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Ergonomic Assessment of Multi Calibre Individual Weapon System in Virtual Reality Platform

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ABSTRACT

The primary objective of the study was to assess the compatibility of multi calibre individual weapon system (MCIWS) with the shorter, medium and larger individual users of Indian Army. Three dynamic digital human models (DHM) 5^{th}p, 50^{th}p, 95^{th}p army pooled (AP) population were considered to accommodate wide range (more than 90 per cent) of the army population for ergonomic analysis of the weapon system with the help of digital human modelling software Jack. Solid model of MCIWS which was in Parasolid file format X_T (*.x_t) was imported into NX5 (solid model design software) and subsequently converted to JT (*.jt) format. This solid model was later translated into Jack 5.0.1 environment. Standing, squatting and crawling with the weapon were adopted for the study. Angular deviations of important joints, posture prediction using OWAS, and comfort discomfort assessment using Dreyfus 3D method were carried out in the study. The result of the study revealed that the operation in squatting and crawling conditions may increase postural load on neck, shoulder and upper arm. The pistol grip size, shape and contour are acceptable for the taller population. Removal of corrugated gripping surface, reduction of grip diameter and space adjustment for gloves use will be effective for optimal use. The position and size of fore grip seemed suitable for the taller users. Sight system could be accessed by all three user populations. It is advised to avoid holding the weapon for long duration with hands to prevent overuse injury or undue fatigue.

Keywords: Digital human models; Solid model; Posture

1. INTRODUCTION

The modern day warfare is characterised by use of advanced weapon systems. Ergonomics can play an extremely important role in design of such a complex system.

The ergonomics aspects of any product design can be approached through human centric design evaluation with the application of digital modelling and simulation. Computer aided design (CAD) is applied to create virtual digital prototype of workstation/ product/ weapon system for useful ergonomic assessment. Digital human modelling (DHM) software use advanced CAD based technology to create and manipulate 3D human models in virtual environment of computer graphics on the computer screen[1-3]. These DHMs can be interfaced with the digital prototype of the product in virtual reality platform for further analyses. The DHM has capabilities to create a specific population attributes which facilitate designers to build systems suitable for operators of varying body dimensions. It provides the developers with a biomechanically correct CAD realistic representation of the human body, i.e. manikin, which can be simulated of operator's posture and motion behaviour[4]. The implementation of digital human model reduces and sometimes eliminates the requirement of dummy model, card board manikin, 2D drawings and even real human trial in expensive physical mock-ups[5-7]. The ultimate goal of this technology is basically to reduce design time and cost of development, improve quality, increase productivity with enhancement of safety and optimisation of human machine interface[8,9]. Digital human modelling software, typically consider spatial accommodation, posture, reachability, clearance/interference of body segments, field of vision, biomechanical stresses of the operators and other standard ergonomic practices for the ergonomic evaluation of any workstation[8,10].

Multi calibre individual weapon system (MCIWS) is an assault rifle developed in India by the Armament Research and Development Establishment, a laboratory of the Defence Research and Development Organisation. The MCIWS is configured to fire in 5.56 mm x 45 mm NATO, 7.62 mm × 39 mm and in 6.8 mm Remington SPC. Its design is influenced by both the AR-15 and the FN FNC. The barrel assembly appears to be based on the AK-47. The design would allow soldiers to configure it according to the needs of the missions by changing rifle barrels[11]. Ergonomic assessment was felt to be necessary before sending the weapon to the production stage to assess human machine interface issues with the user population which possesses huge difference in dimensions and culture. The primary aim of the study was to verify the compatibility of the weapon system with the shorter, medium and larger individual users from Indian Army. The study was also aimed to check the usability of various components of the weapon system. To achieve these targets digital human modelling software Jack

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(5.0.1) was used and ergonomic principles were followed in the virtual environment.

2. OBJECTIVES

Ergonomic assessment of compatibility of the weapon system with different sizes of army population. Ergonomic assessment of specific components like Pistol-grip location and contour, Fore-grip location, contour and length, Sight axis with reference to butt by using comfort-discomfort assessment, angular measurements and postural analysis.

3. MATERIALS AND METHODS

3.1 Study of Anthropometric Database

As the weapon system is developed mainly for the Indian population hence anthropometric database of Indian Army population[12] was considered as the reference population for assessment. 5thp, 50thp, 95thp Army pooled (AP) population were considered for ergonomic analysis of MCIWS. To accommodate wide range (more than 90 %) of the Army population 5th and 95th percentile body dimensions were selected for generation of digital human models.

3.2 Generation of Digital Human Model

Three dynamic digital human models 5thp, 50thp and 95thp AP were generated from the above anthropometric database with the help of digital human modelling software Jack 5.0.1[13]. This software uses 27 key anthropometric measurements for the development of human figure. These figures are having 69 body segments, 68 joints, and 135 degrees of freedom. The ranges of movement of different joints are realistically constrained (Joint limits are derived from NASA studies)[14]. The figure does not contain smooth contour and flesh as observed in normal human being (Fig. 1).

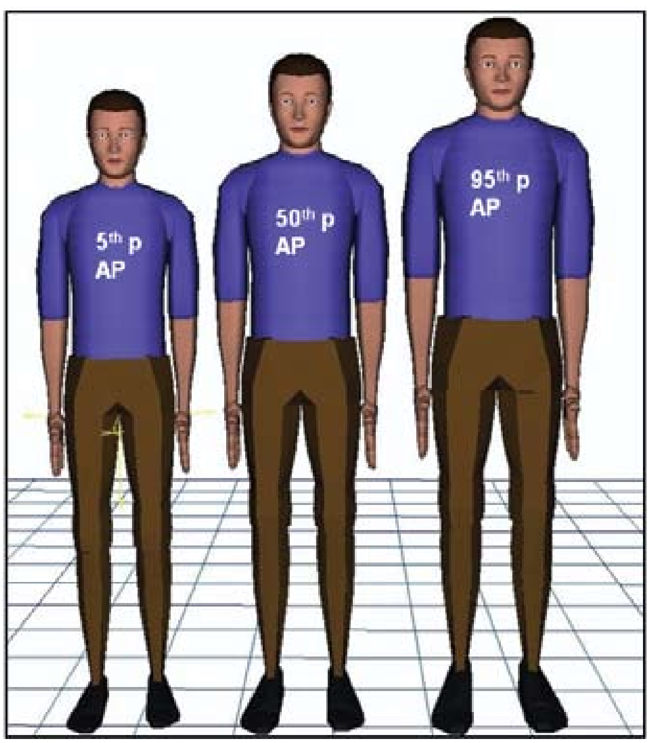


Figure 1. Jack software generated digital human models.

3.3 Generation of Digital Model of the MCIWS Weapon System

Solid model of MCIWS was made in Parasolid file format X_T (*.x_t). It was then imported into NX5[15] and subsequently converted to JT (*.jt) format. This solid model was later translated into Jack 5.0.1 environment. Then it was saved as an environment file (*.env). Ergonomic analysis of MCIWS was carried out on *.env files. Figure 2 shows the weapon system with all components.

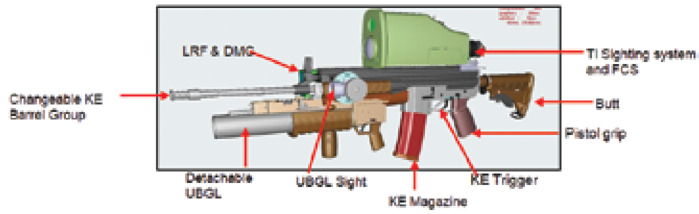


Figure 2. MCIWS with all components.

3.4 Interfacing Weapon Model with DHM

The solid model of MCIWS was interfaced with digital human models of 5thp, 50thp and 95thp AP soldiers. They were brought to the same environment of the MCIWS in Jack soft ware for positioning them to hold the weapon in shooting postures. Snap shots of an Indian Army soldier at different shooting stance holding the INSAS rifle were taken. These were later used to simulate the shooting postures of the human mannequins in Jack software environment. The right eye of all three percentile AP mannequins was pointed at the view point of the sight system of the weapon. Other parts and joints were adjusted accordingly. During interface MCIWS was displaced from its original position depending on the position of human mannequins and their respective right eyes.

Shooting Postures

Three shooting postures were adopted with each percentile soldier as following-

- Standing with MCIWS
- Squatting with MCIWS
- Crawling with MCIWS

Figure 3(a-i) show different shooting postures adopted by 5thp, 50thp and 95thp AP soldier populations. Following components and procedures were considered for ergonomics analyses of the weapon system:

1. Pistol-grip location and contour
2. Fore-grip location, contour and length
3. Sight axis with reference to butt
4. Comfort-discomfort assessment
5. Postural analysis

Following procedures were performed during analysis-

3.4.1 Pistol Grip Analysis

(a) Using 'measure distance' tool of Jack 5.0.1 software[13] the distance between thumb and middle finger was measured at maximum grip and while holding the pistol-grip of all three percentile soldiers. This distance was assumed as the diameter of the right hand. The differences between two diameters were considered for analysis purpose. The distance between tip of thumb and tip of middle finger was

also measured at both maximum grip and while holding pistol grip.
(b) The trigger was pulled backward to the maximum distance possible and the index finger was positioned accordingly.
(c) The right hand along with fingers was enlarged up to 1.2 per cent of the scaling system of human models to adopt a size of hand after wearing a glove. After enlargement the index finger was put inside the trigger guard to check the space provided for glove's use. Similarly the other fingers were also placed in the grip to check their accommodation in the grip.

3.4.2 *Fore-grip Location, Contour and Length*

(a) The component Hand grip vertical was used for analysis of fore-grip as it was not present with the model of MCIWS.
(b) Diameter of hand at maximum grip and while holding fore grip were measured using same process used for pistol grip analysis.

3.4.3 *Sight Axis with Reference to Butt*

(a) Right eye of each percentile soldiers was placed at the view point of the sight system. Eye views of all shooting postures of all three percentiles were captured. This was performed to verify the exact view of the eye with reference to the sight system.
(b) Data from comfort-discomfort assessment and angular changes of neck and atlanto-occipital joints were also taken into consideration as position of the head and neck play effective role in clear vision of the sight system.

3.4.4 *Comfort-discomfort Assessment*

It is possible to simulate realistic posture and motion with task description in both physically constrained and unconstrained condition in the virtual environment of digital human model software. Objective measurement of body parts comfort/discomfort of the digital human model of Indian army soldiers were carried out while holding the weapon in various shooting postures. Comfort ratings for various body joints were performed according to Dreyfuss 3D method[16] for different postures. This rating scale has a wider application for general standing & seating postures. Green colour in the comfort rating tables, indicate joint angle in acceptable range and yellow colour indicates joints outside comfort range. On the other hand the cells kept blank in the table indicate joints are not part of Dreyfuss 3D data source. Figure 4 and Table 1 presents an example of the representation of the comfort discomfort assessment in the Jack software.

3.4.5 *Spatio-temporal Parameters*

Angular deviations of important joints while holding the weapon at various shooting postures were considered for analysis and were achieved using joint angle tool of the

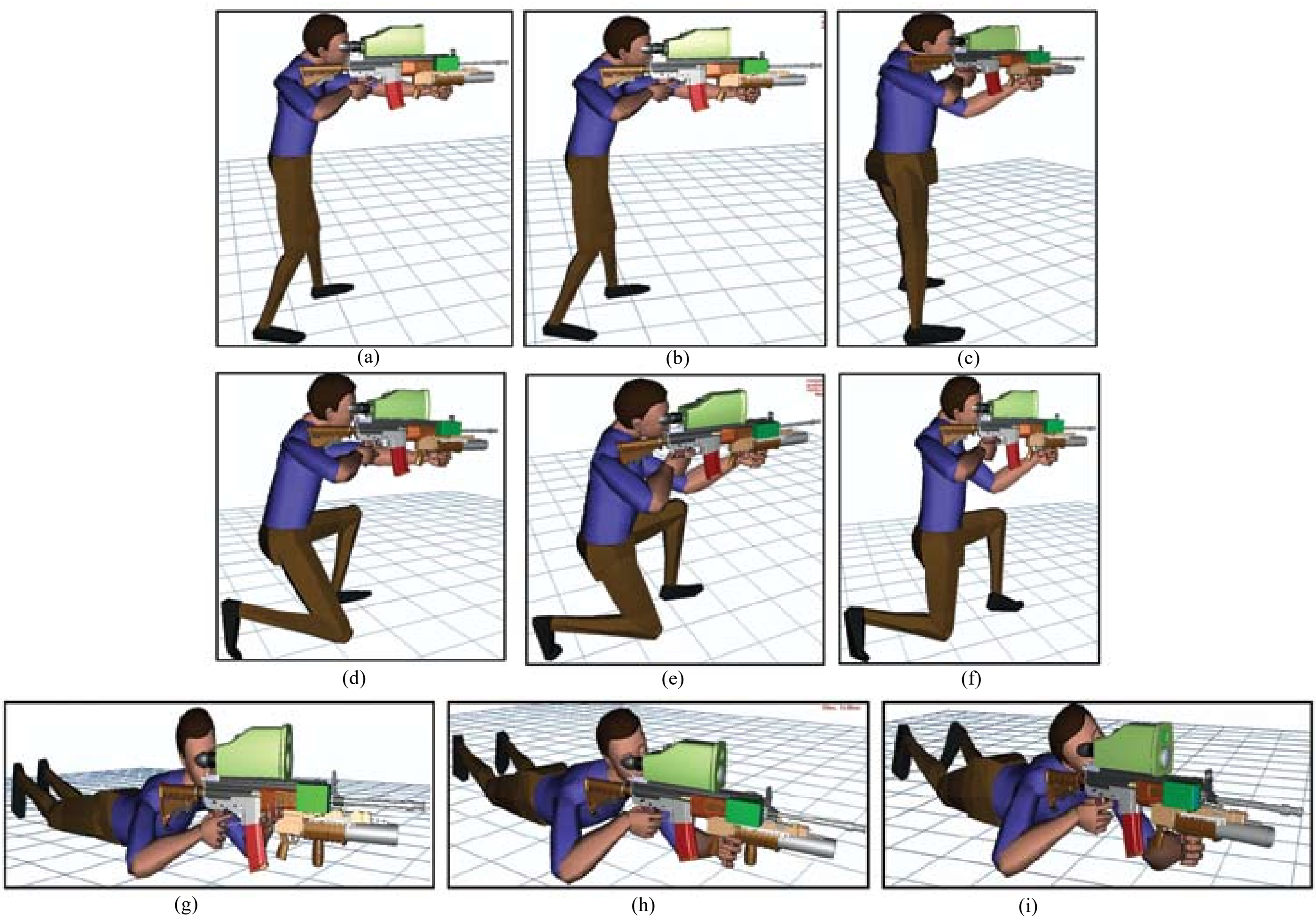


Figure 3. 5thp, 50thp and 95thp AP: (a)-(c) standing with MCIWS, (d)-(f) squatting with MCIWS, and (g)-(i) crawling with MCIWS.

Table 1. Comfort assessment of 95thp AP standing (Dreyfuss 3D method)

Angle	Right		Left
Head flexion		37.0	
Head lateral		20.0	
Head rotation		6.5	
Upper arm flexion	63.4		58.8
Upper arm elevation	61.5		-2.3
Humeral rotation	-60.0		-60.0
Elbow included	52.0		112.9
Forearm twist	31.1		71.7
Wrist ulnar deviation	-7.7		-24.9
Wrist flexion	48.9		1.6
Torso recline		-5.4	
Trunk thigh	176.7		157.4
Leg splay	6.6		11.1
Thigh rotation	40.0		4.5
Knee included	167.5		164.9
Foot calf included	76.2		101.3

Green = within comfort range; Yellow = outside of comfort range; Black = not part of Dreyfuss 3D data source

software[13]. Photographic representation of measurement of angular deviations is provided later in the discussion part.

3.4.6 Postural Analysis

All the shooting postures were analysed using Ovako work-posture analysis system (OWAS); a posture analysis tool of jack 5.0[17].

4. RESULTS AND DISCUSSIONS

Ergonomic assessment of MCIWS was carried out using DHMs of 5thp, 50thp, 95thp Army pooled population at virtual reality platform. The solid model of the weapon system was interfaced with the DHMs in Jack 5.0.1 digital human modelling software. Analyses were carried out with selected Army pooled population adopting the shooting postures generally followed by the soldiers. Results of comfort-discomfort assessment across various populations and different posture with the weapon system are as summarised in Table 2. The Table 3 presents the angular deviations of different joints and movements in different axes across various populations and different posture with the weapon system. Table 4 shows

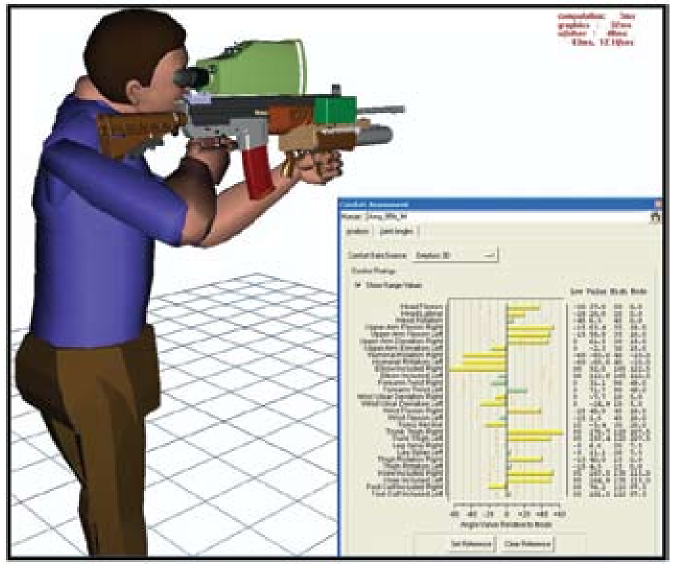
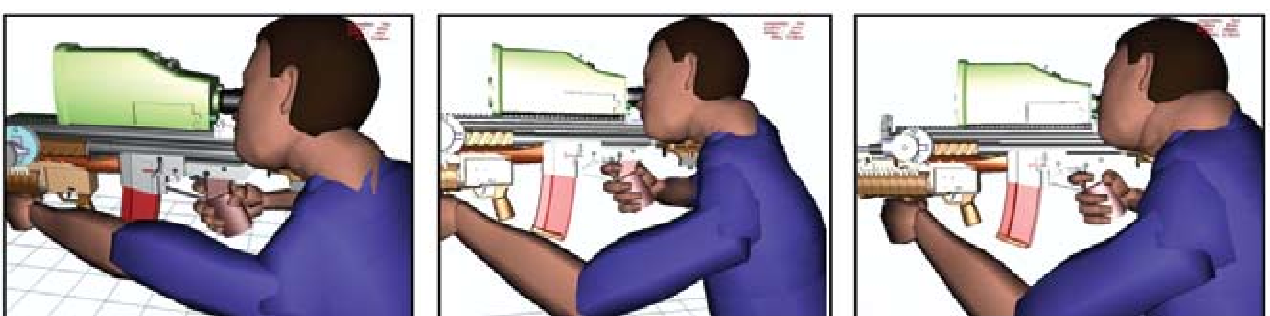


Figure 4. Comfort assessment of 95thp AP standing with MCIWS.

the findings of the postural analyses by OWAS in different postures adopted by various populations holding the weapon. Point wise representation of the ergonomic assessment of MCIWS is provided after that.

4.1 Pistol Grip Location, Contour, Trigger Operation and Space for Gloves

i. Table 5 shows the comparison between diameter of hand and the distance between tip of right thumb and tip of middle finger at maximum grip and with the pistol grip and hand grip vertical of all three percentile soldier populations considered.
ii. The outer diameter of the pistol grip is 5.5 cm. The diameter of pistol grip in INSAS rifle is 4.5 cm. The recommended range of diameter for cylindrical handle is 30-50 mm (3-5 cm)[18].
iii. Location of trigger and its movement- The trigger provided with solid model of MCIWS could be pulled normally with index fingers of all three percentiles of Indian Army soldiers. Figure 5a-c shows the trigger operation by 5thp, 50thp, and 95thp AP.
iv. Space for gloves- Size of each fingers of right arm of each percentile was enlarged from scaling segment up to 1.2. This was done to have a similar size of the hand as



(a) (b) (c)

Figure 5. Pistol grip is held by 5thp, 50thp, and 95thp AP : (a), (b) and (c).

Table 2. Result of comfort-discomfort assessment of different postures

Angle		5thp	5thp	5thp	50thp	50thp	50thp	95thp	95thp	95thp
		St	Sq	Cr	St	Sq	Cr	St	Sq	Cr
Head flexion		Y	Y	Y	Y	Y	Y	Y	Y	Y
Head lateral		N	N	N	N	N	N	N	N	N
Head rotation		N	N	N	N	N	N	N	N	N
Upper arm flexion	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	Y	Y	Y	Y	Y	Y	Y	Y	Y
Upper arm eleven	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	Y	Y	Y	N	N	Y	Y	Y	Y
Humeral rotation	R	N	N	N	N	N	N	N	N	N
	L	N	N	N	N	N	N	N	N	N
Elbow	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	Y	Y	N	N	N	N	N	N	N
Forearm twist	R	N	N	N	N	N	N	N	N	N
	L	N	N	Y	N	N	Y	N	N	Y
Wrist ulnar deviation	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	N	N	Y	Y	Y	Y	Y	Y	Y
Wrist flexion	R	N	N	N	Y	Y	N	Y	N	N
	L	N	N	N	N	N	N	N	N	N
Torso reclined		Y	Y	N	Y	Y	N	Y	Y	N
Trunk thigh	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	Y	Y	Y	Y	Y	Y	Y	Y	Y
Leg splay	R	N	Y	N	N	N	N	N	N	Y
	L	N	N	Y	N	N	N	N	N	N
Thigh rotation	R	N	N	Y	Y	N	N	Y	Y	N
	L	N	N	N	N	N	N	N	N	Y
Knee	R	Y	Y	Y	Y	Y	Y	Y	Y	Y
	L	Y	Y	Y	Y	Y	Y	Y	Y	Y
Foot calf	R	Y	Y	N	N	Y	N	Y	Y	N
	L	N	Y	N	N	N	N	N	N	N

Y- out of range, N- within range, St-standing, Sq-Squatting, Cr- Crawling,

wearing gloves.

(a) 95thp AP could hold the trigger normally with the index finger but difficulty faced when tried to pull it. The other three fingers of the hand could not be accommodated in pistol grip. Thumb after enlargement could not be positioned properly at pistol grip.

(b) 50thp AP could hold and move the trigger with index finger without facing any difficultly. Other fingers could be accommodated within the grip including the thumb. Small portion of little finger was outside the grip when enlarged.

(c) Holding and pulling the trigger was normal with enlarged index finger by 5thp AP. This population could accommodate other four fingers in the grip normally.

(d) The corrugated surface provided in the pistol grip could not match finger shapes of any percentile soldiers.

Therefore, from the above mentioned findings following observations could be cited:

(a) The diameter of the grip is larger than the recommended diameter range. All three percentiles of the soldiers could hold the grip as power grip with little difficulty. Reinvestigation of grip dimension may be required considering the differences in hand sizes in Indian Army population.

(b) Location and movement of the trigger is acceptable for the Army population investigated.

(c) 5thp and 50thp AP was having the provision to operate trigger wearing gloves. Whereas, the triggering operation of 95thp AP was not possible wearing gloves because of their relatively larger dimension of fingers.

(d) Shape of the grip has been studied extensively in previous studies. The most important consideration related to grip shapes is that the shape should maximize the area of contact between palm and the grip in order to avoid pressure ridges and stress concentration points especially in power grips. The groove in the pistol grip must be removed as it can create pressure hot spots and discomfort at the hand and fingers[18].

4.2 Fore Grip Location, Contour, Length

i. Table 5 shows the comparison between diameter of hand grip at maximum grip and with the fore grip of all three percentile soldier populations considered.

ii. 5thp AP could hold the fore grip with left hand engaging all five fingers (Fig. 6(a)). The circumference of the grip was almost appropriate for this percentile of soldiers as there was little overlapping of fingers and a proper power grip was achieved.

iii. At the time of holding the grip in standing and squatting postures (Figs. 3(a) and 3(d)) the left arm of 5thp AP was

(a) (b) (c)

Figure 6. Fore grip is held by 5thp, 50thp, 95thp AP in (a), (b) and (c), respectively.

Table 3. Angular deviations of different important joints of three percentile soldiers in different postures

Joint angles	Axis/ movement	5thp St	5thp Sq	5thp Cr	50thp St	50thp Sq	50thp Cr	95thp St	95thp Sq	95thp Cr
Right Wrist	Y	-12.3	-12.3	-21.4	-11.3	-18.7	-45.0	-7.7	-6.0	-31.1
	X	42.7	42.7	44.1	57.2	84.7	33.0	48.9	42.0	41.6
	Z	-59.2	-59.2	-35.2	-62.0	-51.0	-30.1	-71.3	73.7	-41.6
R Elbow	Y	121.0	121	115.3	128.1	-128.1	118.2	128.0	128.0	124.8
R Shoulder	Z	71.5	71.5	71.5	71.5	71.5	60.6	71.5	71.5	52.2
	X	33.5	33.5	41.1	32.5	31.7	33.5	31.6	33.5	39.6
	Y	83.0	83	129.1	74.4	74.4	122.4	83.0	83.0	114.1
R Clavicle	X	-6.1	-6.1	-11.5	-6.1	-6.1	-12.0	-6.1	-6.1	-12
	Y	5.5	5.5	7.8	3.5	3.5	10.0	-1.9	-1.9	3
Neck	Y	32.4	32.4	-36.6	37.0	37.0	-32.0	37.0	34.0	-31.4
	Z	19.4	19.4	0	-2.0	-2.0	0	6.5	6.0	30.5
	X	20.0	20.0	0	20.0	20.0	0	20.0	20.0	19.5
Atlanta Occipital	Z	13.0	13.0	-15.5	28.1	28.1	-5.5	20.0	18.7	1.5
	X	-44.0	-44.0	-24.5	-41.4	-41.4	-31.3	-51.5	-46.7	-41
	Y	19.0	19.0	23.2	23.5	23.5	23.5	22.0	22.0	10
L Clavicle	X	-3.2	-3.2	20.7	-9.6	-9.6	24.5	-9.6	-9.6	25.0
	Y	5.2	5.2	20.0	0.2	0.2	28.4	0.2	0.2	40.0
L Shoulder	Z	5.5	5.5	31.7	5.5	5.5	11.1	5.5	5.5	25.6
	X	16.8	16.8	31.5	12.6	12.6	30.3	8.5	8.5	38.8
	Y	111.9	112.0	122.8	78.4	78.4	115.7	75.9	75.9	121.5
L Elbow	Y	0.0	0.0	66.6	58.5	58.5	51.8	67.1	67.1	48.6
L Wrist	Y	0.0	0.0	-1.4	-24.9	-24.9	-8.2	-24.9	-24.9	-10.0
	X	6.7	6.7	14.3	1.6	1.6	20.5	1.6	1.6	-6.8
	Z	13.1	13.1	-113.0	8.3	8.3	28.8	8.3	8.3	-23.9
R Knee	Y	24.3	135.5	25.3	15.2	126.9	28.2	12.5	107	32.3
L Knee	Y	11.4	115.4	24.7	10.7	109.6	25.2	15.1	102.9	28.6
Human Torso	Flex	21.0	21.0	-22.0	21.0	21.0	-25.	20.4	20.4	-25.0
	Axi	-39.0	-37.0	0.3	-39.1	39.1	0.3	-38.0	-38.0	-2.0
	Lat	2.0	2.0	-0.3	-3.0	-3.0	-0.3	-2.0	-2.0	10.0

St-standing, Sq-Squatting, Cr- Crawling

Table 4. Posture analysis score using OWAS tool

Posture	OWAS score
5th p standing	2
5th p squat	4
5th p crawling	2
50th p standing	2
50th p squat	2
50th p crawling	2
95th p standing	2
95th p squat	4
95th p crawling	4

St-standing, Sq-Squatting, Cr- Crawling,

Table 5. Comparison between the diameter of hand grip and measured distance between right thumb and tip of middle finger at maximum grip and with the pistol grip

Percentile	Diameter of grip (cm)			Distance between tip of thumb and tip of middle finger (cm)	
	Maximum grip	Pistol grip	Hand grip	Maximum grip	Pistol grip
5th	3.0	4.3	4.0	0.10	2.81
50th	3.5	4.9	3.5	0.75	2.22
95th	3.8	5.2	4.3	0.70	2.25

over-stretched. At these postures shoulder elevation, flexion and elbow extension were above the acceptable range (Table 3). Angular deviations at y axis of shoulder joints were 112˚ while standing and squatting.

iv. During crawling the scenario became worse. The 5thp AP could not hold the fore grip at all as the person has to place the elbow on the floor to support the weapon (Fig. 3(h)).

v. Though power grip is achieved the over stretching of the supporting (left) arm may cause problem for the users during firing with full weight of the weapon (7810 g).

vi. The 50thp AP could not engage all five fingers while holding the fore grip (Fig. 6(b)). The gripping of the fore grip was achieved by leaving the little finger of the respective hand. Still this soldier population managed to achieve the power grip. Thus, it can be argued that the grip length and shape was inappropriate for this population.

vii. Similar problem in gripping the fore grip was faced by 50thp AP during crawling (Fig. 3(h)). Therefore, shooting at this posture may become difficult for the population.

viii. The 95thp Army could not engage all five fingers while gripping the fore grip (Fig. 6(c)). In this case again little finger of the left hand remained hanging. Overlapping of the thumb and other fingers was also observed.

ix. Result of comfort-discomfort assessment at standing, squatting and crawling postures indicate the shoulder elevation, flexion and elbow extension were above the acceptable range (Table 3). Angular deviations at y axis of shoulder joints at these postures were acceptable (Table 4). Shooting with all components of the weapon system may not cause problem for 95thp Army.

From these findings following observations were made

(a) For larger hand sizes of the taller (95thp AP) population the length and the diameter of the grip is not appropriate.

(b) However, the position of the fore grip looked proper for the taller group.

(c) Shorter population like 5thp and 50thp AP the shape and size of the fore grip looked to be appropriate.

(d) Reinvestigation of the placement of fore grip may be required.

4.3 *Analysis of Sight System*

i. All three percentile soldier under consideration were able to place their right eye at sight system properly.

ii. After comfort assessment it was observed that neck flexion was higher than the acceptable range in 5thp AP at standing, squatting and crawling postures, 50th p AP at squatting and crawling and 95thp AP at squatting and crawling postures (Table 3).

iii. Table 4 shows the angular deviation of the neck and the atlanto-occipital joints of the above mentioned postures. The angular deviations of neck and atlanto-occipital joints supports the data revealed from comfort assessment.

iv. Neck movement at z axis (flexion) reached 19.4° in 5thp AP at standing and squatting postures. Thus from the comfort assessment and spatio-temporal data of the neck and atlanto-occipital joints it can be stated that holding the gun for long duration, positioning the right eye at sight system can create problem and discomfort at neck region.

Figure 7 (a-i) show the eye view with neck angular deviations of 5thp AP, 50thp AP and 95thp AP at standing, squatting and crawling postures.

5. CONCLUSION AND RECOMMENDATIONS

Ergonomic analysis of the digital model of MCIWS was carried out with digital human models in digital human modelling software in virtual environment. Evaluation of several ergonomic parameters e.g. location, profile, contour and length of components like pistol grip, and fore grip were carried out. Analysis of sight system was conducted with reference to eye view and sight axis. In addition, posture analysis along with assessment of comfort and discomfort was performed.

Depending upon the results revealed from ergonomic analysis following recommendations are suggested considering the human-machine compatibility:

i. The pistol grip size, shape and contour were acceptable up to 50th percentile of the Army pooled population. Removal of corrugated gripping surface, reduction of grip diameter and space adjustment for gloves use will be effective for optimal use.

ii. Proper placement of the fore grip seems necessary for the shorter population. The size of this component was acceptable for the shorter group of user population.

iii. Reduction of overall weight of the system or limitation in the duration of use is suggested for the optimal use for the shorter population.

iv. Use of the weapon at squatting posture with may pose risk of injury on neck, shoulder and upper arm of shorter, medium and taller population.

REFERENCES

1. Das, B. & Sengupta, A.K. Technical note: Computer aided human modelling programs for workstation design. *Ergonomics*, 1995, **38**(9), 1958- 1972. doi: 10.1080/00140139508925243
2. Naumann, A. & Röetting, M. Digital human modelling for design and evaluation of human-machine systems, 2007, MMI-Interktiv, ISSN 1439-7854.
3. Karmakar, S.; Pal, M.S.; Majumdar, D. & Majumdar, D. Application of digital human modelling and simulation for vision analysis of pilots in a jet aircraft: A case study; Work 2012, **41**, 3412-3418.
4. Patel, T.; Karmakar, S.; Sanjog, J.; Kumar, S. & Chowdhury, A. Digital human modeling for ergonomic evaluation of tractor operator's workplace. *In* Ergonomics for Enhanced Productivity, edited by P. Parimalam; M.R. Premalatha & P. Banumathi, Excel India Publishers, India, 2013. pp. 203–208.
5. Morrissey, M. Human-centric design. *Mechanical Engineering*, 1998, **120**(7), 60-62. doi: 10.1115/1.1998-JUL-2
6. Woldstad, J.C. Digital human models for ergonomics. *In* International Encyclopedia of Ergonomics and Human Factors, edited by W. Karwowski, Taylor & Francis, New

Figure 7. Eye view with neck joint angle of 5thp, 50thp, and 95thp AP while (a)-(c) standing with MCIWS, (d)-(f) squatting with MCIWS, and (g)-(i) crawling with MCIWS.

York, 2001, **2**, pp. 1783-1786.

7. Zhang, X. & Chaffin, D.B. A three-dimensional dynamic posture prediction model for simulating in-vehicle seated reaching movements: Development and validation. *Ergonomics,* 2000, **43**, 1314-1330. doi: 10.1080/001401300421761
8. Chaffin, D.B. Digital human modelling for vehicle and workplace design. SAE, Warrendale, PA, 2001. doi: 10.4271/R-276
9. Chaffin, D.B. Improving digital human modeling for proactive ergonomics in design. *Ergonomics*, 2005, **48**(5), 478-491. doi: 10.1080/00140130400029191
10. Van Der Meulen, P.A. & Diclemente, P. Ergonomic evaluation of an aircraft cockpit with RAMSIS 3D Human Modelling Software. *In* Proceedings of Human Modelling For Design And Engineering Conference and Exhibition, Arlington, VA, USA, 2001.
11. Wikipedia: https://en.wikipedia.org/wiki/Multi_Caliber_Individual_Weapon_System (Accessed on 15 October 2017).
12. Zachariah, T.; Krishnani, S.; Pramanik, S.N. & Selvamurthy, W. Body measurements design application and body composition. DRDO Monograms/ Special Publication Series, DESIDOC, Delhi, 2001.
13. Jack: Siemens PLM software, 2011 [online]. Available from: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/assembly_planning/jack/index.shtml (Accessed on 10 November , 2017).
14. Technical Report NASA RP-1024. Anthropometric Source Book, **2**: A Handbook of Anthropometric Data.
15. NX: UGS, 2007, NX, http://www.ugs.com/en_us/products/nx/. (Accessed on 8 October, 2017).
16. Henry Dreyfuss Associates, The measure of man and woman: human factors in design. Witney Library of Design, 1993.
17. Karhu, O.; Kansi, P. & Kuorinka, I. Correcting working postures in industry. A practical method for analysis (OWAS). *Applied Ergonomics*, 1977, **8**(4), 199- 200. doi: 10.1016/0003-6870(77)90164-8
18. Bhattacharyya. A. & McGlothin. Tool evaluation and design; Occupational Ergonomics Theory and applications. Edited by Marcel Dekker, New York: Marcel Dekker, 1996.

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