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Ergonomics of Bread Making Tools – A Review

P. Rajya Lakshmi[1], Dr. D. Ratna Kumari[2]

[1]H.No-10-8, P & T Colony, Dil;sukhnagar, Hyderabad, Telangana, India

[2]Department of Resource Management and Consumer Science, College of Home Science
Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana, India

Abstract: ***The most common activity in all homes is cooking. The diet consciousness of people in the present days has lead to an increase in Indian bread consumption irrespective of region. Indian breads made of wheat flour and served hot at breakfast, lunch or dinner, and are eaten with dry and semi liquid vegetable preparations, as well as with gravies and other adjuncts. Women spend most of their time in this activity. Indian bread making tools aid to perform this job safely, efficiently and comfortably even in adverse working conditions reinforcing strength and effectiveness of hands. Different varieties of Indian bread include: Chapathi, puri, phulka, roti,*** **parotta,** ***bathura and naan are the main traditional products which form the staple items in the diet of the majority of the population. The common tools used in Indian bread making are the Rolling board and Rolling pin, which are available in a variety of materials and sizes. In India these are must-haves in the kitchen. The review was collected and ergonomically designed tools should be of high quality, lightweight and the heavy weight tools should be suspended or counterbalanced. The handles should be of the correct size to allow control and comfort: the tool should be bent, not the wrist, and the tools should be of firm grip so as to use less energy and be less likely to slip. All of these factors should be considered when choosing or recommending the best adaptive tools.***

Keywords: Posture, Anatomy, Grip strength, Palm Index, Heart Rate

1. Introduction

Indian bread making tools come under the major section of hand tools as classified based on purpose by Frievalds (1997). A hand tool can be defined a metal instrument held in hand and used for preparing and repairing (Oxford dictionary, 2004); or a device used to perform or facilitate manual or mechanical work and an aid necessary for carrying out one's occupation or profession (Lifco dictionary, 2004). The common tools used in Indian bread making are the Rolling board and Rolling pin, which are available in a variety of materials and sizes. Indian breads are rolled out on a rolling board with the help of a rolling pin. In India these are must-haves in the kitchen. A rolling pin which is also known as belan is a cylindrical food preparation tool used to shape and flatten dough. A rolling board which is also known as chakla is an Indian kitchen tool (Heloise, 1963). It is a flat, usually circular board used for rolling kneaded dough into chapatis. Thomson (1978) in the study "Rolling pin construction" mentioned that the rolling of pastry crust is in fact an accelerated flow procedure, the dough acting as a plastic or extremely viscous and somewhat elastic liquid. A wide range of dough is known, from very rich pastry dough to self-rising and yeast dough. It is vital that the dough does not stick to the pin and board when rolling. Dough sticking to the pin has many disadvantages. Although in recent years the use of modern gadgets and appliances have apparently simplified the methods of performing many activities but on the other hand it has brought in several ergonomic issues towards health and safe working performance of the user. While doing any work, different undesirable and un-ergonomic tools to which people become adaptable that effect their health and psychology. To avoid such hazards ergonomic evaluation of hand tools is necessary. Ergonomic evaluation of tools which is the study of anatomical, physiological and psychological aspects of man and tools with the object of performing a task safely, comfortably and efficiently to enhance productivity (Greenberg & Chaffin, 1997). It is needed for all the tools used in Indian bread making to reduce the effort. So, there is a need to consider the methods of evaluation for Bread making tools accordingly the review was collected.

2. Ergonomics of Bread Making Tools

It is important to understand the efficient development of hand tools considering the guidelines and principles of designing the tools. Information about the anatomy of the human hand, it's functioning, problems and diseases faced regarding the wrong postures of the hand and ill design of tools is also necessary to undertake any research related to hand tools and its effects on the user.

2.1 Anatomy of hand
2.2 Ergonomics of hand tool design

2.1. Anatomy of Hand

Hands are the chief organs for physically manipulating the environment, used for both gross motor skills (such as grasping a large object) and fine motor skills (such as picking up a small pebble). The fingertips contain some of the densest areas of nerve endings on the body, are the richest source of tactile feedback, and have the greatest positioning capability of the body; thus the sense of touch is intimately associated with hands. Like other paired organs, each hand is dominantly controlled by the opposing brain hemisphere, so that handedness, or the preferred hand choice for single-handed activities such as writing with a pen, reflects individual brain functioning. (Taehyun et al. 2006)

Human hand is a complex structure of bones, arteries, ligaments and tendons (Figure 1). The extensor carpi and flexor carpi muscles in the forearm control the fingers. The muscles are connected to the fingers by tendons which pass through a channel in the wrist, formed by the bones of the back of the hand on one side and the transverse carpal ligament on the other. Through this channel, which is called the carpal tunnel, pass various arteries and nerves. The bones of the wrist are connected to two long bones in the forearm, the ulna and the radius. When the hand is in its 'palms up' or supine position these two bones are parallel. As the hand is turned into 'palms down' or prone position, the lower end of the radius rotates about the axis of the ulna and the shafts of the two bones cross. Then the movements of pronation and supination occur at the two articulations between the radius and ulna rather than at the wrist as such. The radius connects to the thumb side of the wrist and ulna connects to the little finger side of the wrist. The orientation of the wrist joint allows movement in only two planes, each at 90o to the other. The fist gives rise to radial deviation. The ulna and radius of the forearm connect to the humerus of the upper arm (Nevalapuranen and Sorensen, 1997)

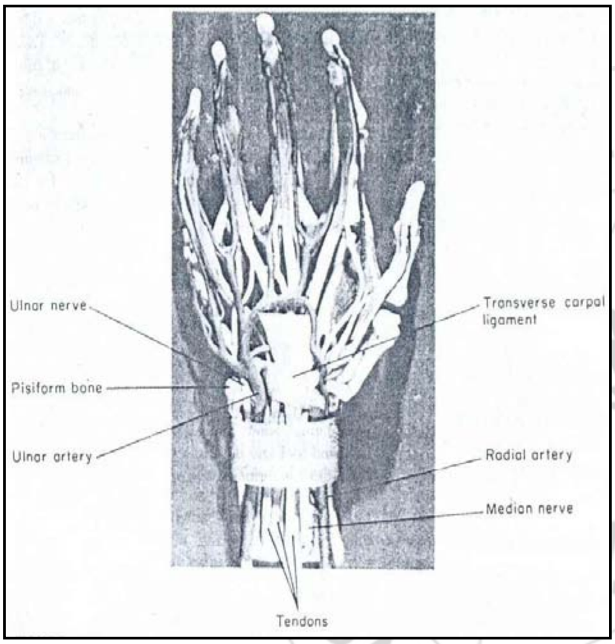

Figure 1: Anatomy of hand

Anatomists have made a number of attempts to classify the infinite variety of actions of which the human hand is capable. The most basic distinction is between gripping actions of various kinds, and non-gripping actions (such as poking, pressing, stroking, slapping, rolling etc.). In a gripping action, the hand forms a closed kinetic chain, which encompasses the object in question.

2.2. Ergonomics of hand tool design

Over the centuries human have used tools to accomplish a variety of objectives typically related to home, agriculture and industry. Many of these tools have incorporated folk norms and evolved into fairly efficient instruments. Others have remained virtually unchanged for centuries. To be functional and effective the tools should be designed with the full operational system, including the human and its capabilities and limitations, in mind.

Hand tools have been in use perhaps a million years, but their design progressed only gradually. The design of some basic tools, such as kitchen tools, screw driver, hammer and pliers changes very slowly.

Ergonomics is the study of work in relation to the environment in which it is performed (the workplace) and those who perform it (workers) (Singh S, 2007). It is used to determine how the workplace can be designed or adapted to the worker in order to prevent a variety of health problems and to increase efficiency; in other words, to make the job fit the worker, instead of forcing the worker to conform to the job. One simple example is raising the height of a work table so that the worker does not have to bend down unnecessarily to reach his or her work. A specialist in ergonomics, called an ergonomist, studies the relation between the worker, the workplace and the job design.

As Dul and Weerdmeester (2001) state in the reference guide: "Ergonomics aims to Design Appliances, Technical Systems and Tasks in such a way as to improve human safety, health, comfort and performance". Effectively, this involves adapting the man-made elements (tools) needed for occupation to the biomechanics of the man. This would require that tools put the least amount of stress on the integrity of the skeletal and soft tissue structures of the user, whilst still providing the means to accomplish the goal.

Physical factors to be taken into consideration in developing new handle models were described by Manlai et al. (2009):

1) The major muscles which flex the fingers and generate grip force are located in the forearm. These muscles have long tendons which span the wrist joint. Thus, the gripping capability of the fingers is affected by the position of the wrist (Winston and Narayan, 1993). According to Tichauer (1976) suggestion, continued use of hand tools with the wrist in a bent position can cause inflammation, chronic pain, and possible permanent injury both to the synovial sheaths protecting the tendons of the wrist and to the median nerve passing through the wrist.
2) For greater comfort of use and less stress, the tool handle should be oriented so that, while working, the hand and the forearm should be aligned to avoid ulnar or radial deviation. Deviations of the wrist from the neutral position under repetitive load can lead to a variety of cumulative trauma disorders as well as decreased performance. If a tool has a short handle that does not span the breadth of the palm, high forces can be created at the center of the palm. Thus, the tool handle should be designed to extend beyond the hand when gripped (Winston and Narayan, 1993).
3) Freivalds (1987) summarizes the results from some experiments of handle diameter, and suggest that the handle diameters should be in the range of 31-51mm with the upper end best for maximum torque and the lower end for dexterity and speed.

The cross-sectional configuration of the tool handle directly affects the operator's performance and health. The forces generated during use should be distributed on as large a pressure area of the palm as possible (Winston and Narayan, 1993).

Hand tools are ubiquitous and they are integral to our daily routines. Sperling et al. (1993) prepared a useful framework for the work environment variables that affect the design and operation of a hand tool. The framework identifies four sets of variables that define the context for the use of a hand tool. They are: -

- User characteristics
- Work place
- Work organization
- Hand-operated device

Sperling *et al*. (1993) also designed a useful cube model for hand tools that categorizes the tools in terms of three dimensions:

- Time – How frequently the hand tool need to be used
- Force – Whether a low or high degree of force needs to be applied to operate the tool.
- Precision – Whether a low or high degree of precision is needed when using the tool.

Workers in the stream of agriculture, industry and homemakers in kitchens make more use of the hand tools and the ill designed tools can adversely affect the user work performance and lead to the increase in the cause of accidents and injuries. As mentioned earlier the hand tools have being used for 4000 million years and the design is being progressed gradually. Whereas some basic tools like screw drivers, hammers, pliers, kitchen tools etc., the design is being progressed slowly as much importance had not been given to these hand tools when compared to the present development of technology and generation.

2.2.1. Factors Causing Musculo Skeletal Stress (Balges and Kreiger, 2000)

The design of some basic tools, such as the screwdriver, pliers, rolling pins, rolling boards, tongs and knives change gradually. It is undesirable since hand tools place much physical stress on the hands, wrists and arms. Tool geometry should be determined by hand anatomy and task design.

- Ulnar or Radial deviation of the wrist: Ulnar deviation, also known as ulnar drift, is a hand deformity in which the swelling of the metacarpophalangeal joints (the big knuckles at the base of the fingers) causes the fingers to become displaced, tending towards the little finger. Its name comes from the displacement toward the ulna (as opposed to radial deviation, in which fingers are displaced toward the radius). Ulnar deviation is likely to be a characteristic of rheumatoid arthritis, more than of osteoarthritis. Ulnar deviation is also a physiological movement of the wrist, where the hand including the fingers move towards the ulna. Ulnar deviation is a disorder in which flexion by ulnar nerve innervated muscles is intact while flexion on the median nerve side is not.

- Palmar flexion or Extension of wrist: Palmar flexion is one of the movements of the wrist and hand which takes place at the wrist joint, where the angle between the palm and the forearm is decreased. The opposite of this is dorsiflexion or extension, where the angle between the back (dorsum) of hand and the forearm is reduced.

- Grip Strength: Grip strength is reduced with any flexion or deviation of the wrist, particularly for palmar flexion. Flexed wrist postures reduce the area of the carpal tunnel potentially increasing the pressure in the tunnel with a concomitant increase in the risk of Carpal Tunnel Syndrome (CTS) (Skie *et al.* 1990; Armstrong *et al.* 1997)

- Tool Handles: To avoid tissue compression stress in the hands, handles should provide as great a force-bearing area as practicable and should be free from sharp corners and edges. This means handles should be either round or oval. A compressible gripping surface is best. Handles should at least have a high coefficient of friction in order to reduce the hand gripping force needed for tool control. Tools should be designed to not place constant pressure particularly on the radial and ulnar arteries.

- The Hand as a Tool: Hand has obvious manipulation skills whenever frequent finger forces exceed about 10N. Physical fatigue and injury can result if frequent hand forces exceed 50N approximately. The palm of the hand should be never used as a tool. Even light tapping with the heel of the hand if done frequently, can injure the nerves, arteries and tendons of the hand and wrist. In addition shock waves can travel up the arm to the elbow and shoulder, causing additional physical problems.

- Repetitive finger action: If the index finger is used excessively for operating triggers on hand tools, excessive local fatigue can result, and a condition sometimes referred to as trigger finger develops. This condition occurs most frequently if the tool handle is so large that the tip of the finger has to be flexed while the middle of the finger must be kept straight. It may also occur with smaller handles.

- Two-handed tools: The handles for two handled tools should be designed to achieve maximum grip strength. Grip strength and the resulting stress of finger flexor tendons vary with the size of the object being grasped. A maximum grip strength is achieved at about 45-80mm. The smaller values of 45-50mm were obtained on a dynamometer with parallel sides (Phesant and Scriven, 1983), whereas the larger values of 75-80mm were obtained on a dynamometer with handles angled inwards.

- Hand and Arm vibration: Vibration of the upper limb, as in the operation of hand power tools can be a continuing source of pain and physical trauma. While not all workers exposed to vibratory hand tools experience trauma, there is a relevant set of symptoms and diseases collectively referred to as hand-arm vibration syndrome.

2.2.2. Proper Working Height and Location:

The appropriate positioning of hand tools with respect to the worker can minimize muscle stress and fatigue and improve productivity. In general the heavier the work, the lower the work surface should be, without causing flexion of the trunk or other awkward postures. A fundamental requirement for all hand tools is that a grip surface needs to be provided. A well-designed tool should achieve the following: (Stanton, 1998).

- The tool should be shaped to avoid extremes of wrist deviation
- The tool should be shaped to assist the grip
- Use universal designs that can accommodate ambidextrous operation

- Use designs that minimize shoulder abduction away from the body during normal tool use.
- Design to reduce hand tool weight and to ensure that the center of gravity passes through the grip.

Putz Anderson (1998) indicated the principles for good ergonomic design which rest on five fundamental requirements that apply to any hand operated device. These requirements are that to the extent that is practicable, the device should-

- Minimize high grip surface contact forces
- Minimize static postural loading and pinch points when using the device
- Minimize awkward joint position and maximize neutral postures
- Minimize repetitive forceful finger action with the hands in a deviated posture
- Minimize the extent to which the device vibrates the load.

According to Pheasant (1991) guidelines for handle design are:

- Force is exerted most effectively when hand and handle interact in compression rather than shear. Hence it is better to exert a thrust perpendicular to the axis of a cylindrical handle than along the axis.
- All sharp edges or other surface features which cause pressure hot spots when gripped, should be eliminated. These include:
- Handles of circular cross section (and appropriate diameter 30-50mm) will be most comfortable to grip.
- Surface quality should neither be so smooth as to be slippery nor be so rough as to be abrasive.

Bernard (1921) said that in order to make breads, biscuits, the flour was mixed with shortening and this shortening was rubbed into the flour before any liquid was added the material cannot be properly worked on the rolling board and with the rolling pin, and more flour must be added. The more of dry flour which was added after the dough was mixed, the heavier and soggier will be the breads, biscuits when cooked or baked. The wetter the dough is the more liable it is to stick to the rolling pin and the board but Glen (1966) patented that too much flour on the pastry board does not only help but as a matter of fact tends to make a tough crust. It is generally conceded that to have flaky pastry one must not handle the rollable dough any more than is absolutely necessary.

Sjoberg (1999) said that there is a need for an improved apparatus and method of maintaining pastry dough chilled during the rolling process. The pastry dough is rolled on a conventional rolling board whose temperature is close to the ambient room temperature. When pastry dough is rolled in the typical manner, heat absorbed by the pastry dough from the rolling pin, rolling board and handling of the dough throughout the rolling process heats a shortening, or fat, ingredient in the dough, causing sticking. It is possible to reduce sticking by applying excess flour to the conventional rolling board and rolling pin, this can have adverse consequences for the final pastry product.

Dua *et al.* (2010) in mentioned that the most important use of a rolling pin is for rolling dough for making pastries etc. It is vital that the dough does not stick to the pin when rolling. Dough sticking to the pin has the following disadvantages.

- It takes more time to complete the job and therefore is less efficient.
- Before and during rolling. flour must be added to the dough and rubbed on the pins to help prevent the dough from sticking. This changes the texture of the dough.
- When the dough sticks to the pin it is needed to be removed, the weight distribution of the dough becomes inconsistent, thereby creating uneven thicknesses and therefore uneven temperature when baking, so that some parts become crisper than others. It would be desirable to develop an improved rolling pin and rolling board which avoid this disadvantages and allows dough to be rolled more easily than previously.

Researchers opined that the purpose of a handle for the hand tool is to facilitate the transmission of force from musculo-skeletal system of the user to the tool. Handles, which are not shaped to fit the hand properly, or which do not conform to the biomechanics of manual work lead to poor performance and in turn is injurious to the user. The hands and fingers are capable of a wide range of movements and grasping actions, which depend partly on being able to bend the wrist and rotate the fore arm. Designing a hand tool considering its design features is vital to reduce the CTDs along with ergonomically intervention.

2.3 Hand posture and Ergonomics

The posture can be defined as the position in which the body is held (Agan, 1956). Frost, (1944) described a good posture is the posture that avoids strain and develops good body carriage while working. The proper posture helps the user or the workers to maintain balance upon the support that helps in ease of movement of body and its parts during the work which helps in reduction of fatigue for the workers (Munider et al. 2007).

For designing a hand tool with ergonomic consideration, a neutral hand posture and the deviated postures are also to be considered. When the hand is in a neutral posture, the fingers can be extended or flexed. When the hands work in a neutral posture, it minimises the risk to the hand or the wrist. The range of wrist movement between 20o extension and 20o flexion is called the sector of maximal utility, and in this range there is minimal pressure on the articular surfaces in the wrist and the ligaments remain slack (Kapandji, 1992). Pressure changes within the carpal tunnel show a curvilinear relationship between vertical extension/ flexion hand movements and Carpal Tunnel Pressure (CTP) increases (Rempel et al. 1994; Rempel and Horie, 1994).

Sustained increases in CTP above 30mmHg are undesirable because they may affect functioning of the median nerve. Whenever the wrists are flexed or extended beyond 20o, CTP exceeds 40 mmHg The lowest CTP occurs in the range of 0-15o wrist extension (Gelberman et al. 1994).

A neutral zone of hand movement can be defined which is bounded by 15-20o wrist extension, 20-40o flexion, 20-25o ulnar deviation and 15o radial deviation (Figure 2). Hand movements within this zone produce minimal adverse changes in CTP on articular surfaces during hand activity. Good ergonomic design of any hand tool should allow the user to work comfortably while his or her hands are moving in this neutral range of motion.

Marco Santello et al. (1998) in their study on "Postural Hand Synergies for Tool Use", asked the subjects to posture the right hand as if to grasp and use a large number of familiar objects. The chosen objects typically were held with a variety of grips, including "precision" and "power" grips. Static hand posture was measured by recording the angular position of 15 joint angles of the fingers and of the thumb. Although subjects adopted distinct hand postures for the various objects, the joint angles of the digits did not vary independently. These results suggest that the control of hand posture involves a few postural synergies, regulating the general posture of the hand, coupled with a finger control mechanism providing for small, subtle adjustments.

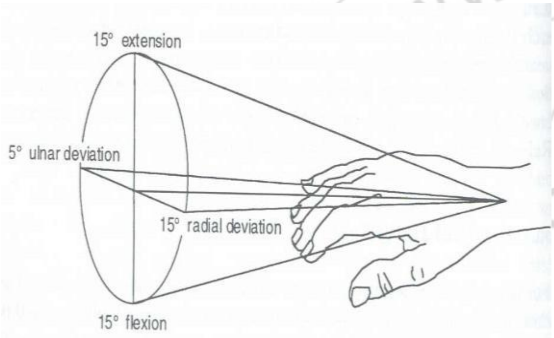

Figure 2: Neutral Zone of Hand Movement

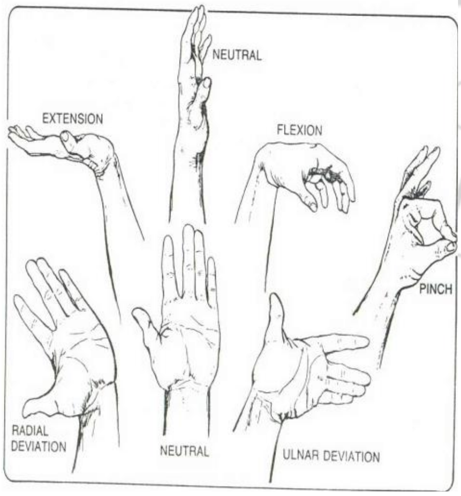

Figure 3: Hand and Wrist Postures

Established anatomy and biomechanical principles assert that in using tools it is important for the hand and wrist to be in a neutral position. Neutral or resting hand position is with the wrist between 12 degrees and 20 degrees of dorsiflexion. Parker and Imbus (1992) stress the importance of avoiding extreme wrist postures, which they define as ulnar deviation greater than 45 degrees from neutral, any amount of radial deviation; palmar flexion greater than 30 degrees and dorsiflexion greater than 15 degrees from neutral.

The review shows that as the hand deviates from the normal position either horizontally towards the thumb (radial deviation) or towards the little finger (ulnar deviation) or vertically up (Extension) or down (Flexion), the pressure in the carpal tunnel increases and accelerations from extension to flexion are thought to pose the greatest risk for carpal tunnel syndrome (Figure 3). For this reason in order to decrease the risk factors and injuries the tools should be designed in such a way that hand movements are in neutral range of movement for physical and biomechanical features of the tools.

The criteria for the design of a hand tool are (Patkin, 1997):

- Product weight should be light, so that it becomes convenient for the person to carry it close to the body with on hand.
- Handles of tools should be designed in such a way that it becomes easier for grasping
- Length of the tool should be convenient to carry.
- For greatest comfort use and least stress, the handles and grasping surfaces should be designed in such a way that the hand and forearm are aligned.
- Grasping surfaces should be slip resistant.
- Edges and corners of the grasping surface should be rounded.
- Protrusions on grasping surfaces should be avoided.

More and more work today is being done by machines. This increase in mechanization and automation often speeds up the pace of work and at times can make work less interesting. On the other hand, there are still many jobs that must be done manually, involving heavy physical strain. One of the results of manual work, as well as the increase in mechanization, is that more and more workers are suffering from backaches, neckaches, sore wrists, arms and legs, and eyestrain.

Lindstrom (1993) in his study 'Modern Pliers' considered four factors relating to the hand in the design of pliers - Size, strength, endurance and working position, he also has taken gender as a criteria. With regard to size he mentioned that longer handles would limit the opening of the tool head. In case of strength, he cited maximum grip strength of 588N for the male dominant hand and 392N for the female (70% of the male strength approximately). The working posture of the hand is extremely crucial since finger flexor muscles cross the wrist and are located in the forearm. Thus when the wrist is flexed, extended or deviated the grip force may reduce as much as 30 per cent.

Hunt (1994) in his study 'A study of screw driver for small assembly work' studied speed of use as a function of handle diameter. The time taken to drive a screw with a 7.6mm diameter handle was 1.9s, while with a 16mm handle it was 3.6s. Thus the smaller the handle diameter the less time was needed for rotation of the handle.

The fish canning industry in Sweden has also been plagued by cumulative trauma disorders (Karlquist, 1994), identified the common straight knives as possible causes for large ulnar deviations. Of the four knives used one was fitted with pistol grip, while others were fitted with larger diameter handles for better balance and movement.

Gulifoyle (1997) in his study 'Look what design has made for the tooth brush' based on time and motion studies, expert opinions and survey on 200 respondents redesigned the common toothbrush using ergonomic principles-a smaller bristle to concentrate brushing action, an angular handle for easier manipulation and a contoured thumb area for comfort were incorporated in the new design.

Chang and Wang (2000) in his study on screw drivers examined maximum torque from a power grip on a screwdriver handle. He investigated different shaped handles of screw drivers and concluded that the best shape was cylindrical with a rounded end. Within the range of diameters used, 18-40mm, an increase in diameter allowed for a greater force production.

Sen (1998) in a study 'Ergonomic design of some tools for maintenance of railway tracks in India' made an attempt to improve and modernize manual maintenance of railway tracks in India through the application of ergonomic principles by modifying the existing designs of tools and equipment to reduce the physiological cost of work, to increase efficiency and productivity and enhance occupational safety and health.

Dhara (2001) in their investigation on agricultural hand tools made efforts to redesign a paddy puller an agricultural hand tool from the ergonomics view point. The hand dimensions of the agricultural workers were taken and they were used to redesign the hand tool. To finalise the handle diameter, handle length and angle between the handle and the blade, paired comparison tests were applied. To evaluate the new hand tool joint angle, productivity tests were done. It has been concluded that the modified hand tool would be suitable for the gathering and shifting of paddy grains and productivity would also be increased.

3. Conclusion

In conclusion, ergonomically designed tools should be of high quality, lightweight and the heavy weight tools should be suspended or counterbalanced. The handles should be of the correct size to allow control and comfort: the tool should be bent, not the wrist, and the tools should be of firm grip so as to use less energy and be less likely to slip. All of these factors should be considered when choosing or recommending the best adaptive tools.

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Author Profile

Mrs. P. Rajya Lakshmi, PG Student of Department of Resource Management and Consumer Science, College of Home Science, Professor Jayashankar Telangana State Agricultural University, Hyderabad.

Dr. D. Ratna Kumari, Professor, Department of Resource Management and Consumer Science, College of Home Science, Professor Jayashankar Telangana State Agricultural University, Hyderabad.