THE IMPACT OF DESIGN FOR AVERAGE

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ABSTRACT

Despite our understanding that we must design for the "limiting user" and offer adjustability wherever possible, ergonomists are often persuaded to provide specifications that accommodate "average" anthropometrics. Designers and clients often seek simple, fixed-height designs, suited to an average worker, to meet the economic demand for lowest cost design. A good proportion of the population is close to average in its dimensions, and, therefore, "design for average" does indeed accommodate more individuals than a design aimed at 5th percentile females, or 95th percentile males. Theoretically, if the "average" worker is accommodated, then equal numbers of larger and smaller workers will be disadvantaged. This seems to be a "fair" approach. However, most work environments involve more than one design parameter (clearance, reach, force), and the "design for average" may end up accommodating a very narrow portion of the population. This paper presents a case study where a workstation is designed for "an average" worker, to allow the evaluation of the impact of this decision on other worker populations.

KEYWORDS: design, anthropometry, average

CONCEVOIR POUR LA MOYENNE : LES RÉPERCUSSIONS

RÉSUMÉ

Même si les ergonomes comprennent l'importance d'adapter la conception aux « utilisateurs limitants » et d'offrir un réglage là où c'est possible, ils sont souvent amenés à opter pour des caractéristiques répondant aux mesures anthropométriques « moyennes ». Afin de répondre à la demande courante de réduction des coûts, les concepteurs et les clients cherchent souvent des conceptions simples à hauteur fixe, lesquelles conviennent au travailleur moyen. Puisqu'une bonne partie de la population présente des dimensions proches de la moyenne, « concevoir pour la moyenne » répond effectivement aux besoins d'un plus grand nombre d'individus qu'une conception correspondant au 5^{e} centile chez les femmes ou au 95^{e} centile chez les hommes. En théorie, répondre aux besoins du travailleur « moyen » signifie aussi qu'un nombre égal de travailleurs plus petits et plus grands seront désavantagés. Or, même si l'approche peut sembler « juste », la plupart des environnements de travail nécessitent la prise en compte de plusieurs paramètres de conception (dégagement, portée, force). « Concevoir pour la moyenne » peut ainsi ne convenir qu'à une très faible partie de la population. Cet article présente l'étude de cas d'un poste de travail conçu pour un travailleur « moyen », afin d'évaluer les répercussions de ce choix sur les autres travailleurs.

MOTS CLÉS : conception, anthropométrie, moyenne

DESCRIPTION OF THE PROBLEM

When ergonomists are asked for input into a new design, they provide recommendations that accommodate as many people as possible. When suggesting limits for forceful exertions, ergonomists evaluate based on acceptability for a "weak" worker, confident that stronger workers will be safe when exposed to the same demands. This method is commonly called the "limiting user" approach (Pheasant and Haslegrave, 2006). This approach similarly applies in the specification of clearances; to accommodate a variety of workers, we design based on the largest worker. If the largest worker can fit, anyone smaller would also fit. When we design reaches, we try to ensure that even the smallest worker can reach. Accommodating a majority of workers, when it pertains to force, reach, and clearance, may have an increased cost, although typically the cost is borne once and the benefits are lasting. For example, a smaller work bench might be suggested in an effort to reduce the reach envelope; to provide space for supplies to be stored within reach on this smaller bench, the designer may need to add vertical shelves. In this way, a slightly more expensive workstation will presumably result in improved comfort and productivity for many years.

One could argue that intentional "design for average" is rare when it regards reach, clearance, and force critieria; most ergonomists will design for the limiting user. However, when we are asked for recommendations for working heights, we often falter, because a design for any one group may create discomfort for the rest of the population. "Design for average adult" (roughly 5' 7 ½", or 171.5 cm with shoes, according to Konz, 1995), actually results in a design that is optimal for a relatively tall female, or small male. If we design for average *female* (5' 5", or 165 cm, from Konz, 1995) in a *virtually* all-female workforce, the impact on that "rare" tall male worker can be significant. According to Pheasant and Haslegrave, a "design for average" is typically reasonable for about 28% of the population. A common ergonomics text book (Konz, 1995) suggests weighing the "seriousness of the exclusion" against the "cost of inclusion". This is the approach that we evaluate in this paper.

Given the opportunity to influence a design, ergonomists typically attempt to provide guidelines to accommodate 90 or 95% of the population. A force exertion would need to be acceptable to even a very "weak" female, in order to be an appropriate design. When we evaluate an existing job, however, we typically set a lower (more achievable) target of 75% of the population (Snook and Ciriello, 1991). We might say to a client, "We wish you had designed this equipment to better standards, but since it's already in production, we won't make you change it, unless fails to accommodate (is not safe for) at least 75% of the worker population." This is also the approach promoted by NIOSH in the NIOSH manual handling guidelines (NIOSH, 1994).

A workstation design with dimensions that were intended to accommodate an "average" worker may present hazards to workers who are on both ends of the anthropometric spectrum, even when force demands are designed to accommodate at least 75%.

1. **METHODS**

To explore this possibility, we created a hypothetical job that required the worker to apply a downward force of 25N with one hand, while gripping/pushing to stabilize the load (10N) with the other hand. This represented a meat processing job, where the knife is dragged downward over a suspended piece of meat, and the non-dominant hand prevents the meat from rotating while the cut is made. We assumed that the cut required 1 second, 11 times every 30 second cycle (37% duty cycle). The height was set such that an "average height adult height worker" would be in a posture that minimised the demands on the torso and back, in our biomechanical program. (We assumed that the job demanded a height difference of 55 cm between the hands, in order to allow the lower hand to stabilize while the upper hand cut from top to bottom.) The remainder of the job was assumed to be "restful" for the muscles of the upper limb and back. These demands would expose a 25th percentile strength female worker of average adult height to less than the maximum acceptable loads for shoulder, elbow and wrist, according to our analysis using University of Michigan's 3D Static Strength Prediction Program and Potvin's duty cycle calculation (2012). (We also confirmed that male workers were at lower risk than female workers for this task.) Peak demands were shown for right elbow (21% of maximum strength, with a target maximum exertion of 21.4%.) Thus, just over 75% of all female workers of average adult height (and more than 75% of all male workers) should be at low risk of injury when performing this job. (Conversely, under 25% of these workers would be at high risk).

Not all workers are of average height. Further investigation shows that demands for this job exceeded guidelines for the right elbow for small and average statured females (who were working at 26% and 23% of maximum, respectively). Thus, a job that is designed to protect the "average" user may create hazards for individuals who appear to be within the protected population. In this case, the 50th percentile female stature probably represented our "limiting user", if the goal was to protect at least 75% of a male/female workforce.

Note that University of Michigan's 3D Static Strength Prediction program assumes that size and strength are not correlated. Therefore, a small female worker is assumed to have the same strength as a large female worker. This creates an "advantage" for smaller workers, as they have lower limb weights, and therefore, for tasks that involve "lifting", in general, a smaller worker will present lower %MVCs than a larger worker. When using 3DSSPP, the user should typically select a larger female worker, if the goal is to protect a majority. This is particularly important if workers are predominantly male, or female; selection of an "average female" anthropometry for "lifting" or "static reaching or bending without external loads" will protect only workers who are *smaller* than this size, which is counter-intuitive. If a majority of workers are larger than 161.6 cm tall, this selection may protect only half of female workers. Typically most males are stronger than average female, but in some instances, particularly for tasks involving back flexion, a tall male may be at higher risk than an average female.

1.1 Impact of design for average with varying frequency and force

Does "design for average" always have negative outcomes? Definitely not! In ergonomics, we always focus on issues where the "force", "posture", and "repetition" (or duration) hazards are combined. When a worker has to press an emergency-stop (e-stop) button overhead, once per shift, for one second at a time, with low force, very little incentive is available to cause the employer to move the e-stop to a lower height. A musculoskeletal injury is unlikely from a once-per-day exposure to awkward, low force demands. In fact, if the button requires 5N of push force, the load on the back, shoulder, elbow, and wrist amounts to less than 15% of average strength. (Average adult height, 50th percentile strength for males and females. No joints reported more than 15% of maximum for males or females.) If the button was at a height that was "just reachable" by the "average" height worker, however, almost half of the population would not be able to reach it. (In 3DSSP, the user sees the "posture not attainable" message when s/he tries to enter a smaller anthropometry with the hands at this height and reach.) This would clearly not be an acceptable design, for safety reasons, and the employer would certainly lower the button to a height that was within reach for all workers. In this case, even a design for 95% of the population would not be acceptable, since potentially 1 in 20 workers would not be able to reach the button to stop the machine in the case of an emergency.

Continuing with the e-stop scenario, if the button required 50 N of push force to activate, even at once per shift, the force would be unacceptable, and in fact, unachievable, for at least 5% of male workers and more than 95% of females of average adult height (task requires greater than 100% of strength).

Proceeding further with the e-stop buttons, let's assume that, during a machine failure, the buttons have to be used to *activate* the machine. If the buttons require only a second to press, how often can this occur before fatigue or injury risk become a problem? At a rate of 18 times per minute, the duty cycle calculation reports that the elbow demands exceed guidelines for average height workers. (This is for a worker of "average adult height" (5' 8 ½", or 168.3 cm, which is the average of both genders in 3DSSPP, and average female strength.) Note that 3DSSPP may not be the most appropriate tool for shoulder demands during this overhead task, as muscle loading is based on the moment around the joint, and work that is close and overhead entails low moments. The "peak" load for this task may occur as the worker raises his/her arms to reach the button.)

An "average strength, average *height*" female worker (5' 3 ½", or 161.5 cm) cannot reach the button at the height that was set for "average adult", of course. However, if the button could be lowered to "just within reach", she would be required to use 46% of elbow strength, and 20% of torso strength. The duty cycle calculation for this exertion indicates a maximum of about 5.5 button activations per minute, before exceeding the maximum acceptable exertion.

1.2 Design for average working height

Predicting optimum working height often presents a significant challenge during design; we all live and work with counters, desks, light switches, and furniture that were, essentially, "designed for average", and rarely do we complain about the effects of this design decision. However, selecting the "best" height is often more difficult than we expect. Even when adjustability is introduced, widespread confusion is found amongst people who market "ergonomic" equipment. For example, in response to an inquiry about the adjustability of a height-adjustable table, a vendor recently responded, "The table can reach to about 51" inches in elevation, and 23" inches at the lowest. For any average person, the height of 51" inches standing is standard." Clearly, even those who market height-adjustable equipment are confused about how they can be used to accommodate workers.

2. **SOLUTIONS**

The limiting user approach is practical and effective in designing reach, clearance and force parameters. However, for working heights, the ergonomist needs to decide whether to design for average, or incorporate adjustability. Where justification for an investment into adjustability is required, the ergonomist should use biomechanical analysis tools to evaluate whether adjustability will yield a risk reduction.

2.1 Cost comparison

An electrically-height-adjustable table for light duty industrial work, or office work, can be purchased in Canada for under $700 (http://www.source.ca/product/4075/Electric-Height-Adjustable-Tables). A comparable fixed-height table from is priced at about $200 (http://www.globalindustrial.ca/g/work-benches/open-leg/fixed-height/workbenches-fixed-height). Similarly, removable work platforms can be purchased for about $80 each (http://usmats.com/productList.asp?categoryID=864199&productTypeCode=800), and height-adjustable platforms in stainless steel (suitable for meat processing) can be purchased for about $2500 (http://www.melnik.ca/product/vlp-counter-balance). What is the benefit associated with height-adjustability?

Let's return to our original case study, where a worker made a downward cut in a piece of meat. Adjusting the hand height (assuming a portable or adjustable platform) can create a situation where the demands are acceptable for 75% of average- or small-statured female workers. Therefore, height-adjustability can allow companies to accommodate more workers; a job that was acceptable. Injury cost estimates vary widely, but clearly it wouldn't take a very high injury cost to offset the increase in cost to purchase the height-adjustable table!

3. REFERENCES

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