Advances in Human Strength Measurement and Modeling in Workspace

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ABSTRACT

Advances made in human strength measurement and modeling in three dimensional workspace are reported. A comprehensive experimental research was conducted to determine isometric and isokinetic push, pull, push-up and pull-down strengths in the workspace and the corresponding muscle activity during exertions. Data were obtained from able-bodied adult male and female participants in the normal, maximum and extreme reach envelopes at various horizontal and vertical angles/heights in both seated and standing positions. A three dimensional isometric strength measurement system was designed and constructed. The Kin-Com dynamometer was used to measure isokinetic strength. The Flex-Com system recorded electromyography (EMG) of four muscles: biceps, triceps, anterior deltoid and erector spiane. Strength profiles or data for isometric and isokinetic strengths were highlighted. Spatial factors affecting isometric and isokinetic strengths were analyzed. Muscle activity of the selected muscles during force exertions were investigated. Predictive models or equations were developed for isometric pull strengths in maximum reach of standing men by applying multiple regression analysis.

Keywords: Human Strength Measurement, Isometric Strength, Isokinetic Strength, , Isometric Strength Measurement System, Kim-Com Dynamometer, Flex-Com System, Electromyography (EMG), Regression Modeling Approach

INTRODUCTION

The measurement of human strength is essential for designing work, equipment, workplaces, tools and controls. Operator screening and job matching procedures based on human strengths are often recommended for manual materials handling activities. This will control injury through the reduction of overloading of muscles. The study of muscle strength capabilities is of great practical importance in ergonomics/human factor. Several researchers recommend the development of worker screening program based on human strength (Ayoub and Mital, 1989; Chaffin 1974; Mital and Das 1987). In order to control the work-related injuries, the process of worker selection is necessary for all physical tasks, especially manual material handling activity. Furthermore, the knowledge of human capacity is required for designing jobs, equipment, workspace, tools and controls, since muscle forces are needed to operate equipment and controls. Insufficient strength can induce the overloading of the muscle-tendon-bone joint system and possible injuries (Mital and Kumar, 1998). Therefore, the determination of human strength capabilities is also essential to establish engineering design guidelines (Mital and Das, 1987).

Human strengths are generally classified as isometric or static and dynamic or isokinetic strengths. In the case of isometric or static muscle exertions, the body segment involved and the object held remain stationary, while in the case of dynamic muscular exertions both the body segment and the object move. Because there is no effective limb-object-muscle movement in the case of isometric strengths, such strength do not account for the inertial forces. Consequently, isometric strengths cannot be used for the determination of an individual's capability to perform

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dynamic tasks, such as materials handling. Thus for the determination of persons physical capabilities, dynamic strengths measurement is more appropriate than isometric or static strengths measurement. For designing industrial jobs and workstations, dynamic strengths should be used even though they are difficult to measure compared to static strengths.

Industrial workers should not generally exceed one-third of their isomeric strength on a sustained basis in task performance (Putz-Anderson, 1994). Overloading of muscles should be avoided to minimize fatigue. Dynamic forces should be kept less than 30% of the maximum force that the muscle can exert; up to 50% is all right for up to 5 minutes. Static muscular load should be less than 15% of maximum force that the muscle can exert. General guidelines suggest that hand forces should not exceed 45 Newtons. On the other hand, it is possible to handle a force of 4 kg for 10 sec., 2 kg for 1min. and 1/3 of maximum force for 4 min.

For optimum design of a workstation, it is important to determine human strength profiles in the workspace. The ideal industrial workstation should be compatible not only with the systems performance requirements but also with the user. The most obvious criteria are comfort and ease of use but other equally important design criteria include work performance, safety and health (Das and Sengupta, 1996). Several factors impinge upon the creation of the ideal workstation, one of which is *reach capability*. Accurate reach capability data are essential to ensure that all hand-operated controls or tasks are located where they can be reached and operated efficiently. Another factor that impinges upon the creation of the ideal workstation is user *strength capability*. To ensure optimal workspace layout, it is imperative that operator's strength profiles be determined. The *strength profile* of a person under specified conditions is essential for the design of tools (e.g., their weight, ease of use), controls (e.g., type of grip required, spatial placement), and equipment – in other words, the workstation. Furthermore, the selection or job placement of workers requiring strength exertion in task performance, the measurement of strength profiles of such individuals can be useful.

Studies have shown that horizontal distance and vertical height exertion significantly affect the force exertable both in static and dynamic strength tests (Chaffin and Park, 1973; Davis and Stubbs, 1977). However these studies have not attempted to relate anthropometric reach space envelopes to the strength data obtained. Researchers have measured strength at varying elbow angles (Hunsicker, 1955), fractions of mean reach for the population (Davis and Stubbs, 1977) or fixed distances (Mital and Faard, 1990). Measurement locations have not been determined by individual functional reach regions. For optimum workstation design a link must be established between an individual's ability to reach and exert force at functional reach regions.

Isometric push-pull strength profiles were determined for the able-bodied population in the normal, maximum and extreme workspace reach envelopes and the effect of spatial factors were subsequently analyzed (Das and Wang 2004 a & b). Also, isometric push, pull, push-up and pull-down strength profiles were determined for the paraplegics in the similar workspace and the effect of spatial factors were analyzed subsequently (Das and Forde, 1999 a & b; Das and Black, 2000 a & b). Research was undertaken recently at Dalhousie University, Canada to determine a comprehensive database for both static (isometric) and dynamic (isokinetic) strength profiles in workspace and analyze the effect of spatial factors on isometric and isokinetic strengths (JangKol and Das, 2002 & 2004) Das and Jongkol, 2005 & 2006)

Insufficient physical capability while performing manual materials handling activities and tasks requiring hand tools usage can lead to overloading the muscle-tendon-bone-joint system and possible injury (Ayoub and Mital, 1989). These tow activities account for about 45% of all industrial overexertion injuries. It accounts for billions of dollars in workers compensation cost (Water and Putz-Anderson, 1996). The overall objective of this investigation is to report on the advances made in human strength measurement and modeling in three-dimensional workspace.

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A COMPREHENSIVE EXPERIMENTAL RESEARCH IN HUMAN STRENGTH MEASURMENT

The investigation was undertaken to determine isometric and isokinetic strengths, push, pull, push-up and pull-down strength in the workspace and the corresponding muscle activity during exertions. The strength and the corresponding muscle activity data were obtained for the able bodied adult, male and female subjects in the normal, maximum and extreme reach envelopes at various horizontal and vertical angles/heights in both seated and standing positions.

Measurement locations were defined in terms of normal, maximum and extreme reaches with horizontal angles (theta) = 0º, 90º and 135º relative to the frontal plane, and vertical angle (phi) = 0º, and 45º relative to the elbow joint for normal reach, and -20º, 0º, 45º, and 90º relative to the shoulder joint for maximum and extreme reaches for isometric exertions, and at elbow, shoulder, and head heights for isokinetic exertions.

For the purpose of this investigation a three-dimensional computerized isometric strength measurement system was designed and constructed. The system consisted of an extended arm and handle, force transducer, supporting track, locating plat form, adjustable chair and data collection system (Black and Das, 2007).The Kin-Com dynamometer was used to measure isokinetic strengths. The Flex-Comp system recorded electromyography (EMG) of biceps, triceps, anterior deltoid and erector spiane during force exertions.

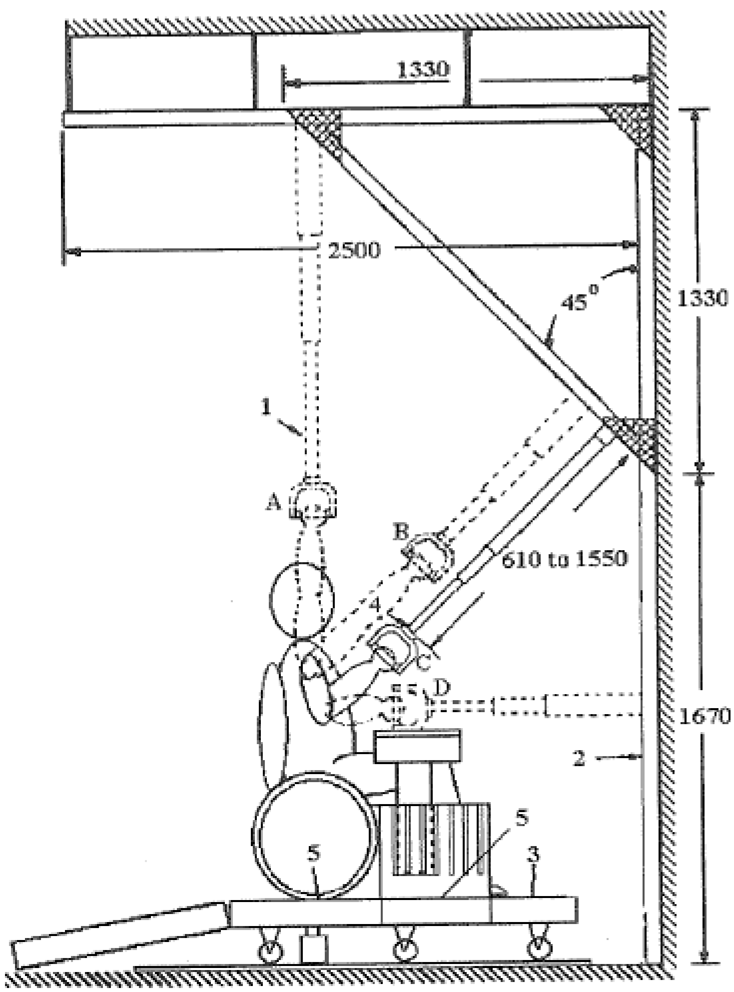

Figure 1: A three dimensional computerized isometric strength measurement system. All dimensions are in mm Legend: 1. Extendable arm, 2. Vertical supporting rack, 3. Rotating platform, 4. Force transducer, 5. Stability sensors. Positions: A: Maximum reach, θ = 90º, ϕ = 90º; B: Maximum reach, θ = 90º, ϕ = 45º; C: Normal reach, θ = 90º, ϕ = 45º; D: Normal reach, θ = 90º, ϕ = 0º

The data were collected to investigate the effect of workspace design parameters on isometric and isokinetic strengths push, pull, push-up and pull-down strengths. The effect of force direction, gender and working position on isometric and isokinetic strength capabilities were also investigated. Muscle activity of four muscle groups: biceps, triceps, anterior deltoid and erector spiane were measured by electromyography (EMG) during isometric and isokinetic exertions in workspaces. The effect of reach level, horizontal angle, vertical angle/heights, force direction, gender, and working positions on muscular activity were investigated. The results of this investigation are highlighted below.

Measurement of Isometric Strengths in Workspace: Strength Profiles

- The greatest isometric push strengths of men and women are 175 N (Newtons) and 106 N, respectively.
- The maximum isometric pull strengths were 331 N for men and 219 N for women.
- The highest isometric push-up strengths were 140 N for men and 88 N for women.
- The greatest isometric pull-down strengths were 269 N for men and 190 N for women.
- The greatest strengths were measured in standing position at phi = 90º and theta = 90º at maximum reach for push and push-up strengths but at extreme reach for pull and pull-down strengths.

Measurement of Isokinetic Strengths in Workspace: Strength Profiles

- The highest isokinetic push strengths of men and women were 98 N (Newtons) and 64 N, respectively.
- The greatest isokinetic pull strengths were 115 N for men and 79 N for women.
- The greatest isokinetic push and pull strengths occurred in extreme reach at shoulder height when theta = 0º in seated position.
- The greatest isokinetic push-up strengths, which were recorded in normal reach at theta = 90º in standing position, were 100 N for men and 61 N for women.
- The greatest isokinetic pull-down strengths found in maximum reach at theta = 90º standing position were 111 N for men and 68 N for women.

Analysis of Isometric and Isokinetic Strengths Data

- Overall, the mean isokinetic strength was 59% of isokinetic strength.
- Isometric push, pull-down and push-up strengths were 76%, 68%, and 49% of isometric pull strength, respectively.
- Isokinetic push strength was 76% of isokinetic pull strength.

- Isokinetic pull down strength was 89% of isokinetic push-up strength in normal reach, but isokinetic push-up strength was 58% of isokinetic pull-down strength in maximum and extreme reaches.
- Women were 68% as strong as men.
- The mean push and pull strengths in standing position were 92% and 77%, respectively, of those in seated position, whereas the mean push-up and pull-down strengths in seated position were 93% and 92%, respectively, of those in standing position.

Analysis of Spatial Factors Affecting Isomeric and Isokinetic Strengths

- As reach increased, push and pull strengths increased, in most cases, whereas push-up strength and isometric pull-down strength mostly decreased.
- Isometric pull-down strength was greatest in maximum reach and lowest in normal reach.
- As vertical angle increased, isometric push, pull, pull-down strengths increased, whereas isometric push-up strength mostly decreased.
- Isokinetic push and pull strength at shoulder height were greatest and those at head height were lowest.
- Push and pull strength decreased as horizontal angle increased, but push-up and pull-down strengths at theta = 90º and 135º were greater than those at theta = 0º

Electromyography (EMG) of Muscle Activity during Force Exertion.

- The greatest EMG activity in biceps was found when exerting isokinetic push-up force in normal reach at theta = 90º in standing position (85% of maximum voluntary contraction, MVC, for men and 81% MVC for women).
- The greatest EMG values of triceps was found in isokinetic pull-down exertion in normal reach at theta = 90º in standing position (78% MVC for men and 75% MVC for women).
- The EMG activity in the anterior deltoid was greatest when exerting isometric push-up strength in extreme reach at phi = 45º and theta = 135º in standing position (79% MVC for men and 81% MVC for women).
- The greatest EMG activity in erector spinae was elicited during isokinetic push-up exertion in extreme reach at theta = 135º in standing position (76% MVC for men and 62% MVC for women).

MODELING OF ISOMETRIC PULL STRENGTH

Experimental measurement of strength is time consuming and needs special measuring devices. One of the objectives of this research was to investigate the relationships between isometric pull strength and age, anthropometric variables, arm posture, and isometric strengths of elbow flexion, elbow extension, and shoulder flexion. The development of multiple regression equations would allow prediction of the isometric pull strength capability in maximum reach of a specific subject group.

Predictive models for estimating isometric pull strength were developed. Anthropometric data and muscle strengths were used as predictors. The predictive models of isometric pull strengths in maximum reach for male subjects in the standing position were built through a multiple regression analysis. Using these models, it was possible to determine the isometric pull strengths from simple measurements, which would be completed in less than half an hour.

The isometric strengths of elbow flexion, elbow extension, and shoulder flexion were more useful in isometric pull strength prediction than physical (anthropometric) characteristic variables. The model, which included chest depth, isometric strengths of elbow extension and shoulder flexion, and vertical and horizontal angles of the arm, provided

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the highest coefficient of determination (R^2) of 0.82.

CONCLUSIONS

This investigation reported the advances made in determine isometric and isokinetic push, pull, push-up and pull-down strengths in the workspace and the corresponding muscle activity during exertions. A three-dimensional isometric strength measurement system was designed and constructed. The strength profiles and the corresponding muscle activity data were presented for the able bodied adult male and female subjects in the normal, maximum and extreme reach envelopes at various horizontal and vertical/angles/heights in both seated and standing positions. The database will facilitate the design of work, equipment, workplaces, tools and controls and enhance operator screening and job matching procedures. Through the use of multiple regression analysis, predictive models were developed for isometric pull strength in maximum reach of standing men.

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REFERENCE

Ayoubm, M. M., Mital, A. (1989) "*Manual Materials Handling*", London, England: Taylor and Francis.

Black, N. L., Das, B. (2007), "*A three dimensional computerized isometric strength measurement system*", Applies Ergonomics, Vol. 38, No. 3, pp. 285-292.

Cahffin, D. B. (1974). "*Human strength capability and low back pain*", Journal of Occupational Medicine, Vol. 16, No. 4, pp. 248-254.

Cahffin, D. B., Park, K. S. (1973), "*A longitudinal study of low back pain as associated with load lifting factors*", American Industrial Hygiene Association Journal, Vol. 34, pp. 513-525

Das, B., Black, N. L. (2000a), "*Isometric pull and push strengths of paraplegics in the workplace: 1. Strength measurement profiles*", International Journal of Occupational Safety and Ergonomics, Vol. 6, No. 1, pp. 47-65.

Das, B., Black, N. L. (2000b), "*Isometric pull and push strengths of paraplegics in the workplace: 2. Stastical analysis of spatial factors*", International Journal of Occupational Safety and Ergonomics, Vol. 6, No. 1, pp. 67-80.

Das, B., Forde, M., (1999a), "*Isometric push-up and pull-down strengths of paraplegics in the workplace: 1. Strength measurement profiles*", Journal of Occupational Rehabilitation, Vol. 9, No. 4, pp. 279-291.

Das, B., Forde, M., (1999b), "*Isometric push-up and pull-down strengths of paraplegics in the workplace: 2. Stastical analysis of spatial factors*", Journal of Occupational Rehabilitation, Vol. 9, No. 4, pp. 293-299.

Das, B., Jongkol, P.. (2005), "*Effect of spatial factors on isometric push, pull, push-up and pull-down strengths*", Proceedings of the International Conference on Humanizing Work and Work Environment, Guwahati, Assam, India, CD-Rom, pp. 1-6.

Das, B., Jongkol, P.. (2006), "*Isometric push, pull, push-up and pull-down strengths profiles in the workspace*", Proceedings of the International Ergonomic Association Conference, Maastricht, Netherlands, CD-Rom, pp. 1-5.

Das, B., Sengupta, A. K. (1996), "*Industrial workstation design: A systematic ergonomics approach*", Applied Ergonomics, Vol. 27, No. 3, pp. 157-163.

Das, B., Wang, Y. (2004a)," *Isometric push and pull strengths in workplace: 1. Strength profiles*", International Journal of Occupational Safety and Ergonomics, Vol. 10, No. 1, pp. 43-58

Das, B., Wang, Y. (2004b)," *Isometric push and pull strengths in workplace: 2. Analysis of spatial factors*", International Journal of Occupational Safety and Ergonomics, Vol. 10, No. 1, pp. 59-64.

Davis, P. R., Stubbs, D. A. (1977), "*Safe levels of manual forces of young males (2)*", Applied Ergonomics, Vol. 8, pp. 141-150.

Hunsicker, P. (1955), "*Arm strength of selected degrees of elbow flexion*", WADC Technical Report 54-548, United States Air Force, Project 7214.

Jongkol, P., Das, B. (2002), "*Isometric push, pull, push-up and pull-down strengths profiles in the workspace*", Proceedings of the Annual International Occupational Ergonomics Conference, Toronto, Ontario, Canada, CD-Rom, pp. 1-5.

Jongkol, P., Das, B. (2004), "*Effect of spatial factors on isometric push, pull, push-up and pull-down strengths*", Proceedings of the Annual International Occupational Ergonomics and Safety Conference, Huston, Texas, USA , CD-Rom, pp. 1-6.

Mital. A., Das. B. (1987), "*Human strength and Occupational Safety*", Clinical Biomechanics, Vol. 2, pp 97- 106.

Mital. A., Faard, H. (1990), "*Effect of sitting and standing, reach distance and arm orientation on isokinetic pull strengths in the horizontal plane*", International Journal of Industrial Ergonomics, Vol. 6, pp. 241-248.

Mital. A., Kumar, S. (1998), "*Human muscle strength definition, measurement and usage, Part 1-Guideline for the practitioner*", International Journal of Industrial Ergonomics, Vol. 22, pp. 101-121.

Putz-Anderson, V. (1994), "*Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs*", London, England: Taylor and Francis.

Waters, T. R., Putz-Anderson, V. (1996), "*Manual material handling*", in Occupational Ergonomics: Theory and Application, A. Bhattacharya and J. D. McGlothlin (Eds.) Marcel Decker, In., pp 329-349.