to DIN 33402-2 [3] anf GERMAN Population Tx Jack.

MEN	Percentile	DIN 33402-2	GERMAN Population Tx Jack

Hand length [cm]	5	17,5	17,9
	50	18,9	19,0
	95	20,7	20,2
Hand breadth [cm]	5	8,0	7,7
	50	8,7	8,7
	95	9,4	9,2

Table 3. Comparison of hand anthropometry according to Anthropometric Survey of The Armed Forces of The Republic of Korea [4] and KOREAN_2003 Population Tx Jack.

MEN	Percentile	Anthropometric Survey of The Armed Forces of The Republic of Korea	KOREAN_2003 Population Tx Jack
Hand length [cm]	5	16,9	17,2
	50	18,1	18,6
	95	19,3	19,9
Hand breadth [cm]	5	7,8	7,7
	50	8,5	8,4
	95	9,1	9,0

After verifying the suitability of anthropometric databases it was accessed to verify the suitability of weapons. For the individual percentiles of each population there were evaluated ranges on trigger, selector level and bolt catch. These controls are shown on illustrative picture (Fig. 1). Next analysis was collision between fingers and selector level. Tests and analyses were conducted on 3D model of new weapon type.

Fig. 1. The illustration of evaluated controls.

3. Results

3.1. Controls reach and collisions

As previously mentioned, a digital human model was used to evaluate the ranges on trigger, selector level and bolt catch, and potential collisions. Summary results are presented in table 4.

Table 4. Control reach and collisions

Population	Percentile	Trigger	Selector level	Bolt catch	Collision
ANSUR	5	1	1	2	*
	50	1	1	1	**
	95	1	1	1	**
GERMAN	5	1	1	2	
	50	1	1	1	*
	95	1	1	1	*
KOREAN	5	1	2	2‘	
	50	1	1	1	
	95	1	1	1	*

Nomenclature

1	finger reaches on control
2	finger reaches on control with difficulties
2’	finger reaches on control with difficulties, press is complicated
*	collision occurs only during pressing bolt catch
**	collision occurs as during pressing bolt catch as with the finger on trigger

From the presented results it is evident that the greatest problems with reach are for 5th percentile of all evaluated populations. The problem is particularly prevalent in the reach on bolt catch which is located in a great distance from the weapon back. It causes difficult reach. If the finger reaches on bolt catch in extreme limit, it is necessary to think about maximal forces, which the extended index finger can perform. If the force for bolt catch pressing is great, pulling out of magazine will be very difficult and shooter will have to change the grip to take out the magazine.

Other problems appeared with selector level between single shots and burst. In this case there was collision especially for 95th percentile of all evaluated populations. The worst situation was in American population, its hand dimensions are the biggest from all compared populations. In this case there was collision not only with reach on bolt catch but also with normal position of finger on trigger or during trigger pressing. This analysis thus showed absolutely unsuitable position and design of selector level. This small lever is located downwards and it leads to undesirable contact with index finger. Thus it is necessary to design new selector level.

3.2. Gun-stock inclination

Digital human model was also used for the evaluation of the grip position during weapon firing. When gripping the pistol gun-stock two wrist positions may occurs, which is extension (pull-back dorsum of the hand to the forearm) and ulnar deviation (wrist movement towards the little finger side), as shown in Fig 2. When in neutral position the wrist axes are aligned at 0°. In the Tx Jack extension is represented by positive values, while ulnar deviation is represented by negative values. After performed measurements, following values have been identified .

- ANSUR population – 5th till 95th percentile – ulnar deviation ranges from -22,3° to -31,0°, extension from 26,0° to 30,5°.
- GERMAN population – 5th till 95th percentile – ulnar deviation ranges from -29,9° to -33,2°, extension from 19,5° to 29,2°.
- KOREAN population – 5th till 95th percentile – ulnar deviation ranges from -32,3° to -39,8°, extension from 25,4°to 27,2°.

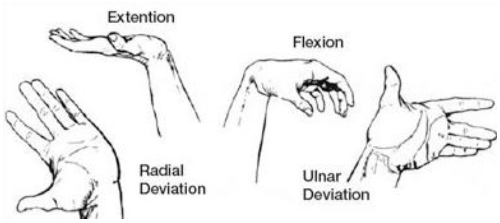


Fig. 2. Wrist positions [5].

4. Discussion

4.1. Gun-stock inclination

Apparently there is no dependence between population type, eventually body size, and wrist misalignment. So we cannot say for sure whether the wrist will bend more for large or small persons. Each person can grasp the gun in different way. Misalignment, respectively wrist ulnar deviation is affected by gun-stock inclination. According to the measurement [6], it was found that extension and ulnar deviation causes carpal tunnel compression. Dynamic load creates a temporary reduction in blood flow, static load permanent reduction. Compression of 20 mmHg can lead to reduced blood flow to the nerve. Compression of 30 mmHg leads to cessation of nutrient transport to the nerve. Fig. 3 and Fig. 4 show how big the pressure on carpal tunnel caused by wrist misalignment is.

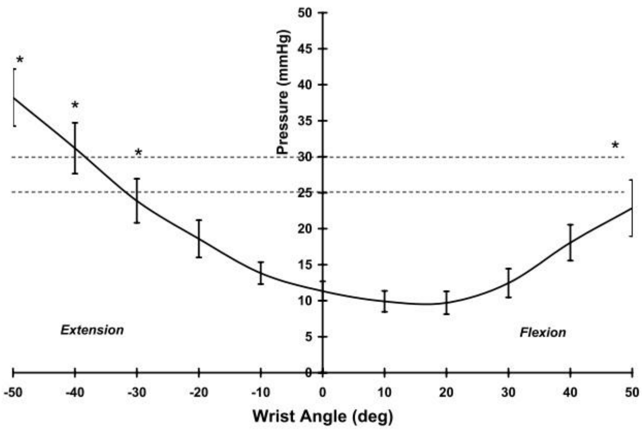


Fig. 3. Pressure on carpal tunnel during extension/flexion [6].

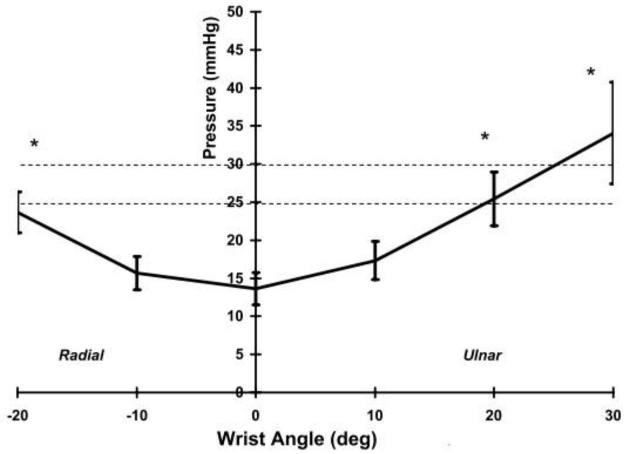


Fig. 4. Pressure on carpal tunnel during radial/ulnar deviation [6].

Bad gun-stock inclination may therefore cause such wrist misalignment, which leads to poor blood supply to the nerves, leading to tingling in the fingers and palm or reduced sensitivity of the wrist [7].

Highest misalignment was measured at the 5th percentile of the Korean population (-39.8°). In order to reduce ulnar deviation below 20° at 50% of the models, it is necessary to reduce gun-stock inclination minimally by 9.8°. Maximum angle reduction was recommended by 14°. The mean value is then 11.9°. The current gun-stock inclination is 120°.

4.2. Anthropometry database for Czech population

As described in the introduction, the new firearms are obviously designated for a wide range of users, however primarily targets the Czech population. There is also a problem with the lack of necessary data. Last measurements of the Czech population were performed in 1985 [8] so the actual body dimensions are missing. At the University of West Bohemia on the Department of Industrial Engineering and Management we therefore decided to carry out new anthropometric measurement of the population. We will use direct method, it is simple, low cost, time consuming method [9]. The newly collected data will be used for the development and design of a new firearm. It will be possible to use data also for other applications and evaluate the correlation between collected items [10].

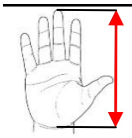
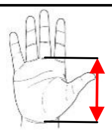
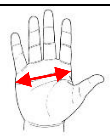
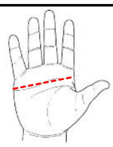
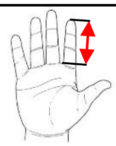
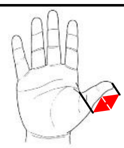
Measurement will be based on currently valid international standards, such as EN ISO 15535:2006 General requirements for establishing anthropometric databases [11] and EN ISO 7250:1997 Basic human body measurements for technological design [12]. Created database will contain the following items:

- Subject number
- Sex
- Exam location
- Exam date
- Birth date
- Decimal age
- Age
- Birth place
- Education
- Occupation
- Population group
- Stature

- Body mass

With regard to time consumption of the measurement, it will be performed only on hands, which are relevant for our subsequent research. On every person a measurement of both left and right hand will be performed. On each hand a total of 6 dimensions will be measured (see Table 5).

Table 5. Review of measured dimensions .

Hand length	Palm length	Hand breadth	Palm circumference	Index finger length	Thumb length
					

Measurement will be performed on population aged 20 to 70 years. Population groups will be divided by 10 years, resulting in a total of 5 population groups. In each group a minimum of 500 measurements will be performed, or a relevant number of measurements so that sufficient accuracy and validity of the measured dimensions will be ensured.

Conclusion

This article summarizes the use of digital human models technology in the firearms evaluation and upgrading. Although the technology of digital human models have been available for longer time, their use in the development of firearms is still rather rare. A digital human model from software Tecnomatix Jack has been used in presented research. To address the suitability of weapons for the widest possible spectrum of users, three vastly different population groups have been selected. These groups are the Europeans, Americans and Asians. Specifically used anthropometric databases were American ANSUR [2] (U.S. Army Anthropometry Survey), GERMAN [3] and KOREAN [4]. With the help of these databases a tests were conducted that were focused on controls reach and gun-stock inclination evaluation. These tests were always carried out for the 5th, 50th and 95th percentile of the population. The results of measurements were subsequently used for improvement of the design and changes proposals for new weapons types. During the research a bad condition regarding the current status of actual anthropometric data for the Czech population was stated. As the development of new firearms is targeted primary at the Czech population, it is also necessary to take into account the anthropometric dimensions of this particular population. Further work will therefore be dedicated to anthropometric measurements. This measurement will be conducted according to international standards so that the resulting data can be compared and used universally. The newly created database will contain mainly the dimensions of the hands, which are vital for our further research.

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