

Maximizing User Safety Through Ergonomic BSC Design

Abstract

Unlike many industries and professions, the very nature of 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 care should be taken in selecting equipment that maximizes safety by reducing the risk of the workstation's effect on the user. This review focuses on the associated risks of laboratory and clinical procedures and the required equipment that keeps the scientist safe from the agents being used; with emphasis on the evolution of human factors research and ergonomic features on biosafety cabinet engineering and design 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 is no different; many scientists may not associate potential hazards and injuries to the layout and configuration of their work centers.

The field of Human Factors and Ergonomics is a multidisciplinary approach to understand how humans physically interact with their work environment and how design changes can help with safety and productivity. As defined by Merriam-Webster (n.d.), ergonomics is an applied science concerned with designing and arranging things people use so that the people and things interact most efficiently and safely. One area of research in this field strives to improve how equipment design directs ease of use and positively impacts user safety.

Laboratory and Clinical Risk Factors

The biological and chemical agents utilized in 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:

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



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To lessen work-related 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. Ergonomic improvements aim 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. OSHA provides a free template here: https://www.osha.gov/sites/default/files/2018-12/fy14_sh-26336-sh4_Ergonomic-Assessment-Checklist.pdf

Biosafety Cabinet Risks

Working with biohazardous samples or compounded sterile preparations (CSPs) often require the use of a biological safety cabinet (BSC) to protect both the scientist and the samples. Within this environment, scientists often perform repetitive tasks for long hours. There are intrinsic risks associated with all of these tasks, and they are compounded when combined.

Cumulatively, the risk factors accompanying these tasks 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, noise, 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 NSF International's NSF/ANSI Standard 49 or the European Union 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 ergonomic features and user comfort 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 organization. Effective use of ergonomics will make work safer, healthier and more productive” (HSE, n.d.).

Currently, the safety standards have not established requirements for ergonomic 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 features, as there are vast differences between how each manufacturer approaches BSC design and human factors 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 ergonomics, strategies have been developed to reduce the strain placed on researchers 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 ensure 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 Labconco biosafety cabinet design has consistently lead the industry in the evolution human factors holding the position as the industry's premier innovator in ergonomic features.

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

The First Purifier

In 1983, Labconco released the first Purifier Class II BSC. 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 by tilting the sash 10° away 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 limb and neck fatigue; and thus, reducing risk factors. The angled sash decreased the reflection of light, eliminating glare which ensured good visibility. 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. Always striving for the best, though, Labconco enlisted the assistance of a Human Factors Practitioner, and consulted with several microbiologists to once again create progress in biosafety.

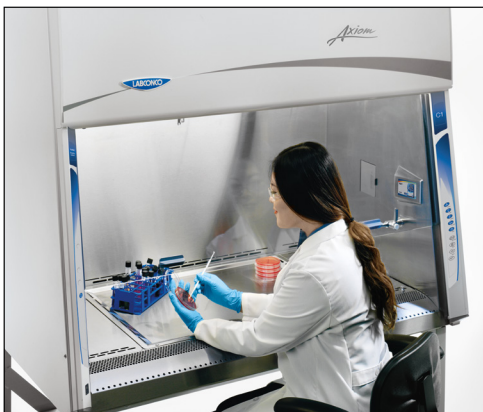
Delta Brings Change

The 2000 release of the Delta® brought to the industry a new standard for human factors design.

Delta's novel design brought unprecedented comfort to almost every user. Unlike previous BSC's that were designed for the average sized user, the Delta cabinet was optimally designed around users ranging from 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 about ergonomics, building a cabinet around a human operator. This meant addressing each and every risk factor identified by the Human Factors Practitioner and end users like 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 airflow slots were 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 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 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 and removes all seams; which creates a dished work surface 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). This technology has since been deleted for more accurate torque-sensing filter metering through an LCD display. The BSC's 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).

Logical Comfort

To increase the basic safety of BSC design, Labconco engineers incorporated an Electronically Commutated Motor (ECM) driven blower into the 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 provides valuable status information.

The efficiency of the ECM can be experienced by a user. Long time BSC users complained of two inescapable characteristics of a BSC: 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 ergonomic 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).

Embracing Human Factors

Building on four decades of ergonomic innovation, the 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 ergonomic package, 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 a 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 the Logic+ design is to maximize safety through observing and understanding human habits. Modifications that enhance 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 a portal was designed that keeps connections out of the way, 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 and formally adopted into BSC design.

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 ergonomically designed, but the outlet covers protrude into the interior of the BSC's and utilize stiff, loaded springs. The self-closing mechanisms, required by laboratory design codes, utilize loaded springs that exert significant force on the doors; turning them into high velocity pinch points. To counter this the Logic+ utilizes custom stainless steel covers and the hinges are dampened for soft, slow closing execution. Further more, the stainless steel electrical outlet cover is flush mounted, easing access and easing cleanability during surface decontamination of the cabinet's interior.



In today's fast paced world, it is expected that a device be 'plug-and-play'. 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, the 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 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.

**“...the goal of Inclination
Technology is to maximize safety
through observing and
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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 human factors and 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 06 human factors 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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