Experimental study: effects of typical man-rifle parameters on aiming performance

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Abstract. The purpose of this study was to examine the aiming performance implications of three typical man-rifle parameters, including the stock length, stock axis height and front grip position. An orthogonal test with three factors and three levels was designed. The EMG data of selected muscles and muzzle fluctuations were obtained by surface electromyography test system and 3D motion capture system. The results showed that different man-rifle parameters led to an alteration of muscle fatigue, thereby affecting aiming stability. The length and height of stock caused different muscle fatigue levels of right arm, and left arm muscles were sensitive to front grip position and stock length changes. The stock length and stock axis height affected horizontal aiming stability, and vertical aiming stability responded to all three man-rifle parameters. Overall, the stock axis height had the greatest impact on the aiming stability.

1. Introduction

Shooting accuracy is an important tactical technical indicator of firearms. For hand-held shooting rifles, in addition to the structure of firearm itself, the behavior of the shooter also affects shooting accuracy. The change of man-rifle parameters, such as the stock length, position of the stock axis to the barrel axis, grip shape, front grip position, weight and weight distribution of the rifle, etc., will affect the shooter posture, thus leading to the difference in muscle response and man-rifle stability.

By ergonomics tests, Yuan (1997) analyzed the effects of man-rifle parameters on aiming stability and firing accuracy, and “lighter weight and shorter handling length can improve the aiming stability and shooting performance” was concluded. Kemnitz (2001) found the same results and considered that the stock length mainly affected the shooting precision while the weight affected the shooting tightness. Selinger (2010) obtained the effect of weight and weight distribution on upper extremity muscular fatigue during static rifle aiming. Kuo (2012) found that the bullpup weapon provided an advantage in accuracy and shooter stability.

The above work had guided the study of the effects of man-rifle parameters on aiming stability and shooting accuracy, but the research parameters were limited. Therefore, three parameters were selected in this paper: the stock length, position of the stock axis to the barrel axis (hereinafter referred to as the stock axis height) and the front grip position. Through the aiming test, the effects of three man-rifle parameters on muzzle stability and upper limbs muscle fatigue were analyzed. It provided a theoretical basis for improving rifle ergonomics and shooting accuracy.
2. Methods

2.1. Procedure
In this paper, three variable man-rifle parameters, the stock length, stock axis height and the front grip position were set as factors A, B, C, respectively. The modified rifle used in the test can change the above three parameters through the guideway system. Each factor considered three levels, including two extreme values and the most comfortable position for shooters. Table 1 shows the orthogonal experimental design with three factors and three levels. As a result, there were 9 test trials. The parameters were shown in the figure 1.

| Trial | Level combination | Stock length | Stock axis height | Front grip position |
|-------|-------------------|--------------|------------------|---------------------|
| 1     | A_1 B_1 C_1       | Shortest     | Lowest           | Front               |
| 2     | A_1 B_2 C_2       | Shortest     | Comfortable      | Comfortable         |
| 3     | A_1 B_3 C_3       | Shortest     | Highest          | Back                |
| 4     | A_2 B_1 C_2       | Comfortable  | Lowest           | Comfortable         |
| 5     | A_2 B_2 C_3       | Comfortable  | Comfortable      | Back                |
| 6     | A_2 B_3 C_1       | Comfortable  | Highest          | Front               |
| 7     | A_3 B_1 C_3       | Longest      | Lowest           | Back                |
| 8     | A_3 B_2 C_1       | Longest      | Comfortable      | Front               |
| 9     | A_3 B_3 C_2       | Longest      | Highest          | Comfortable         |

Figure 1. Man-rifle parameters of the test.

The test environment was a 100m indoor target channel, with sufficient natural light and moderate temperature. Three right-handed experienced marksmen participated in the test. Subjects aimed from a free-standing unsupported position at a standard military target 100m away and performed 10s. Each trial repeated 5 times and a rest was provided between each test to avoid muscle fatigue.

2.2. Test system
The test system consisted of a Codamotion 3D motion capture system and a Delsys surface electromyography test system. The test system was triggered synchronously.

The Codamotion 3D motion capture system obtained the spatial coordinate position of the muzzle marker, which was used to analyze the muzzle aiming stability. The sampling frequency was 200Hz. The direction parallel to the barrel was designated as longitude direction. The direction perpendicular to the barrel was horizontal direction, and the up-down direction was vertical direction.

The Delsys surface electromyography test system recorded the muscle EMG signals, which were used to explain the muscle fatigue level. The sampling frequency was 1000Hz. Based on the previous
studies, the deltoid (DM), trapezius (TR), biceps (BB), triceps (TB) and brachioradialis (BR) muscle of both arms were tested.

![Graph](image1)

(a) The position of muzzle fluctuation. (b) The EMG and MF signals of right trapezius.

**Figure 2.** The test data.

2.3. Statistical analysis

ANOVA was used to study the effect of inter-subject variability, stock length, stock axis height and front grip position. An alpha level of 0.05 was selected as the minimum level of significance.

3. Muzzle aiming stability analysis

During the aiming process, the position of rifle changed slightly caused by muscular fatigue. The aiming stability was indicated by the amplitude of muzzle fluctuation (AMF). The greater AMF shows the more aiming instability, leading to the worse shooting dispersion (Yuan, 1997). The position and amplitude of muzzle fluctuation in three directions were shown in figure 2(a). This paper focused on the horizontal and vertical muzzle aiming stability, which can affect the shooting accuracy.

![Graph](image2)

(a) Horizontal direction. (b) Vertical direction.

**Figure 3.** The effect of man-rifle parameters on aiming stability.

The effect of man-rifle parameters on the horizontal aiming stability was shown in figure 3(a). The stock axis height had a significant impact on the horizontal aiming stability (P<0.01). The muzzle was most stable when the stock axis coincided with the barrel axis (comfortable position). The stock length and front grip position didn’t cause significant differences in aiming stability of horizontal direction.

Figure 3(b) showed the influence of man-rifle parameters on the vertical aiming stability. The stock axis height had a significant impact on the vertical aiming stability (P<0.01). The vertical aiming...
stability was worst when the stock axis was lowest. The effect of stock length and front grip position on the vertical aiming stability was lower than the stock axis height. The stock length, stock axis height and front grip position didn’t significantly affect the aiming stability in longitude direction. In general, the muzzle was most stable with the shortest stock, the comfortable front grip position and stock axis coincided with the barrel axis (Trial 2). When stock length and front grip were in comfortable position and the stock axis was lowest, the aiming stability was the worst (Trial 4).

4. Muscle fatigue analysis
The median frequency (MF) was obtained by fast Fourier transformation of surface EMG signals, showed in figure 2(b). MF represents the degree of muscle fatigue, and the MF value gets lower when the muscle becomes more fatigue. Overall, the MF value of right deltoid and left triceps were significantly lower than other muscles. The right deltoid and left triceps muscle became more fatigue during the aiming process. The influence of front grip position change on muscle fatigue was showed in figure 4.

![Figure 4](image.png)

Figure 4. The influence of front grip position change on muscle fatigue.

The difference of man-rifle parameters will change shooter’s posture, which affects muscle strength and fatigue level. Holding a rifle, muscles play different roles and man-rifle parameters have different effects on muscles. The P value and F value of ANOVA can indicate whether the muscle responds to the man-rifle parameters change and the response degree. The muscle fatigue response to man-rifle parameters was shown in table 2.

| Muscle          | Order of three man-rifle parameters influence                          |
|-----------------|------------------------------------------------------------------------|
| Right deltoid   | Stock length > Stock axis height > Front grip position                 |
| Right trapezius | Stock length > Stock axis height                                       |
| Right biceps    | Stock length > Stock axis height                                       |
| Right triceps   | Stock axis height                                                      |
| Right brachioradialis | Stock length                        |
| Left deltoid    | Front grip position > Stock axis height > Stock length                |
| Left biceps     | Front grip position > Stock axis height                                |
| Left triceps    | Front grip position > Stock length                                     |
| Left brachioradialis | Stock axis height            |
| Left trapezius  | Stock axis height                                                      |
As the above table showed, the main factors that caused the right arm muscles fatigue were the stock length and stock axis height. The left arm muscles were mainly sensitive to the change of front grip position and stock length. All three man-rifle parameters affected the deltoid muscles. The biceps, triceps and brachioradialis, which were used to hold the weight of rifles, were less sensitive to man-rifle parameter changes than other muscles.

To explore the relationship between muscle fatigue and aiming stability, multiple linear regression with stepwise method for regression independent variables was used. The large absolute value of the regression coefficient \((b)\) indicates that the muscle contributes significantly to aiming stability. The contribution of muscle fatigue to aiming stability was shown in table 3. The aiming stability was improved when the fatigue level of right trapezius, right deltoid and left triceps increased, while the fatigue level of left deltoid and right brachioradialis decreased.

Table 3. The contribution of muscle fatigue to aiming stability.

| Horizontal aiming stability | Muscles          | Right brachioradialis | Right trapezius |
|-----------------------------|------------------|-----------------------|-----------------|
| \(b\)                       | Right deltoid    | 0.477                 | 0.473           |
| Vertical aiming stability   | Left deltoid     | 0.525                 | 0.479           |
| \(b\)                       | Right deltoid    | 0.479                 | 0.359           |
| Longitude aiming stability  | Right trapezius  | 0.479                 | 0.339           |
| \(b\)                       | Left triceps     | 0.459                 |                 |

The horizontal aiming stability was related to the right trapezius and brachioradialis, which were mainly affected by the stock length and stock axis height. Combined with the above analysis, it was concluded that the horizontal aiming stability depended on the stock axis height and the front grip position had little effect on it. With the lowest stock axis and the shortest stock, the aiming stability was the worst in horizontal direction.

Multiple muscles were related to the vertical aiming stability, and all three factors had an impact on it. However, the stock axis height had the greatest effect on vertical aiming stability. The muzzle was most unstable in vertical direction when the grip was at the front and stock was longest and lowest.

5. Conclusion
The effects of three man-rifle parameters on the muscle fatigue and aiming stability were explored in this study. The length and height of stock caused different muscle fatigue levels of right arm, and left arm muscles were mainly responsible to the change of front grip position and stock length. The deltoid muscle was sensitive to all three man-rifle parameters. The biceps, triceps and brachioradialis, which were mainly responsible for the rifle weight, showed lower sensitivity than other muscles.

Combined with the analysis of muscle fatigue and aiming stability, the stock length and stock axis height had an impact on right trapezius and brachioradialis, thereby affecting horizontal aiming stability. All three factors affected deltoid muscle fatigue, which was related to the vertical aiming stability. Overall, the stock axis height had the greatest impact on the aiming stability.

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