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The Eppendorf PhysioCare Concept® – 3 Spheres Model

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Abstract

Healthy working conditions will gain in importance, not least due to demographic trends. Responsible organizations will discover the importance of personal health for their company culture, since providing healthy conditions in the workplace is a prerequisite for long term competitive advantage. Many studies show that laboratory work in particular carries numerous health risks if the working conditions do not satisfy the requirements of the holistic ergonomic principle. By providing healthy working conditions in accordance with such ergonomic principle, the company will benefit from the fact that efficiency is increased while at the same time health-promoting working conditions are created. Here, the Eppendorf PhysioCare Concept comes into play, which integrates ergonomics into the modern laboratory.

The Eppendorf PhysioCare Concept (PCC)

In accordance with the definition of the International Ergonomics Association (IEA, the international umbrella organization for the societies for Human Factors/ Ergonomics), a holistic ergonomic principle encompasses the consideration of physical, cognitive and organizational ergonomics [1]. All three areas are integrated into the Eppendorf PhysioCare Concept (PCC, Figure 1) in a meaningful and easy to comprehend fashion.
In order to redesign the workspace/laboratory using ergonomic guidelines, the identification of three core areas is useful. Within the PCC these are referred to as "Spheres". Sphere 1 orients itself by the needs of the user with respect to ergonomic product design and product performance, optimized to suit their individual requirements. Sphere 2 expands this view to include the system "laboratory" with the aim to integrate products in harmony with the specific requirements of the workplace. Sphere 3 then captures the workflow. The goal is continuous support in order to improve processes around the laboratory and thus the results of the entire organization. Hence, each of the three spheres has different ergonomic foci and requirements.

Figure 1: The Eppendorf PhysioCare Concept – the assurance for an ergonomic product concept.

Sphere 1: The pipette and daily work habits – in harmony with ergonomics

Let’s recall: The pipette is the workhorse of the laboratory and therefore takes center stage in critical ergonomic considerations within the first sphere of the PCC (Figure 2). Health problems are caused by long term physical strain over a period of months and years.

Therefore even small differences in weight between the pipettes used on a daily basis may make the difference between the development or the continued absence of a health problem. A difference in weight of only 40 g results in 4 kg if lifted 100 times, and a ton after 225 work days per year. Thus, a pipette intended for daily use should be as light as possible. Furthermore, the balance of a pipette plays an important role, as a badly balanced pipette requires more intense gripping and holding, placing unnecessary strain on the muscles of the hand and fingers. This is more often the case with electronic pipettes, due to an angled and heavy “head”. Therefore, an ergonomic pipette should not be top-heavy; its center of gravity should be located in the geometric center of the pipette. At the same time, it should exert slight pressure on the ring finger, alleviating the feeling of needing to hold or grip at all times.

Figure 2: The pipette is the workhorse of the laboratory.

During the pipetting action, the thumb is the main actor among the fingers. It is moved by two antagonistic and two agonistic muscles. Repetitive strain on these muscles, in connection with extension of the metacarpophalangeal joint (the tip of the thumb moves the push button up and down: a constant switch between extension and flexion) may lead to tenosynovitis [2] in particular, or to more generalized repetitive strain injuries (RSIs). Regrettably, the aspect of repetitive movement cannot be eliminated, even with an ergonomic pipette; however, low operational forces reduce the strain during each individual pipetting stroke.

During the latter, clearly defined first and second stops are crucial for reliable work. The resistance for reaching the second stop (expelling of remaining liquid) is higher than that for reaching the first stop (aspiration and dispensation of the liquid). This difference in haptic feedback enables easy differentiation between the two processes. From an ergonomic perspective, this is important. At the same time, the forces of resistance, while easily differentiated, should be low altogether. The sum of force applied may make a difference in determining whether strain or even injuries will develop or not. This should be taken into consideration as early as during the development stage of a pipette (Figure 3). Differences in operational forces between different pipettes are easily detected by pressing two pipettes horizontally against one another, their push buttons touching. The age-old wisdom “The smarter one gives in” prevails.

During processes which require high precision, low operational forces are much more relevant, since precision tasks such as gel loading and removal of supernatants are associated with increased physical strain on the thumb muscles mentioned earlier and thus pose a risk for fatigue and injury in conjunction with the local tendons [2]. Such tasks are most frequently characterized by static muscle activity and therefore, in conjunction with an extension of the metacarpophalangeal joint, pose a risk for tenosynovitis [2]. The harm caused by static muscle activity has been demonstrated in many different studies [3] [4] [5] [6]. Typically, electronic pipettes require the lowest operational forces for pipetting and are therefore to be favored with regard to this ergonomic aspect.

Figure 3: Ergonomic studies during pipette development.

However, operational forces do not only play a critical role during the pipetting action itself, but also during fitting and disposal of the pipette tips (Figure 4). An ergonomic pipette optimized in this regard is characterized by easy and comfortable tip fitting, secure and reproducible fit, as well as equally easy disposal of the tip. In some pipettes, an integrated spring absorbs excessive force which is exerted during tip fitting (*spring loaded tip cone*). This prevents “rocking”. From an ergonomic perspective, this is particularly harmful, as it is associated with increased physical strain and simultaneous repetitive movement and vibration.

The ergonomically relevant operational forces include those for volume setting. From a physiological perspective, volume setting is not to be underestimated, as it encompasses a highly complex pattern of movements and as such requires extraordinary muscle activity. An ergonomically designed volume dial ring should be large in order to provide high friction with the fingers (with and without gloves), and it should require low torsion force, as well as a small number of rotations. Considering these aspects, electronic pipettes offer certain advantages over manual pipettes, as the ring is replaced by keys. However, this advantage must not be compensated by the necessity to operate the keys extensively.

Figure 4: An ergonomic pipette should also regard the aspect of fitting and disposal of the pipette tips.

Apart from physical-ergonomic aspects, cognitive-ergonomic considerations are relevant during the process of volume setting. This is with respect to the volume display of the pipette. The latter should not be covered by the hand holding the pipette, as in this case unnecessary and possibly harmful movements are necessary in order to view the volume setting. The volume display should be readable equally well for left and right handed people. If this is not the case, additional movements and actions will also be required at this step, the sum of which may be harmful. Furthermore, the display should be intuitive. This implies that the set volume may be read at a glance without having to think about it.

In reality, these requirements are not met for all commonly available pipettes. For electronic pipettes, these deliberations may be taken one step further. The display of an electronic pipette should be readable from all standard working positions. At the same time, the menu should not be divided into too many sub-menus, and programming should be easy. The ergonomic angle of the pipette head and background illumination should allow readability from all positions. The intensity of the background illumination should be variable and selectable, and it should be sufficiently bright at maximum illumination that easy reading is possible under all possible lighting conditions encountered in the laboratory. Finally, user-friendly software creates an intuitive interface for the user with the instrument.

The handle of a pipette should be made from a skin-friendly material which feels pleasant to the user. A slip-resistant surface precludes the need for constant holding and gripping of the pipette. The latter are associated with strain. Furthermore, high expectations are placed on the design shape of the pipette handle. As early as the 1970s, the Institute for Labor Science at the TU Darmstadt with its former head Professor Walter Rohmert conducted studies on handling conditions of pipettes in co-operation with Eppendorf. One result of these studies was the design of the Eppendorf Pipette 3130 with its characteristic handrest. In contrast, many commonly available pipettes do not consider the ergonomic knowledge available and are therefore too short, too wide or too thin, their inner radius is too narrow, or they do not provide a clearly identifiable handrest.

All these ergonomic deficiencies are potential sources for harmful and tiring hand positions during pipetting. At the same time, esthetic considerations must not be left out during the design of grip conditions, since especially the handle of a pipette is typically a hallmark of design.
Ergonomically correct pipetting is not solely based on the ergonomic pipette; the user must play his part. He should hold the pipette in a vertical position during pipetting, and little force should be exerted on the grip. The wrist should remain straight (no angles), without cramping. The arms are to be held close to the body (which supports the vertical pipetting position of the hand). Simultaneously, the resting of arms and elbows on hard surfaces is to be avoided. The arms should not be lifted (as erroneously practiced by a majority of users). Chairs (or tables, if applicable) need to be adjusted to individual height. Furthermore, steep leaning of the neck and upper body, as well as uncomfortable positions, should always be avoided. Finally, the habit of "rocking" during tip fitting is to be broken, or, better, not taken up at all.
Cognitive ergonomics requires the design of an intuitive interface between the instrument and the user. Intuitive design of the interface of a pipette may be reflected in the volume display, the ease of reach and intelligibility of keys and the practicality of software, as well as the degree of difficulty encountered when assembling or dis-assembling the pipette, respectively. Taken together, this means that an instrument should be understood and used without the need to consult the user manual. The rules of usable design are to be followed (keyword: usability) [7]. Electronic pipettes in particular may be seriously flawed with respect to cognitive ergonomics.

Sphere 2: Order in the workplace

The advantages of an orderly work situation are obvious: It allows one to keep all required instruments in view and within reach, therefore generating smooth work flow. Instruments and devices do not have to be found and brought to the bench first. Even leaning forward and stretching the upper body in order to reach something violates the ergonomic concept of an orderly workplace. The more chaotic and untidy a workspace, the more unnecessary or even harmful additional movements are required. Finally, an untidy work area can lead to increased mental strain, since constant searching interferes with the concentration required for the actual task at hand (Figure 5).

Figure 5: An orderly workplace allows one to concentrate on the actual task at hand.

One solution for lack of order stems from the principles of Kaizen (from the Japanese: "change for the better") which is often employed in production. This Japanese term stands for a stepwise approach, with the help of which increasingly higher standards in the improvement of quality and reduction of waste can be achieved. Thus, Kaizen implies small but nevertheless steady improvements. According to Kaizen, there are seven forms of waste which are to be kept to a minimum: overproduction, waiting times, preventable transports, complex and useless processes, large stock, superfluous movements, as well as mistakes and useless fixes. These forms of waste are universal. They can be identified equally well in a global pharmaceutical or biotech company, in the molecular lab at a University, or in a private home.

In order to reduce these forms of waste, Kaizen offers 4 different sets of rules: Best Point – workplace design, One Piece Flow (flow principle), 5 S-rule and Poka Yoke. The 5 S-rule prescribes 5 simple rules which are to be followed: first, those things which are useless and superfluous are removed from the workplace (Seiri). Those items which are then part of the work area are organized (Seiton). The thus defined workspace should from then on be kept clean and organized (Seiso).

In order to put these points into practice, a personal desire for cleanliness and order needs to be developed and cultivated (Seiketsu). Finally, standards must be defined and implemented for these 5 rules to become habit (Shitsuke).

The rules of Seiton and Seiso imply that means and ways must be found to organize items and, furthermore, maintain that order long term. To this end, deviations should be noticed quickly and rectified immediately and in an uncomplicated fashion. No strictly defined rules apply, as each workplace and each laboratory have their own expectations with respect to order. As such, individual creativity is essential. For example, a diagonal line drawn across the front of a row of binders in sequence will help keep these binders in the correct order. It is easy to spot missing binders immediately. In order to guarantee efficiency in the workplace/laboratory it is further necessary to avoid large stocks of gloves, tips, etc (Seiri and Seiton). Large stocks are one of the 7 types of waste which are to be avoided. However, this does not imply the complete elimination of stocks; on the contrary, the availability of a certain minimum stock is a prerequisite for efficient work. A simple solution must be found for keeping the necessary stock without over stocking or under stocking. One such solution could be the traffic light system, where the colors green, yellow and red, in that order, represent a decreasing minimum stock. Shelves, drawers, etc. are easily and economically equipped with such a system.

Most laboratories, however, present an entirely different picture: drawers are filled to the maximum with boxes of gloves, tips, etc., in a disorganized fashion. This, however, is a false assumption. It would be much better to note the threat of low supply of various items in drawers, cupboards and shelves via their “traffic lights” and to prevent this occurrence with one trip.
When organizing a core workstation (Seiton) with consideration for physical-ergonomic requirements, in addition to the 5-S rules, the Best Point Principle should be consulted as well. This principle of workplace design states that items which are a part of a core work space should be kept in locations which are easiest to reach by the user. Ideally, all items would be within arm’s reach. Even in a simple office, this would be difficult to implement, and it sounds like utopia when considering the work space at hand – the laboratory. Therefore, in order to be able to implement the Best Point Principle in the laboratory, it is crucial to sort items into three different areas of reach, according to their frequency of use. The optimum area of reach is equivalent to a radius of the length of a person’s lower arm, including the hand, without stretching. This radius is the actual work area. For a range of body heights between 1500 and 1900 mm (4’11” to 6’3”), this radius is approximately 35 cm (13 ¾”). However, the maximum physiological reach comprises a radius of the length of the outstretched arm without severe leaning forward of the upper body (approx. 50 cm or 19 ½” for body heights between 1500 and 1900 mm or 4’11” to 6’3”). This is the ideal area in which items for daily use should be kept. The anatomical area of reach for persons of heights between 1500 and 1900 mm (or 4’11” to 6’3”) is up to 60 cm (23 ½”) and thus requires leaning forward in order to reach items located within this radius. It is suitable for items used in the long term. It is recommended that one get up in order to retrieve or use them, rather than leaning over to reach. Leaning forward should generally be avoided. Within the entire work area, both hands should be used. This supports coordination and distributes strain between two hands.

Following the successful sorting of items, the ergonomic requirements during sitting and standing need to be considered. This is a part of orientation along the Best Point Principle. Mainly the task and the furniture in the laboratory determine whether one is sitting or standing while working. In fact, a German study of laboratory personnel revealed that approximately half the people sit while pipetting while the other half stands [8].

If one stands exclusively, a chair with a high seat should be used as a sitting-standing support, and ergonomic workplace mats should be used. If one sits without exception, care should be taken to adjust the chair to the individual body height. The height is to be adjusted to allow the knees to form a 90 degree angle and the lower back to lean against a back rest. To the disadvantage of lab personnel, laboratory benches are often equipped with countless under-desk cupboards which preclude sitting altogether, or allow it only at an angle. From an ergonomic perspective, a combination of standing, walking and sitting is superior, as in this case all stabilizing muscles are in turn activated and relaxed, depending on the state of activity. Hence, it makes sense that following a pipetting task which has been performed while standing one would move to an office area, sit down at a table and record the data into the lab book. This combines ergonomics with responsible laboratory work.

In addition, the introduction of organization is subject to cognitive-ergonomic requirements. These are extensively considered within the Poka Yoke rules of Kaizen. Poka Yoke desires to uncover mistakes in all possible areas of work as early as possible, thus helping prevent them. This is rooted in a form of process visualization, which allows one to recognize the flow and therefore “missteps”. Error reduction saves cost, energy and time. Productivity increases. Inevitably, products of higher quality are produced. With regard to the laboratory work space, color coding of pipettes and tips takes center stage. While many manufacturers are now color-coding their tips, not all of these color codes actually help prevent errors. Color codes only make sense if they are visible unequivocally from all work positions. The advantage of intelligent color coding is rooted in minimizing pipetting errors and unnecessary actions, which result from searching for the correct pipette. Apart from color coding, there exist many other aides in the sense of Poka Yoke.

A calibration warning device installed in some electronic pipettes acts as an automatic reminder for calibrations due. Some pipettes are equipped with special mechanisms which protect the volume setting from being changed accidentally. Some electronic dispensers automatically recognize the volume of the tip fitted.

The requirement for order in accordance with the rules of Seiri and Seiton extend beyond the individual workplace and are applied to the structure of the laboratory as a whole. The flow of movement in a laboratory may be compared, in a simplified view, to those in a kitchen. In 1922, the American Christine Fredericks conducted a study to analyze the organization of kitchens. To this end, she pinpointed the paths she took in her kitchen during the preparation of an evening meal with the help of a thread. The result was a chaotic structure. Based on this observation, she re-organized all utensils and appliances according to the flow during cooking and repeated the experiment.

The result was considerable reduction of distance covered and faster preparation of the evening meal. Employing similar studies of the optimization of flow in the kitchen, the German architect Margarete Schütte-Lihotzky designed the “Frankfurt kitchen” in the 1920s. Parallels to the laboratory abound. Apart from over stock, many drawers and shelves contain items (single pieces, etc), the designation of which may be difficult even for a long term member of the laboratory team. Furthermore, products (e.g. samples) are often distributed among several refrigerators. The location of instruments often does not represent the work flow for which they are intended. It is generally advisable to keep products and instruments which are always used together in close proximity to one another. The same is true for the storage of parts and items which are functionally related. Samples which are to be measured or processed together should be stored in the same refrigerator.

A waterbath/thermomixer should be in the vicinity of a photometer if enzyme activity is to be analyzed. As a positive side effect, the risk of contamination will be reduced. Furthermore, if possible, all work stations within a laboratory are to be organized. This will not only reduce the need for detours, but it also improves safety (toxic substances no longer need to be transported between individual laboratories, etc.). However, his type of laboratory restructuring does not aim to eliminate walking altogether. Walking should always be a part of the daily routine in the laboratory, as it provides natural breaks from repetitive tasks, and it relaxes the stabilizing muscles.

The organization described above can only be maintained over time if a long-term desire for order is created (Seiketsu).

Therefore, the introduction of a new ergonomic organizational system requires the participation of all employees involved [9]. Despite the participation-based approach, the realization just how effective a new organizational system can be does not appear by itself. In the beginning phase of the new organization, this realization needs to be supported by the implementation of standards and rules (Shitsuke). During the early phase, clear delegation of responsibilities for the maintenance and reinstatement of order is essential. The introduction of a schedule for order and cleanliness is helpful. However, the guarantee of cleanliness is subject to large variation according to the understanding and expectations of the individual. Thus, checklists are still required, which need to be adhered to by the person in charge according to the schedule. For example, this person makes a trip to the storage room as soon as he or she notices the need during regular check of the traffic light system. Further, the location of all individual items must be available to everyone (location of instruments, devices, consumables, chemicals, etc.).

Attitude is the readiness to react to certain environmental stimuli in either a consistently positive or a consistently negative manner. In this case, the affective component plays a major role. It represents the emotional evaluation of an object. In the case where the object to be evaluated is a task or the work in its entirety, the affective component is strongly influenced by the environment. Mainly light, noise and climate play critical roles. Especially during precision tasks such as pipetting, light which is too dim places a strain on the eye muscle (focusing). Therefore, illumination between 500 and 1000 Lux is recommended for office areas and 750 to 1500 Lux for older employees [10]. The higher the demand for precision during the performance of a task, the stronger the illumination required [10]. When working with electronic instruments (e.g. electronic pipettes), the illumination of the display should be adjusted to ambient light conditions. A screen which is too bright irritates the eyes in dark or dimmed rooms [10]. As a rule: Natural daylight is the best and most healthy illumination. With its unique spectrum, it regulates many physiological processes; it is a well known fact that the circadian rhythms of humans and animals are dependent on daylight. Therefore, a laboratory should have a sufficient number of windows. Furthermore, these windows need to be equipped with blinds against direct sunshine. Nevertheless, artificial light may be necessary from time to time, depending on the time of year and time of day. In addition, rooms without daylight are consciously chosen for certain research projects and the experiments involved therein.

Loud background noise interferes with concentration. If one is subjected to it long term, it may, in extreme cases, lead to cardiovascular disease [11]. For these reasons, the noise level should be kept as low as possible in order to facilitate stress-free and concentrated work. The noise level can be expressed in decibels. The decibel is a relative value, where an increase in 10 decibels is felt to be twice as loud. Normal breathing has a noise intensity of 10 decibels, whispering is already 20 decibels, and speaking in a low voice is 40 decibels. Hence, quiet speech is perceived to be 8 times louder than normal breathing. The stress or tolerance level, respectively, is at 60 decibels and is equivalent to loud speech. During highly concentrated work, an average daily noise level of 35–40 decibels should not be exceeded [10].

For tasks which require less concentration, 55 decibels are not to be exceeded [10].

In terms of climate, a temperature between 21 and 22 °C (but not higher than 26 °C), relative humidity of 40–60 % and air current of 0.1–0.15 m/s (at 21 °C) are considered optimal [10]. Furthermore, air should be free of toxic gases and low in carbon dioxide. Chemical aerosols and dust are also to be avoided. In order to achieve this, opening of windows for 10 minutes every day is recommended [10].

Sphere 3: The workflow in the laboratory

It is a well known fact that a close connection exists between psychological processes (e.g. stress) and physiological reactions, which may express themselves in the form of psychosomatic disturbances. The direct mutual influence of satisfying work and muscular-skeletal illness was demonstrated in a number of studies. In contrast to illness of the hand, the risk of developing a shoulder injury is 8 times higher if the content of the work is unsatisfactory [11]. This could be based in the fact that hand injuries have a direct connection with physical strain, whereas shoulder injuries may also be attributed to psychosomatic causes [11]. According to a study by Björksten et al. from 1994 [11], versatile work is an important parameter for a healthy work environment, as seen from a physical and mental perspective, where versatile work may be generated by implementing the above mentioned measures for re-organizing the work space.

Figure 6: Versatile work and well-trained worker lead to more efficient work with less mistakes and create joy at work.

Besides avoiding monotonous and boring work, one has to ensure that all workers receive sufficient information and training for the duties they perform. Under these conditions will they be more efficient, make fewer mistakes and perceive joy during and for their work (Figure 6). They will understand what they are doing! Work should be divided: When a complex pipetting task is to be performed, asking colleagues for support is natural. This approach offers two advantages: the length of a repetitive task is reduced for each individual, and the versatility is increased.

Cognitive aspects also play a role when considering the workflow in the laboratory. Insufficient maintenance and cleaning of a pipette leads to high systematic error and high operational forces. As a result, pipetting errors, as well as hand strain, will increase. The entire work flow is disrupted.

When purchasing devices and instruments, it is important to ensure not only the satisfaction of all ergonomic requirements, but also the availability of product services provided by the manufacturer. Good product service radiates several positive effects. Good service is a prerequisite for long product life, and time loss through periods of disrepair and errors are prevented and operational forces are kept low.

Conclusion

When considering PCC in its entirety, it becomes evident that the three spheres do not represent strictly separated areas, but rather a complex structure with three core areas which overlap and build on one another at the same time. Therefore, none of the spheres should be viewed in isolation and separate from the structure. A holistic consideration is essential. Similarly, ergonomics can only be comprehended fully by including physical, cognitive and organizational aspects. A solution which only satisfies the requirements of one of the three aspects is often sub-optimal when held to ergonomic standards. Only the holistic ergonomic approach is able to secure long term success of design measures which excel through improved efficiency and simultaneous support of health and improved motivation [12].

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