Designing and Ergonomic Evaluation of a Shoe-Rack in CAD Environment

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ABSTRACT
Most of the shoe racks available in market are required to be in tune with ergonomic criteria to enhance their usability. Keeping this fact in mind, an attempt was initiated to design an ergonomic multi-purpose shoe rack for a small family with 5-6 members of varying age group starting from kids to grandparents to suit present day apartment model residential dwellings. Following a small user survey and brain storming, it was decided that the intended design should be usable for all family members and all shoes in each rack to be visible for someone standing in front, easy to move, simplicity in use (taking shoes/socks, put on shoes, tying lace etc.), compact and aesthetically appealing. Protection from dust, availability of proper clearance dimensions and inclusion of safety aspects were also considered as added features. Following development of 3D-CAD model of desired shoe rack from concept sketching, various human factor aspects were evaluated in DELMIA software with digital manikins representing Indian anthropometric data to justify the design for Indian users.

Present paper demonstrates virtual ergonomic evaluation process to confirm whether design of shoe rack would really be acceptable to targeted users and satisfy their need in real scenario. Readers are expected to visualize the simplicity of using digital human modeling tools for virtual ergonomic evaluations and thus advocate its use as and when required for diverse applications.

Key words
shoe rack, ergonomics, CAD, DHM, human factors, product design

Relevance
Pro-active design and ergonomic evaluation of product in virtual environment with digital human modeling software as described in the present paper would encourage designers to avoid preparation of costly, time consuming physical-mockups for ergonomic studies with real human trial and thus would ensure user friendly product with saving production cost, time and manual labour.

1. INTRODUCTION
Consumer durable market is flooded with products having features aimed at stimulating shoppers buying instinct. It is no exaggeration to say that in majority of cases, worth of a finished product is mainly judged by its quality (capability to meet stated purpose for specified time) and aesthetic appeal. Of course these attributes should not and cannot be neglected but it is equally true that intended user anthropometric/ biomechanical characteristics and/or capabilities are scarcely discussed in manufacturing circles while conceptualizing products. Mostly it is taken for granted that a product designed will fit to user regardless of user's age, capabilities/limitations and anthropometry [1]. As a result many products fail to generate sales volume and contribute considerable loss on all accounts (design development costs, prototype testing costs etc.) to manufacturing/marketing enterprises. As customer awareness is increasing due to knowledge boom, industry can no longer afford to think whatever it produces will be accepted by intended end users. Moreover occupational health, safety and product liability related regulations being gradually implemented across the world will force all manufacturers/ engineers/ designers to include ergonomic evaluations for products which they develop and produce in near future. Therefore, this paper aims to highlight relevance of digital human modeling (DHM) software in indentifying 'fit' of product to intended users during product conceptualization stage itself. A concept model of a shoe rack was designed for this purpose and significant insights are reported here.

Literature review from electronic media, journal publications, books and technical reports reveal that DHMs have been used in evaluation of automobile products [2], [3], [4], [1], [5], [6], [7]. The above mentioned body of publications are concerned with automobile door assembly evaluation, improvement in design of a new chassis, identification of design elements influencing occupant packaging in car design process, optimizing reach, fit and vision around a seated driver in cockpit design, estimating hand posture needed for pushing a button using thumb tip on an automobile steering wheel, design evaluation of vehicle interiors with respect to SAE standards and investigations into army vehicle workstations for army population. Karmakar (2012) [8] and his associates have made use of DHM for a complete vision analysis of a jet aircraft cockpit. Application of DHM in evaluation of radial drill, carts to carry loads and accessibility of social housing for a person seated in a wheel chair has been put forth by Okimoto (2011) [9]. Other product evaluations included testing reach responses while accessing an Automatic Teller Machine with the digital manikin seated on a wheel chair [10], [11], postural behavior in sewing machine workstations [12], marine vessel design and simulation [13] and new-concept VDT workstation chair with an adjustable chair and keyboard-mouse support [14]. Although there are wide applications of DHM software in various industries (specifically, automobile and aerospace) as stated earlier, use of DHM for evaluating consumer products is less reported. Hence, in the present paper an attempt has been made to demonstrate how a shoe rack can be evaluated in virtual environment of DHM software from ergonomic view point.

2. METHODOLOGY ADOPTED

2.1 Video recording

Since contextual knowledge is necessary for successful implementation of DHM simulation [15], video recording of subject's postural behavior while putting/removing shoes in various scenarios was done and thoroughly studied before conducting trials using DHM in a virtual environment. This exercise helped authors to fairly understand the general postural behavior of Indian people.

2.2 Generation of digital human models

Digital human models/manikins were created with help of DELMIA human modeling software (version 5.19). A male and a female digital manikins representing 95^{th} and 5^{th} percentile anthropometric data, respectively were developed using Indian anthropometric data [16]. Another male model was created corresponding to 50^{th} percentile pooled data of Indian population. These 3 digital Indian models (5^{th} percentile female model, 50^{th} percentile pooled data model and 95^{th} percentile male model) were used to represent smallest, medium and largest dimensional Indian people respectively. 'Variable list tool' under 'human measurements editor workbench' was used to manually input anthropometric dimensions for building digital manikins.

2.3 Conceptualization and generation of digital prototype of shoe rack

Often it is seen that people are accustomed to leave their footwear on the floor by side of main entrance door in Indian houses. Of late some locally manufactured wooden cupboards, platforms and metal/plastic/wooden racks are being used. Interestingly, it was observed that existing designs were inadequate to support varied anthropometric characteristics of users and most importantly shoe lace tying/untying provision was found to be lacking in majority of such products available locally. Moreover, it was noticed that space constraint was forcing many families to keep one foot wear on top of another which was unhygienic and unpleasant to view. Taking the above facts into consideration a shoe rack design was conceptualized to meet every possible need of the users. The shoe rack was comprised of 8 inclined racks at four different heights, two cupboards at bottom and inclined platforms at two different heights to assist different age group of users for shoe lace tying/untying (fig. 4). The racks were provided with raised boundaries to prevent footwear from falling and also to enhance their visibility. Moreover it could be covered with a wrap-able polythene sheet for protection from dust. Wheels were provided at bottom four corners which will come in handy for easy movement of shoe rack. Effort was employed to make the shoe rack compact (1100mm x 450mm x 940 mm approx.) and aesthetically appealing too. Mechanical design option in DELMIA human modeling software (version 5.19) was utilized to create 3D CAD model of conceptualized shoe rack.

2.4 Interfacing shoe rack with digital human models in proper position

Proper interfacings of digital manikins with CAD model of shoe rack following appropriate working/ functional posture was achieved with help of change current axis and snaps compass, distance and band analysis, measure between and create multi-view tools in human task analysis workbench.

3. CONCEPT PRODUCT EVALUATION

The conceptualized shoe rack was evaluated with respect to vision, reach and posture (shoe lace tying/untying) for finding its suitability to the intended user population in performing necessary activities. Important inferences have been highlighted in following paragraphs.

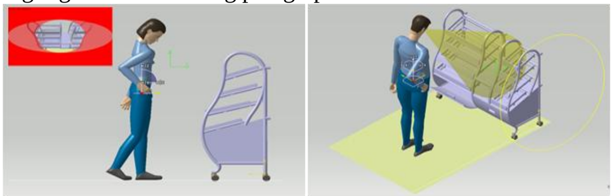

Fig 1: View of the shoe rack a) 5^{th} percentile female manikin b) 95^{th} percentile male manikin

For performing vision analysis respective digital manikins were stationed in front of shoe rack at a distance equivalent to olecranon-stylion length. This distance was selected (from video data) as people normally tend to stand near about same distance while beginning to perform any activity involving interfacing with a product of this magnitude. Vision evaluation tools like vision window (fig. 1 a) and vision cone (fig. 1 b) were used for analysis of visual requirements. Analysis revealed comfortable complete view of shoe rack except for 5^{th} percentile female model. This problem for 5^{th} percentile female was persistent even though the head was flexed to it maximum limit as indicated by software. This suggests that 5^{th} percentile female should stand at a distance further away from the shoe rack to get its complete view.

Fig 2: Lower rack vision analysis for 95^{th} percentile male

The inside of bottom cup board was visible for all manikins selected for investigation even in uncomfortable postures. The above mentioned evaluation has been shown in fig. 2, where 95^{th} percentile male manikin was positioned appropriately for viewing the lower rack. Major body segments like full spine, thigh and leg were flexed on the higher side of their range of movement (49˚, 113˚ and 135˚), and vision window showed a fair view of lower rack.

General reach for placing and removal of shoes was found to be comfortable for all manikin populations under study using reach envelope function. This observation holds good for lower rack reach ability too (fig. 3a and 3b).

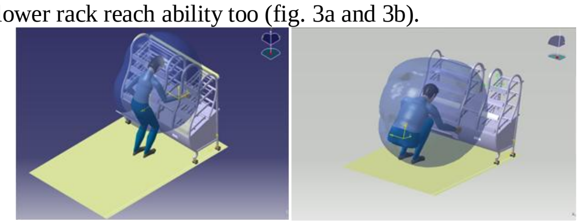

Fig 3: Reach envelope for right hand a) standing 5^{th} percentile female manikin b) lower rack reachability for 95^{th} percentile male manikin

While using platform provided for shoe lace tying/untying (fig. 4 a, b) it was observed that all the studied manikins had to flex their full spine (lumbar + thoracic) and thigh virtually to maximum extent permissible (Table 1) in order to keep the foot in lower rack (first from floor level) provided for shoe lace tying/untying but when foot is placed on second rack then knee obstructs the vision directed at shoe/foot. Thigh needed to be laterally moved towards right side for better vision. In order to reach for the shoe at this posture left leg needs to be squatted. Squatting left leg beyond 650 mm made right leg tilt towards right side making it relatively difficult to position right hand properly for shoelace tying/untying. This aspect necessitates proper design features for facilitating comfortable shoe lace tying/untying activity for all manikins considered for present study.

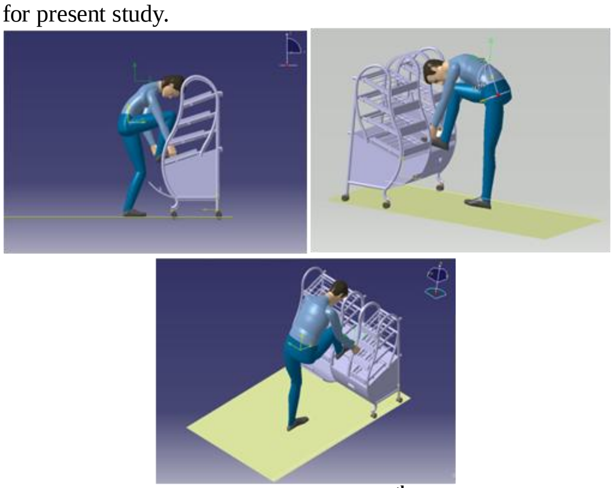

Fig 4: Shoe lace tying/untying a) 5th percentile female manikin b) 50th percentile pooled data male manikin c) 95th percentile male manikin

Table 1. Angular details

Angular details (in flexion degrees)			
Body segment	**5th percentile female manikin**	**95th percentile male manikin**	**50th percentile pooled data male manikin**
Full spine (lumbar + thoracic)	27.5	43.1	56.8
Right Thigh	101.2	112.8	112.9

It was visualized from manikin data readout tool that approximately 66% of body joints for 50th percentile pooled data male manikin (while performing shoe lace tying/untying by placing tight foot on lower rack) deviated from their neutral position indicating the necessity of some design modifications for comfortable use. In addition it was observed that clearance between frames supporting the shoe lace tying platforms (approx. 225 mm) was found to be inadequate for manikin representing pooled data. The combined values of anthropometric variables foot breadth and fist circumference for pooled data indicates a situation needing action for change in this clearance distance as this will definitely pose problems for higher percentile male users.

4. DISCUSSION AND CONCLUSION

While conducting evaluation trials it was evident that DHM can be used for product appraisal from an ergonomic perspective well before actual prototype/product without much difficulty. Many ergonomic mismatches can be easily identified using DHM. Posture editor and inverse kinematics features were found to be handy in giving realistic postures for digital humans as adopted by real humans. This is really profitable for rendering postures which are context specific and culture/behavior induced for different population groups. In near future it can be foreseen that factory layouts when conceptualized will necessarily be evaluated with software like DHM as hinted by Bley et al. (2004) [17], to find out their usability for intended user population. This prediction definitely holds true for product design and development. Thus it is strongly recommended for manufacturers/industry to adopt this highly useful tool and achieve financial gains by reducing cost on account of building physical prototypes and testing with real human beings. Further manufacturing/ marketing firms can reach out to potential buyers using virtual technology as a training/demonstration tool [18] regarding how to use their products and also giving gender, somatotypes specific instructions if any (where ergonomic compromise is inevitable) enabling them to make well judged buying decisions [19] for satisfying error free use.

However during this study, it was found impossible to create manikins representing children and elderly populations as desired by authors. Reasons are attributed to software incapability and lack of published/validated Indian anthropometric data representing the above mentioned population groups. The investigations would have been complete in all respect if cognitive aspects were also simulated as it was done for physical features. These issues should be taken as a challenge by software developers/industry/academia to incorporate these essential features and also facilitate creation of global population data base representing their complete human anthropometric details. DHM developers and users community should join hands and work together to overcome present challenges to promote wide adoption of DHM software. User community of DHM tools will be glad to help software developers in gathering local anthropometric data for achieving above goals. It should also be testified that majority successful applications of DHM has been in automobile and aviation sectors [20], [21] and that too in developed countries. From this paper it can be envisaged that DHM can be used advantageously to a great extent in developing countries for variety of applications and its diverse scope of application is yet to be explored to its full potential [22]. Further it is deemed important to highlight that traditional ergonomic evaluation techniques based on trial and error method using physical mockups and real human, has proved to be time consuming, costly and mostly overlook anthropometric and biomechanical aspects involved in performing tasks [23], [24]. Going through the present paper, one can easily visualize that virtual evaluations of a CAD product with digital manikins have the potential to overcome known drawbacks of traditional ergonomic evaluation methods.

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