Maximizing User Safety Through Human Factors Design

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Abstract

Unlike most industries and professions, the very nature of laboratory science is hazardous. Technicians and researchers are required to handle and are in close proximity to substances, agents and materials that are inherently risky. For this reason, greater heed should be taken in selecting equipment that maximizes safety by reducing the risk of the workstation's effect on the user. This analysis focuses on the associated risks of microbiological laboratory procedures and the required equipment that keeps the researcher safe from the agents being used; with emphasis on the evolution of human factors design in biosafety cabinets at Labconco Corporation (Kansas City, MO).

Introduction

Though it may not seem obvious, every job has its own hazards. The majority of these hazards are due to how we, as humans, interact with our work. Laboratory science, microbiology specifically, is no different; many employees do not associate potential hazards and injuries to the layout and configuration of their work centers (EOHSS, 2009).

The field of Human Factors, more commonly known as Ergonomics (HF/E), is a multidisciplinary approach to understand how humans physically interact with their surroundings. Research in this field strives to improve how these systems more efficiently and therefore more safely, integrate with human users.

Microbiology and HF/E Risk Factors

The biological agents utilized in microbiological laboratories inherently come with risk. However, other risks present include "…repetitive motion injuries during routine laboratory procedures such as pipetting, working at microscopes, operating microtomes, using cell counters and keyboarding at computer work stations," (OSHA, 2011). These risks are cited to be significant in the onset of several Repetitive Strain Injuries, or RSIs. Laboratory acquired RSIs can include:

- Tendonitis and tenosynovitis
- Rotator Cuff Tendonitis
- Thoracic Outlet Syndrome (TOS)
- Carpal Tunnel Syndrome (CTS)
- Wrist ganglion cysts
- Back injuries

To combat HF/E risk factors, users and equipment manufacturers should strive for so-called 'neutral posture' – a position where the human body is under the least amount of stress or discomfort. Human Factors Design, simply, seeks to promote this posture (Mitchell & Longyear, 2012).

Ergonomic Risk Assessments are performed to identify the risk factors associated with the criteria of a specific job or task. Several resources exist that provide check-lists, gap analysis, or risk assessment worksheets.

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Biosafety Cabinet Risks

Microbiology, the study of microscopic biological systems, requires tools and procedures that attempt to put the researcher in the world of the infinitesimal. The challenge is to balance comfort with the need for such precision when designing equipment for microbiology. Pipetting and microscopy are two of the worst offenders. When conducting these activities with biohazards that require a biosafety cabinet, the HF/E risks are compounded.

There are exclusive risks that are intrinsically associated with use of biosafety cabinets (BSCs). Cumulatively, the risk factors accompanying these microbiological jobs are:

- Poor Working Posture – Head bent forwards for long periods, raised and/or outstretched arms, fixed postures held for prolonged periods.
- Upper Limb Disorder Risks – Repetitive actions, awkward wrist/arm posture, forceful actions (including pinching grips).
- Environment – Space constraints, lighting temperature, vibration, etc…
- Load – Working with sharp, hot, cold or toxic/hazardous objects.
- Other Factors – Personnel Protective Equipment (PPE) that might make work more taxing.
- Fatigue – An accumulation of multiple risk factors listed above.

BSC Design Standards

Biosafety Cabinets should be designed, tested and listed to an approved performance standard such as the National Sanitation Foundation's NSF/ANSI Standard 49 or the European Union's standard EN 12469. These standards and product listings ensure that BSCs provide a basic safe environment for working with biohazards, provided the cabinet is operating properly. A BSC's human factors design and end user comfort (features) dictate how an operator works, thus directly affecting their productivity and safety. "Designing tasks, equipment and work stations to suit the user can reduce human error, accidents and ill-health. Failure to observe ergonomic principles can have serious consequences for individuals and for the whole organisation. Effective use of ergonomics will make work safer, healthier and more productive" (HSE, n.d.).

However, the safety standards have not established requirements for HF/E and user comfort specifications. Driven by competition, manufacturers have made great advances by engineering products to increase safety through improved comfort. These design features must be evaluated by researchers, technicians and safety officers. It is of utmost importance for these users to completely evaluate a product for all of the safety, ergonomic and comfort features, as there are vast differences between how each manufacturer approaches BSC design and HF/E engineering

Ergonomics & Pipetting

The standard risk factors associated with Pipetting involve heavy usage of the hands and lower arms. Such factors include repetitive movements and thumb usage, static posture, reach and twisting of the arms and wrists in 'unnatural' ways. As laboratories have been analyzed for Human Factors, or ergonomics (HF/E), strategies have been developed to reduce the strain placed on researches due to incessant pipetting. OSHA recommends the following (OSHA, 2011):

- Position the chair as to eliminate the need to reach up to pipette.
- Do not twist or rotate the wrist while pipetting.
- Hold the pipette with a relaxed grip.
- Select a lightweight pipette, properly sized for the user's hand.
- Where possible, utilize a multi-channel pipette.
- Use pipettes with finger aspirators and thumb dispensers to reduce thumb strain.
- Take a 1-2 minute break after every 20 minutes of pipetting.

When using a pipette in a biosafety cabinet, extra planning should be performed to be sure that the layout of the work center allows for directional work, reducing the amount of strain placed on reaching across one's body.

Evolution of the Human Experience

For over four decades, Labconco has recognized the need for BSCs to address these risks and their resulting effect on end user comfort, productivity and safety. The history of the Purifier® Biosafety Cabinet shows how Labconco has consistently lead the industry in the evolution of BSC HF/E design, holding the position as the industry's premier innovator in human factors design.

The first Class II Biosafety Cabinets resembled fume hoods in general appearance. They were console units with 90° vertical safety glass sashes. These sashes pivoted and would not fully close when the BSC was not in use. There was a flaw in these designs, however, unlike chemistry applications, microbiological tasks tend to require significant time to perform, and work is highly repetitive in nature. Standing at a BSC, as one would in front of a chemical fume hood, is not realistic; putting substantial strain on the back, legs, arms and neck.

The First Purifier

In 1983, Labconco released the first of its Purifier Series Class II BSCs. This was the first BSC of its kind, designed for a seated operator. A reconfiguration of internal systems (the blower and filters) allowed for these BSCs to be bench-mounted, and simply tilting the sash 10° from vertical permitted a researcher to sit with their legs comfortably below the BSC, placing them much closer to their work, improving working posture, reducing fatigue upper limb and reducing task risk factors. Furthermore, the angled sash decreased the reflection of light, eliminating glare. Labconco removed all console models from their catalog by 1995.

The changes brought on by the Purifier cabinet addressed the immediate comfort needs of users, and were quickly adopted by other industry leaders. Never satisfied, though, Labconco enlisted the assistance of a Human Factors Practitioner, and consulted with several microbiologists to once again create progress in biosafety.

Delta brings Change

The 2000 release of the Purifier Delta® brought to the industry a new standard for HF/E design.

The Delta's preeminent design brought unprecedented comfort to almost every user. Unlike previous BSC's that were designed for the average sized user, the Delta was optimally designed around users between the 2.5 and 97.5 percentile for height of both men and women (Labconco & Erickson-Harper, 2003).

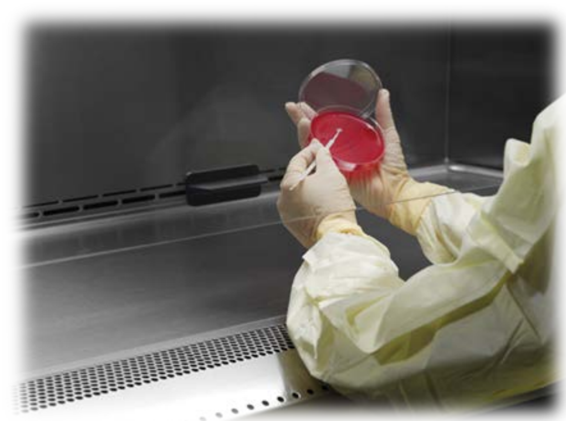
To achieve this optimization, Labconco attempted to forget everything they had learned to date and build a cabinet around a human operator. This meant addressing each and every risk factor identified by the Human Factors Practitioner and microbiologists.

To alleviate lower limb discomfort from hard and sharp angles, the air inlet grille was elevated and curved, building in an arm/elbow rest. A second row of slots was added to ensure continued safe airflow when the user's arms were at rest.

Several aspects of the safety glass sash were addressed. The use of ultraviolet (UV) light in cabinets was, before 2000, handicapped by the inability to fully close the sash. The new sash, still tilted, was fully closing and the counterbalanced and anti-racking design ensured easy, smooth movement. The inclined sash could be operated by any user with a single finger anywhere along the width of the sash. To better accommodate different body sizes and heights, the Purifier Delta came in two different nominal sash heights, 8" and 10". The sash handle extrusion was substantially reduced in width to maximize sight lines into the BSC (Labconco & Erickson-Harper, 2003).

The work zone of the BSC underwent changes as well. The total depth was configured to allow for comfortable reach distances anywhere in the cabinet, while not feeling claustrophobic (the Purifier Delta boasted the largest cubic foot volume of any Class II). The work surface was designed for easy cleaning and to be removable. Today, it continues to be the only work surface that is a single piece of stamped stainless steel. This requires no welding; removing all seams and provides for a dish with perfectly radiused edges.

The last piece of the puzzle involved changing how the user and BSC controls interacted. First, the analog pressure gauge used to indicate safe cabinet performance was transplanted from its position in the header panel above the sash and out of view of the user, and integrated with the Delta's interior for easy viewing (at line-of-sight while seated). The BSCs controls were also removed from the header panel, placed on the right hand corner post, removing the need of the operator to stretch above their head to control cabinet function. Finally, provisions and installations of utility service valves (fixtures) and the internal electrical outlets were moved forward, toward the operator, and up on each side wall within close reach, but out of the way of manipulations at the work surface. With these changes, all BSC controls and gauges were compliant with the American with Disabilities Act (ADA) and accessible by wheel chair bound users (Equal Employment Opportunity Commission and the U.S. Department of Justice., 1991).



It required innovation in the HVAC industry to cause another punctuated event in the evolution of HF/E design in biosafety cabinets.

Logical Comfort

To increase the basic safety of BSC design, Labconco engineers incorporated an Electronically Commutated Motor (ECM) driven blower into the Purifier Logic®. This motor technology comes with a host of advantages over previously used motors (Hunter & Rouse, 2008). These benefits come from two key features of the ECM.

1. The design of the ECM is much more efficient than that of other motor systems.
2. The ECM can be paired with a monitoring system that can be programmed/trained to provide valuable status information.

The efficiency of the ECM can be experienced by a user. Long time users complained of two inescapable characteristics of BSC use: *heat* and *noise.* Traditional motor systems required the induction of magnetic fields to turn the blower, a by-product of which is heat. Subsequently, the air moving through the cabinet would heat, causing sweating, discomfort and fatigue of the researcher. The ECM does not require this magnetic induction and therefore does not heat up, maintaining ambient temperatures. Also, a provision of the ECM's design and efficiency is a reduction in the noise emitted from the motor blower. Operators realize a 50% reduction in noise levels when BSCs utilize an optimally sized ECM.

The Logic continued to add value to the HF/E efforts of Labconco when the antiquated analog gauge was replaced by a Digital LCD display (mounted at line-of-sight while seated, of course). Icons were utilized for at-a-glance monitoring of critical working parameters including filter loading, airflow disruption, and cabinet component functions. Furthermore, a status line gives descriptive feedback on system conditions using words, replacing the commonly used but vague red indicator light and buzzer, the minimum requirements of BSC safety standards.

The microbiologists Labconco consulted also expressed the need for a cabinet to clearly communicate when the HEPA filters require service. The HEPA Filter Life Remaining gauge (expressed as a percentage) delivers an accurate, real-time evaluation of filter life. This is only made possible by the incorporation of the ECM (Hunter & Rouse, 2008).

Opportunistic developments have once again allowed Labconco to stay at the forefront of BSC design, and, again, a new cabinet introduction will revitalize human factors design in microbiology and biosafety.

Embracing Human Inclination

Building on four decades of ergonomic innovation, the Purifier Logic®+ design team scrutinized every BSC, looking to find, design and utilize the best features found throughout the industry. Their work resulted in the development of the most extensive human factors package, Inclination™ Technology, and the MyLogic™ Operating System.

Ergonomics & Microscopy

Anyone who has performed even the most simple of tasks in a microscope has realized that these devices are not without their drawbacks. The arch of the oculars, bright lights and control knobs place extra strain on the eyes, neck, shoulders, lower back and wrists. Human Factors Design has come a long way in microscopy to address each of these risk factors. Articulating ocular heads and telescoping eye pieces have helped to reduce strain on the neck and shoulders. Many microscopes now have accessories such as digital displays with optical and digital zoom that are easier on the eyes, and pads to support the arms while controlling the focus and stage of the microscope.

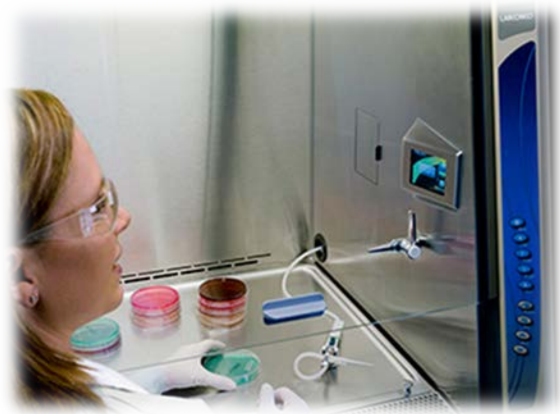
Some of the biggest improvements in safety and performance when working with microscope cannot be purchased, but are practiced by the operator. These include (OSHA, 2011):

- Sit close to the work surface or microscope.
- Avoid leaning on hard edges.
- Adjust the chair, workbench, or microscope as needed to maintain upright head posture.
- Take short breaks every 15 minutes, close the eyes or focus on something in the distance.
- Every 30-60 minutes, get up, stretch and move around.

Keeping the ergonomically sound design of the Delta and Logic as the foundation, the goal of Inclination Technology is to maximize safety through observing and understanding human habits. Modifications that evoke the essence of the human experience were added to the counter balanced, anti-racking, inclined sash, line-of-sight digital display, ADA compliant cabinet controls, electrical outlets and utility service fixtures. For safe entry of cords, cables and tubing connecting two devices, one outside of the BSC the other in the BSC's work zone, a portal was designed that remained within easy reach of a seated user, keeps such connections out of the way of a busy work station, and protects both the lab and the BSC interior from loss of containment through a vacuum lock system. The Vacu-Pass™ Cord & Cable Portal was first submitted for NSF/ANSI Standard 49 approval in 2012; only after ensuring the design met all three of the above requirements, was it formally adopted into BSC design.

"…the goal of Inclination Technology is to maximize safety through observing and understanding human habits."

Another feature commonly cited as a safety feature only intrigued and confounded the design team, the internal electrical outlet. Their presence and location in the BSC is designed for HF/E; outlet covers that protrude into the interior of the BSCs work zone and utilize loaded springs are anything but ergonomic. The self-closing mechanisms, required by laboratory design codes, utilize loaded springs that exert significant force on the doors; turning them into high velocity finger traps. To counter this bear-trap like operation, the stainless steel covers' hinges have been dampened for slow closing execution. Furthermore, the stainless steel electrical outlet covers, of the Logic+, are flush mounted increasing cabinet access and are easy to clean during surface decontamination of the cabinet's interior.



In today's fast paced world, it is expected that a device be 'plug-and-play' or turnkey. In consumer products, this typically means that the set-up of a device is launched at initial start-up and is a 'self-guided' procedure. This fact was not lost on the design team. Building from the digital display employed in the Logic, MyLogic OS utilizes an optimized, multifunction, color display with intuitive programming designed to guide an operator through cabinet set-up, calibration and diagnostic assistance. Using full sentences, MyLogic OS leads a new user through Smart-Start™ set-up, allowing for control of the cabinet's entire operation with simple sash movement. Cabinet status is displayed on the digital display, and utilizing system feedback, a diagram of a BSC highlights areas of the cabinet affected by or causing an alert or alarm condition. This graphic is accompanied by a status message that describes the condition and provides correctional walk-through instructions. Though not recommended, the Logic+ could easily be set-up and operated without ever consulting the Operator's Manual.

Conclusion

The first Class II biosafety cabinets were developed with the advent of laminar airflow in the 1960's (CDC, 2009). Even though comfort is paramount to the safety of the operator, it took nearly 40 years before industry manufacturers began taking ergonomics seriously. In the time since then, BSC design has taken on its own look and feel, with thoughtful regard toward how form should meet function. However, there exists a paradox in HF/E engineering, it has become expected that there be greater advances made in a shortened period of time between product releases.

For Labconco, this paradox has been met in different ways, but always with the same goals – to provide *total comfort, effortless operation & maximum safety.* To this end, there is only one road to take; collaboration with laboratory users leading to innovation in design. Invention in BSC human factors design will continue to develop, and will have positive impact on safety performance. How each BSC manufacturer approaches this concept is the underlying reason why biosafety cabinets, when designed to meet just a safety standard, are not created equally.

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