Pipetting, Ergonomics, and You

An overview of ergonomics, pipetting risk factors, methods for reducing risk of injury, and recommended solutions.

RAININ

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FOREWORD

> "*Work-related musculoskeletal disorders… are the most prevalent, most expensive and most preventable work-place injuries in the country. The good news is that real solutions are available.*" [2]
>
> Alexis M. Herman
> U.S. Secretary of Labor

INTRODUCTION

The pipette is a fundamental tool used in multiple disciplines, and the number of applications that use pipettes is growing at a rapid pace. It is not surprising that laboratory personnel spend considerable amounts of time pipetting: an average of nearly 500 hours per year (roughly 2 hours per day) of pipetting activities are reported by Bjorksten.[4]

Unfortunately, pipetting activities are identified as a cause of work-place injuries to the hand, arm, and shoulder.[4, 7, 10] In fact, Bjorksten concludes that laboratory personnel who pipette more than 300 hours per year (about 1.3 hours per day) are at an elevated risk of injury.[4]

Why is a pipette dangerous? What kind of injuries can pipetting cause? How can the risk of injury be reduced? These questions are the focus of this paper.

An understanding of ergonomics – *a science that explores human limitations and applies that knowledge to the design of "user-friendly" tools, environments, and practices* – will help us to identify and reduce risk factors found in laboratories and with pipettes, specifically.

- The first section of this paper defines ergonomics and discusses its values.
- Section two specifically identifies pipette risk factors.
- The third section briefly discusses the types of injuries commonly seen among pipette users.
- Prevention, the topic of section four, highlights practices that reduce risk of injury.
- Design features of pipettes that reduce the risk of injury are discussed in section five. Three ergonomically designed pipettes by RAININ are introduced.

DEFINITIONS

ergonomics the science of fitting the job to the worker, is used to design environments, procedures, and tools that improve efficiency, alleviate physical and psychological stress, and reduce the potential for injury.

musculoskeletal disorders (MSDs) are injuries to muscles, tendons, ligaments, cartilage, spinal disks, and nerves, resulting from repetition, excess force, poor posture, inadequate rest, vibration, cold and hot temperatures, etc.

repetitive strain injuries (RSIs) are musculoskeletal injuries that mostly affect muscle, tendon, ligaments, and nerves, resulting from repetition, excess force, poor postures, inadequate rest, vibration, cold and hot temperatures, etc.

cumulative trauma disorders ***(CTDs)***
see repetitive strain injuries.

carpal tunnel syndrome occurs when the median nerve and blood vessels that run through the carpal tunnel, a small opening inside the wrist, are compressed. Compression can come from a swollen tendon or tendon sheath. The opening can also be reduced if the wrist is flexed, extended, or deviated sideways.

Symptoms include pain, numbness, tingling sensations, and weakness in the palm and in the thumb, index and middle fingers. Sharp pains radiating through the neck are frequently reported in advanced cases.

force the rate of change of momentum. When the mass of an object is constant, force = mass x acceleration. The international standard unit of force is the Newton:

$$1\ \text{N} = \frac{(1\ \text{kilogram} \times 1\ \text{meter})}{1\ \text{second}^2}$$

Many historically acceptable units exist, such as the pound-force (lbf) and kilogram-force (kgf). To convert between units, use the following relationships:

1 lbf = 4.448 N 1 kgf = 9.807 N

ERGONOMICS

The Occupational Safety and Health Administration (OSHA) defines ergonomics as "the science of fitting a job to the worker."[1] More broadly defined, ergonomics is a science that explores human abilities and limitations, and applies that knowledge to improve people's interactions with their environments, tools, products, and practices.

Importance

The application of good ergonomic principles improves efficiency, alleviates physical and psychological stress, and reduces risk of injury. However, when ergonomic principles are not considered, and a mismatch exists between a person's physical abilities and an element of their work, such as a tool, practice, or environmental condition, injuries – musculoskeletal disorders – result.

Musculoskeletal disorders, also known as cumulative trauma disorders and repetitive strain injuries, are injuries to muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs, resulting from repetition, excess force, inadequate rest, vibration, poor posture, etc. They do not include acute traumas such as bone fractures, lacerations, and burns, associated with slips, falls, electrical shock, fires, etc.

Pain

The effects of the pain and cost of musculoskeletal disorders are substantial. Although most people can and do work while experiencing pain (i.e., headaches, muscular aches and inflammation, etc.) their productivity suffers. Because pipetting is a highly technique dependent activity, especially with low volume pipettes, any change in a person's ability to repeatedly perform the pipette cycle may affect their accuracy and precision. For example, pain may force a scientist to sporadically change their pipetting rhythm, the pressure they apply to the pipette plunger, or their ability to draw and deliver a complete sample. All of these factors affect precision and accuracy.

Pain experienced from work-related injuries usually continues after the work-day is complete. Hence, hobbies and other everyday activities are negatively affected by injuries and pain experienced at work. Furthermore, those activities contribute to the severity of the injury.

Additional pain can be created by the corrective measures (physical therapy, surgery) used to remedy the physiological problem. Unfortunately, some injuries are so severe that permanent damage, pain, and disability are experienced.

Cost

OSHA reports that each year 1.8 million workers in the U.S. experience musculoskeletal disorders. One-third of the injuries are serious enough that the worker misses work. Furthermore, one-third of all workers' compensation costs are due to musculoskeletal disorders, which account for more than $15 billion per year in compensation claims. The total costs of these injuries add up to about $50 billion per year.[1]

European countries report significant costs associated with work-related upper limb musculoskeletal disorders. For example, those injuries resulted in 5.5 million lost working days in Great Britain.[8] The Health and Safety Executive in Great Britain estimated the cost of those injuries to be approximately £1.25 billion per year.[5] The cost of these injuries in Nordic countries is estimated to be between 0.5% and 2% of those countries Gross National Product.[5]

PIPETTING INJURIES

Several of the most common injuries are briefly described in Table 1. Muscle fatigue in the thumb and forearm is typically reported as one of the first symptoms. Pain, inflammation, weakness, and rigidity (locking) in the thumb, wrist, forearm, or elbow are also commonly reported. Other symptoms include numbness, tingling, burning sensations, and sharp pains in the thumb, fingers, elbow, neck or shoulder. While most injuries are temporary, some, such as Carpal Tunnel Syndrome, may be permanent.

INJURY DEVELOPMENT STAGES

While the onset of musculoskeletal disorder symptoms can be either gradual or sudden, severe injuries generally do not appear suddenly. The symptoms develop progressively. Three stages of the disorder are frequently identified.[9]

Stage 1

Minor aches and pain are experienced while performing a task. The pain goes away given a break and at night. Generally, no reduction in productivity is noted. (Note, however, that the accuracy and precision of a low-volume pipette are very dependent upon technique. Even a minor change in technique because of temporary pain may impact results.) The condition may persist for months, but is reversible. Ergonomic methods can be used to reverse stage 1.

Stage 2

Symptoms begin early and last well past cessation of the activity and may disturb sleep. The capacity to perform the repetitive activity is reduced. Conditions can persist over months and medical intervention is often needed.

TABLE 1: PIPETTE-RELATED INJURIES		
POSSIBLE CAUSE/PIPETTING ACTION	**SYMPTOMS**	**INJURY**
Tip insertion and using wrist movements to manipulate the pipette.	Pain and inflammation in the wrist and elbow.	**Tendinitis** inflammation of the tendon.
Gripping the pipette tightly and performing repetitive and forceful plunger and tip ejection activities with the thumb.	DeQuervain's—pain on the thumb side of the wrist; thumb may be tender to touch and a small knot may be felt; the thumb may lock in position when bent. Trigger Finger/Pipettor's Thumb—pain where the finger or thumb joins the palm; swelling; finger or thumb lock in position while being extended.	**Tenosynovitis (paratenonitis)** inflammation of the sheath that surrounds a tendon. Specific forms: DeQuervain's Trigger Finger Pipettor's Thumb
Flexing, extending, and rotating the wrist while pipetting, and inserting and ejecting.	Weakness in the hand; numbness or tingling in the; thumb and index and middle fingers; numbness or tingling of the palm of the hand; tips.wrist pain; reduced finger and thumb movement; sharp, radiating, pain from hand to elbow or neck.	**Carpal Tunnel Syndrome** compression of the median nerve and vessels running through the carpal tunnel in the wrist.
Tip insertion and extension of the pipette away from the body.	Elbow pain that gradually worsens; pain radiates to the forearm and back of the hand when grasping or twisting; weakened grip; pain when the tendon is gently pressed near where it attaches to the upper arm.	**Tennis elbow (epicondylitis)** inflammation of the muscles of the forearm, or their tendons near their origin on the bone of the upper arm.
Resting the elbow on a hard lab bench while pipetting.	Numbness or tingling in ring and little finger; loss of finger and hand strength, inability to straighten fingers; sharp sudden pain when elbow is touched.	**Cubital Tunnel Syndrome** compression of the ulnar nerve in the cubital tunnel in the elbow.

Stage 3

Symptoms are experienced almost all the time, with even non-repetitive movements being painful. Productivity is severely limited and frequently ceases completely. Long-term damage is possible and medical attention is necessary.

An understanding and application of ergonomic principles to work-place environment, techniques, and tools can reduce and even remove the risk of progressing through the stages of a disorder. Solutions to these problems, though, can only be found through an understanding of the risk factors that lead to injury. The next section focuses on pipetting risk factors.

PIPETTING RISK FACTORS

Risk factors are conditions that increase the possibility of injury. Some of the most common risk factors leading to musculoskeletal disorders are listed below.

- Repetition
- Force
- Posture
- Vibration
- Temperature

While evidence connects individual risk factors to the development of musculoskeletal disorders in the upper limbs, strong evidence exists that combinations of risk factors increase the risk of injuries common to pipette users, such as Carpal Tunnel Syndrome, tendinitis, and elbow injuries.[3] Specifically, the combination of repetitive and forceful activities is responsible for those types of injuries.[9]

Repetition

Activities requiring repetitive contractions of muscles and tendon movements are known to be a causative factor for upper limb and neck injuries.[9] Pipetting is one of the most repetitious activities in laboratories.[7] One study reported that laboratory technicians at the U.S. National Institute of Health performed between 6000 and 12,000 pipetting activities per day.[10] As stated earlier, an average of nearly 500 hours per year of pipetting activities were reported by Bjorksten, where more than 300 hours were shown to lead to increased risk of injury.[4]

Force

Many of the forces used to grip a traditional pipette, mount traditional tips, aspirate and deliver a sample, and eject the tip exceed safe levels.

What are safe levels? To determine a safety threshold, the maximum and sustainable strength capacities of men and women must be identified. The maximum strength capacity for thumb-pinching and squeezing activities is reported to be 5 to 7 kgf for women and 10 kgf for men.11 A dynamic activity that requires repetitive or sustained exertion of more than 20% to 30% of the operator's maximum strength capacity should be avoided to reduce the risk of injury.6, 9 Using 30% as an upper limit, the average woman and man should avoid sustained activities that exceed 2.1 kgf and 3 kgf, respectively. Static activities (i.e., gripping and holding) should not exceed 15% of maximum capacity.9 Hence, forces greater than 1.1 kgf for women and 1.5 kgf for men should be avoided during static activities. Table 2 summarizes average strength capacities for thumb-pinching and squeezing activities required during the operation of a traditional mechanical pipette.

TABLE 2: THUMB-PINCHING STRENGTH CAPACITIES

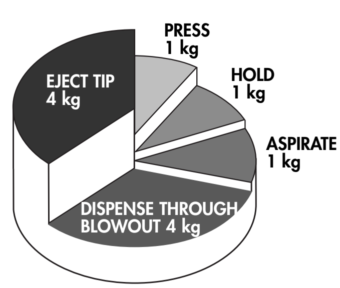
	% of Maximum Strength Capacity	Force (kgf) Men	Force (kgf) Women
Maximum Strength	—	10	7
Dynamic Forces	30%	3	2.1
Static Forces	15%	1.5	1.1

How do these limits compare to the thumb-pinching and squeezing activities found in the pipette cycle? A brief overview of a pipetting cycle will provide an answer to these questions.

Traditional Pipette Cycle: Force and Repetition

A complete pipetting cycle consists of several activities as shown in Figure 1. Note that dispensing a sample through blowout and ejection of the tip each exceeds recommended maximum strength capacity for dynamic forces for men and women. The "Hold"

FIGURE 1



position also comes close to matching the maximum strength capacity for static forces.

The values shown in Figure 1 and discussed below were measured from traditional 200 µL manual pipettes. Larger volume pipettes, i.e., 1000 µL, require even higher forces to operate, elevating the risk of injury.

Sample Aspiration

Aspiration of the sample into the tip requires the following steps and corresponding forces:

- The plunger is pressed to the first stop using 1 kgf. (dynamic)
- The plunger is held in the depressed position about 1 kgf, while the tip is placed in the sample. (static)
- The plunger is slowly extended to its original position, drawing sample into the tip. This action requires 1 kgf. (dynamic)

Sample Delivery

Forceful activities are observed during sample delivery:

- The plunger is pressed through the first stop to the end of the second stop, a stage known as "blow-out," to dispense sample residuals: blowout requires 4 kgf. (dynamic)
- The plunger is returned to the fully extended position. (dynamic)

Tip Mounting and Ejection

An average of 5.5 kgf is needed to seal a tip onto a traditional pipette shaft. Tip mounting techniques vary greatly from user to user. Some people only press the pipette into the tip, while others press and rotate the pipette with their wrist. Others seal tips onto shafts by finger-tightening them. Application of several, sharp, pounding (hacking) motions is another very common method.

While the entire arm and body-weight are used to insert the pipette shaft into the tip, only the thumb is used to eject the tip on pipettes that have thumb ejection buttons. When 5 kgf is used to mount tips, ejection forces average about 4 kgf. Greater insertion forces result in higher ejection forces. Over 10 kgf for ejection are regularly observed when pounding and finger-tightening methods are used.

Grip

For a pipette without a fingerhook, the force used to grip a pipette must be greater than any force exerted on the pipette, otherwise the pipette would move or fall from the hand.

Additional Factors

Although not within the scope of this paper, a number of other factors are frequently present (such as poor lighting, stress, inadequate sleep, etc.), which further elevate the risk of injury.

PREVENTION

Both the pain and cost of workplace injuries can be reduced through preventive measures. More than 90 studies of ergonomic programs showed a 70% decrease in musculoskeletal disorders.[1] Ergonomic programs include education about sound ergonomic practices, and integration of ergonomic environments and tools.

PRACTICES

At the center of almost every ergonomic program that targets physical activities is one principle: proper posture. Briefly, proper posture is achieved through maintaining the natural curve of the spine. Hold the shoulders slightly back and level. Ears should line up with the shoulders. The pelvis should be shifted forward so the hips are aligned with the ankles while standing.

Hold objects close to the body and keep work items within easy reach. Eliminate twisting motions and avoid bending at the hips. Lift objects with your back straight and upright using your legs. Lift objects from waist height when possible.

Many other simple practices, once applied, can reduce the risk of pipetting injuries. Vary pipetting activities. Rotate activities between pipetting, keyboard work, and other lab activities to minimize the possibility of repeating the same motions for extended periods. Stretch hands and arms frequently. Grip the pipette lightly and apply only the minimum plunger forces. Avoid pipettes and tips that require high insertion forces. Use the pipette with either hand, if possible. Recognize warning signs. Do not work through pain.

Ergonomic Tools

Finally, reduce the inherent risk of the tool by using pipettes designed with ergonomic features. The next section specifically discusses design characteristics of ergonomic pipettes.

ERGONOMIC PIPETTES

Many tool manufacturers want their customers to believe that if they design a comfortable handle, their tool is ergonomic. Pipettes are tools, and as such, the physical fit of the pipette can improve its fit and feel in the hand of the operator. Several physical features are designed to make the pipette comfortable: reduced handle size, a fingerhook, reduced weight, rounded edges, left and right hand operable. While a comfortable handle plays a role in making a pipette more ergonomic, it does not reduce the main problem of excessive force and repetition. An ergonomic pipette design must integrate features that…

1. reduce tip insertion and ejection forces, and
2. reduce plunger forces.

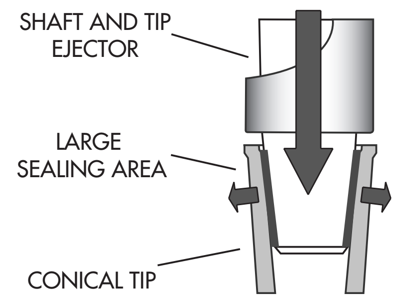
The following sections discuss the reasons for high pipetting forces and solutions that reduce those forces.

Tip Insertion and Ejection Forces

Traditional Shaft-Tip Design

Traditional pipette tips mounted with 5.5 kgf require an average of 4 kgf to eject tips. The high tip (insertion and ejection) forces, which exceed safe levels, are directly due to the traditional shaft-tip design, illustrated in Figure 2.

FIGURE 2



An analysis of the mechanism for mounting and ejecting pipette tips easily explains why almost 40% of the forces exerted during a pipette cycle are from tip ejection:

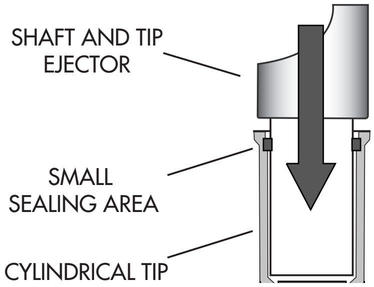
1. A large sealing area between the conical shaft and the tip results in high frictional forces. As the shaft is inserted into the tip, significant contact is made between the two surfaces. The force of insertion causes the tip to stretch to conform to the shape of the shaft, increasing frictional forces.

2. No feedback mechanism alerts the user when the tip is properly sealed. Hence, many people exert more force then necessary and over-insert the shaft into the tip.

LTS™ LiteTouch™ Tip Ejection System

Figure 3 illustrates a cylindrical shaft and tip design, LTS LiteTouch Tip Ejection System which reduces the surface area shared between the tip and shaft without compromising the seal. The LTS tip and shaft are both cylindrical.

FIGURE 3



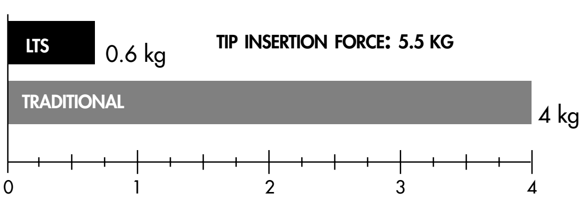
1. A small sealing area efficiently seals the tip to the shaft, greatly reducing the contact surface area.

2. The tip's molded positive-stop, gives the user a clear indication when the shaft rests against it. Hence, over-insertion is not possible even when the shaft is driven into the tip.

The LTS system results in easily loaded tips and dramatically reduced tip insertion and ejection forces.

For example, 5.5 kilograms of force were used to load both traditional and LTS tips in this study. While several kilograms of force are needed to load a traditional tip, LTS tips require less then 1 kgf to load. If more force is used to insert a traditional tip, more force is necessary to eject the tip. An LTS tip ejects with the same low ejection force, no matter how much insertion force is used. Figure 4 shows that only 0.6 kgf is needed to remove a 200 µl LTS tip from an LTS shaft. Nearly 4 kgf is needed to eject 200 µl traditional tips from traditional pipette shafts.

FIGURE 4



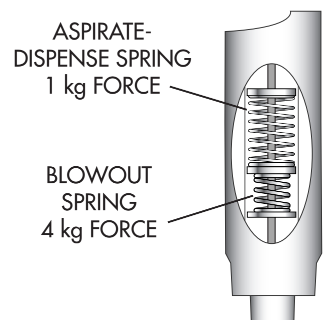
Ejector Shock Absorber

Immediately after a tip seal is broken during ejection, the ejector button suddenly plunges to the end of its travel. Ending a forceful motion abruptly may cause impact stress and strain on the thumb and tendons. Integration of a shock absorber into the tip ejector mechanism, such as those found in the LTS designed pipettes, reduces the severity of that impact.

Traditional Plunger Forces

When using traditional pipettes, dispensing a sample completely requires roughly 4 kgf. High plunger force originates from the compression of two springs, illustrated in Figure 5. The first spring is a light, aspiration-dispense spring that yields to about 1 kg of force. The second spring, also known as the blowout spring, is intentionally designed to resist operator force to enable the operator to find and hold the first stop, between the aspiration and blowout positions.

FIGURE 5: PIPETTE PLUNGER



If both springs were similarly weak, the operator would have difficulty finding and holding the first stop repeatedly, significantly reducing precision and accuracy.

New Technologies Reduce High Plunger Forces

Rainin developed three technologies that reduce plunger forces without sacrificing precision, accuracy or pipette durability. Pipet-Lite™ pipettes reduce plunger forces in a classically styled pipette. Pipet-Plus® pipettes reduce plunger forces, eliminate activities, and divide the operational mechanism between the thumb and fingers. EDP3™ electronic pipettes eliminate thumb-actuated plunger motions and increase accuracy and precision. Each pipette also features LTS LiteTouch Tip Ejection System, significantly reducing tip insertion and ejection forces.

***Pipet-Lite*™**

Pipet-Lite pipettes with Magnetic Assist operate like traditional air-displacement pipettes. However, aspiration and blowout forces are greatly reduced because weaker aspiration and blowout springs are used. Accuracy, precision, and durability are maintained, even improved, because a magnet is integrated into the plunger motion to help the user find and hold the first stop. Pipet-Lite's aspiration stroke needs 0.5 kgf and blowout uses 1.7 kgf, compared with 1 kgf aspiration and 4 kgf blowout activities of the traditional pipette. Thumb-strain is further reduced by the shortened plunger stroke.

Combined with LTS tips, which require 0.6 kgf to eject, Pipet-Lite yields an average force reduction of 65% over traditional pipettes.

Rainin Pipettes Reduce Plunger Activities

***Pipet-Plus*®**

Traditional pipetting mechanisms require several thumb-actuated plunger activities, not including tip insertion or ejection: depress plunger, hold, aspirate, dispense through blowout. Because force and repetition increase risk of injury, elimination and division of activities is advantageous. Rainin eliminated plunger activities and reduced the remaining plunger forces with Pipet-Plus pipettes with Latch-Mode™ technology.

Furthermore, Pipet-Plus pipettes divide the remaining two activities (dispense and aspirate) between the thumb and fingers. The thumb depresses the plunger during the first activity, simultaneously dispensing the sample completely and resetting the pipette for aspiration. Only 1.0 kgf is measured for this activity in a 200 µl model. The heavy blowout spring is completely removed. A magnet latches the plunger in place, securing it in the same position every time. User error, associated with finding and holding the plunger at the first stop, is eliminated. Requiring only tenths of a kilogram of force, a finger triggers aspiration, the second activity. Once triggered, aspiration is automatic; the speed controlled via an aspiration rate controller.

Pipet-Plus with LTS tips reduces forces by 85% over traditional pipettes.

Rainin Electronic Pipettes

***EDP3*™**

Rainin introduced the world's first electronic pipette in 1984. Weighing only 150 grams—similar to many mechanical pipettes—Rainin's latest electronic pipette, EDP3, virtually eliminates all user-experienced plunger forces. EDP3 incorporates technologies that enhance performance and productivity through ease of use, programmability, and reproducibility. When combined with the LTS system, EDP3 pipettes require 95% less force than traditional pipettes.

Figure 6 compares the forces necessary to complete one pipetting cycle using a traditional 200 µL pipette to Pipet-Lite, Pipet-Plus and EDP3 pipettes. Tip insertion is not included. However, several kilograms of force are required for tip insertion using traditional pipettes, while less than a few kilograms of force is needed for pipettes with LTS, Lite-Touch system. It is clear that Pipet-Lite, Pipet-Plus and EDP3 with LTS can greatly reduce pipetting forces, diminishing the risk of injury from pipetting.

FIGURE 6

FORCE (kg)	PIPETTE: TRADITIONAL PIPETTE	PIPET-LITE™	PIPET-PLUS®	EDP3™
EJECT TIP	3.9 kg	0.6 kg	0.6 kg	0.6 kg
DISPENSE THROUGH BLOWOUT	4.1 kg	1.7 kg	1 kg	-----
ASPIRATE	1 kg	0.5 kg	-----	-----
HOLD	0.9 kg	0.5 kg	-----	-----
DEPRESS	0.9 kg	0.5 kg	-----	-----
TOTAL	10.8 kg	3.8 kg	1.6 kg	0.6 kg

CONCLUSION

The pipette is an indispensable tool in the laboratory. As with any tool that requires repetitious application of force, work-related musculoskeletal injuries are frequently observed. Unfortunately, many laboratory personnel are unaware of the daily and cumulative risk they take. Remember, you are at risk if you pipette regularly for more than one hour per day with a traditional pipette.

The risk of injury can be greatly reduced through prevention, including improved pipetting practices and the use of ergonomically designed pipettes. An ergonomic pipette must offer more than just a comfortable handle to offer much relief. To reduce the risk of injury, an ergonomic pipette must also reduce the pipetting forces and number of pipetting activities.

RAININ's Pipet-Lite, Pipet-Plus, and EDP3 pipettes with LTS LiteTouch Tip Ejection System offer a full range of ergonomic solutions. They reduce the risks of injury from force and repetition, while maintaining the highest standards for performance, reliability, and durability.

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