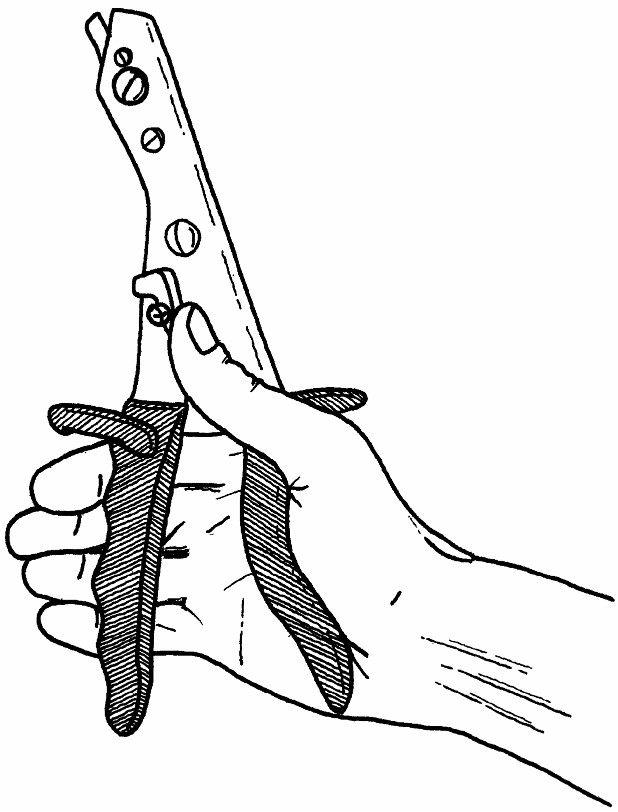
The ergonomics of tools



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Ergonomic improvements

For it to be meaningful to try to improve a tool, it should an improvement potential. The greater the potential for improvements, the more reason to try to improve it. The ergonomic improvement potential could be divided into a number of levels (figure 1).

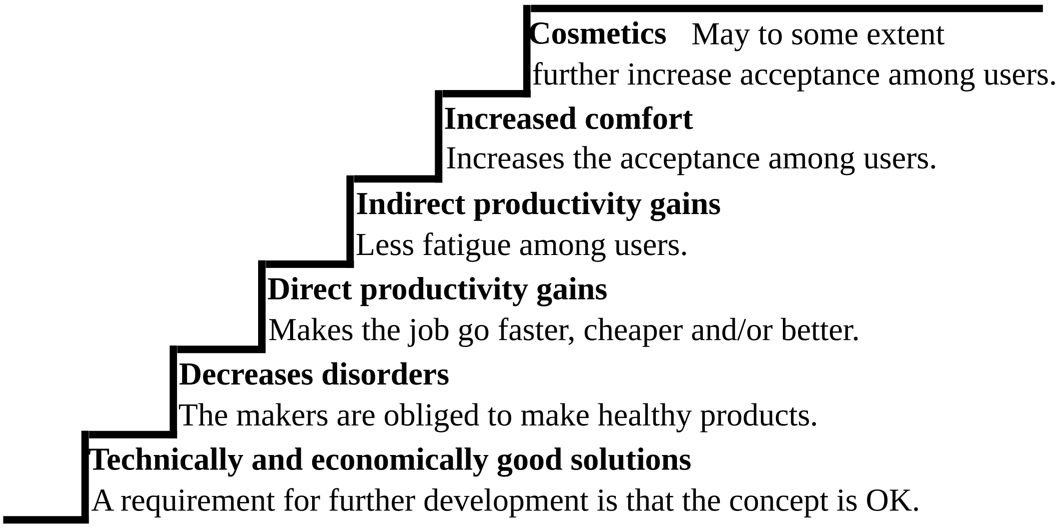


Figure 1. Ergonomic improvements.

Many of our facilities have, during a shorter or longer period, evolved from ergonomically unsound, but working solutions to ergonomic and visually appealing tools. Though there are still those that have, or recently had, great ergonomic improvement potential. Mobile phones, for example, have since the mid 1980ies evolved from ergonomically unsound to ergonomic aids (figure 2).

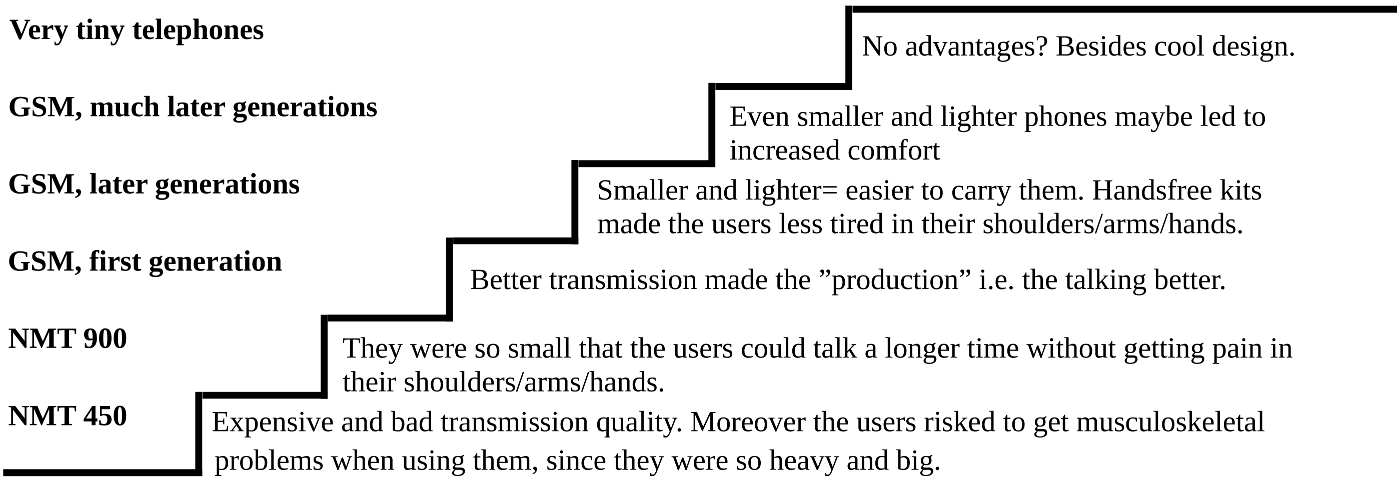


Figure 2. The development of mobile phones from ergonomically unsound but working solutions, to ergonomic and visually appealing solutions.

Musculoskeletal disorders

We still have a rather vague idea about how a vast part of the usual musculoskeletal diseases arise. What we are the least uncertain of are (see also figure 3):

Musculoskeletal disorders in the shoulder/neck

Highly repetitive arm movements, static contractions of neck and shoulder muscles and perhaps prolonged forward bending of the neck, can cause musculoskeletal disorders in the neck-/shoulder muscles (Hagberg M and others 1995). According to the same source frequent work with the arms raised (if it is not supported with an armrest) induces a risk for inflammation in the shoulder muscle tendons. And frequent extreme forward bending of the head may cause neck pain.

Musculoskeletal disorders in the arm, wrist and hand

Repetitive extreme twisting of the wrist (like when you flick off a ball) has traditionally (Putz-Anderson V 1988) been considered to be the primary causative factor for disorders in the tendons at the elbow, known as "tennis elbow". But recent studies (Hägg GM 1997; Hägg GM and Milerad E 1997; Hägg GM, Öster J and Byström S 1996) have shown that prolonged gripping work without passive stabilization of the wrist, also can cause such problems.

Repetitive hand movements, particularly in combination with applying force (as for instance when using a manual staple gun (figure 4)), carries the risk of inflammation in the tendons and/or tendon sheaths in the wrist (Hagberg M and others 1995; Viikari-Juntura E 1997) and Carpal Tunnel Syndrome (CTS) (Hagberg M and others 1995; Viikari-Juntura E 1997). Prolonged severe twisting of the wrist (De Krom MCTFM and others 1990) and vibration increases the risk (Hagberg M and others 1995; Viikari-Juntura E 1997).
If a finger is bent while high pressure is applied on the outermost part, it can cause a problem called "trigger finger" (Tichauer ER and Gage H 1977).
Prolonged use of vibrating hand tools increases the risk of white finger (fingers go numb and turn white in the cold), the problem is called "vibration-induced white Finger" (VWF) (Griffin MJ 1990). High gripping force increases the risk of VWF (Färkkilä M 1978; Gurram R, Gouw GJ and Rakheja S 1993, Hartung E, Dupuis H and M Scheffer 1993). Vibrating hand tools can also cause other problems (Griffin MJ 1990), commonly known as Hand-Arm Vibration Syndrome (HAVS).

Musculoskeletal disorders of the back

Manual material handling, vibrations, frequent forward bending and/or twisting of the spine can cause back pain (Burdorf A and G Sorock 1997; Viikari-Juntura E 1997).

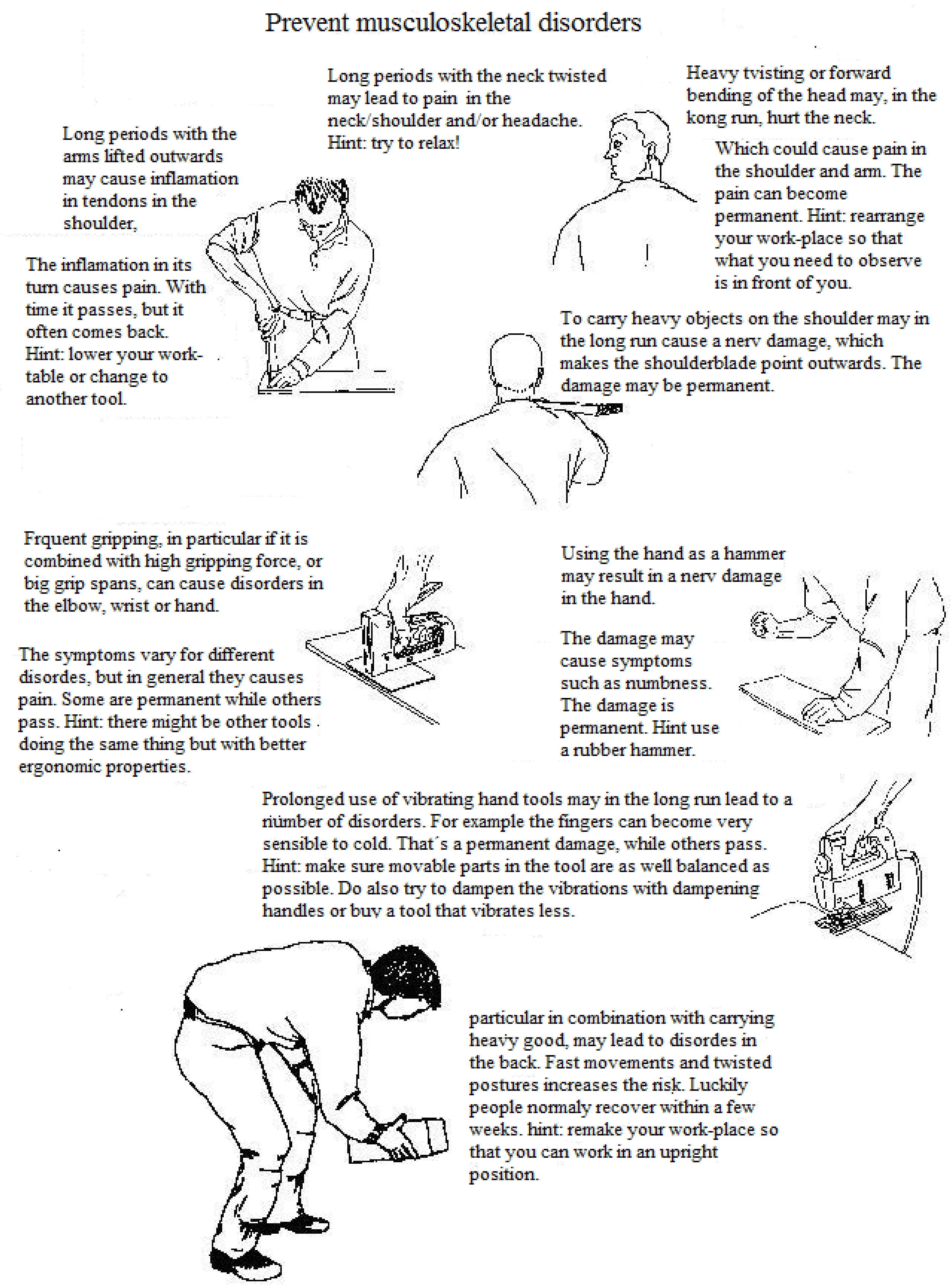


Figure 3. Some risk factors for musculoskeletal disorders which are related to manual work.

Ergonomic factors important to consider in the design/use of hand tools

This chapter describes some important factors for the prevention of musculoskeletal disorders when choosing or designing tools.

Gripping movements

Repetitive gripping movements, especially if the movement requires high gripping force, are a risk factor for a number of musculoskeletal disorders in the forearm, wrist and hand. It is reasonable to believe that the risk increases with increasing demands on gripping force.
It is recommended (Mital A and Kilbom On 1992 Part 1 & 2) that the trigger force for an index finger-operated trigger should not exceed 10 N. Some hand tools have a trigger that is operated with both the index and middle finger. In that case the trigger force should not exceed 20 N (C Fransson and Winkel J 1991; Hazleton FT and others 1975) and if the tool is equipped with a four finger maneuvered trigger, the trigger force may be up to 30 N.
What gripping force that the user must develop when using pliers and the like, is largely dependent on the character work piece and it is therefore impossible to determine any limits. For these tools, it is important to design the tool so that the work requires a minimum gripping force (i.e. long torque arm, sharp edges).
The hand can develop different maximum gripping force at different grip spans. According to many researchers the optimal grip span for hand tools, held in a power grip is between 50 and 60 mm, for the majority of both men and women.
The larger gripping motion the more the tendons move the wrist and the greater the total friction load. It is reasonable to believe that the greater the friction load, the greater the risk of inflammation of the wrist tendons. Thus, it is, from a preventive point of view, better the shorter the gripping movement is. There are, still today, tools that have a too large grip range and/or requires to high gripping force, such as manual staple guns (figure 4).

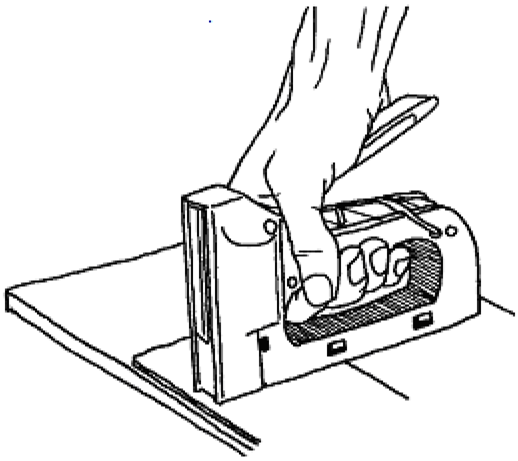


Figure 4. An example of a tool with poor ergonomics.

Tool weight and the weight torque

The heavier hand + tool is and/or the longer the distance between the hand and the point of gravity of hand + tool and/or the stiffer any cable/hose to the tool is, the higher the biomechanical load on the back/shoulder/arm/wrist/hand. And the higher the biomechanical load the greater the risk of getting musculoskeletal disorders (Hagberg M with several 1995).

Vibrations

Vibrating hand tools can cause a number of musculoskeletal disorders (see also the sub-chapter related musculoskeletal disorders in the arm, wrist and hand).
The vibrations transmitted from the tool to the hand can either be absorbed by the hand or returned to the tool. The more vibrations that are absorbed, the greater the risk for HAVS (Lidstrom IM 1974). Some relationships between the vibrations, the vibration exposure and the human response are described in figure 5.

To reduce the risk for HAVS, the problematic hand tools used in the industry (as sanders) should be fairly new (since a worn tool may have higher levels of vibration than a new ditto). The external moving parts on tools (such as grinding wheel on a grinder) should be properly secured and well balanced. The amount of vibration transmitted from the tool to the hand can be reduced by providing the tool with vibration-absorbing handles (Andersson S 1990). When switching to such a handle, it is important to select a handle with vibration-damping characteristics suitable for the type of vibrations. Vibration dampening gloves may also be a mean to dampen the transmission of vibrations. But many of these gloves, does not dampen the vibrations sufficiently (Koton J, Kowalski P and Szopa J 1998; Xiao J and Zheng Q 1998). Furthermore, there are in some cases "new" technologies such as electro-pneumatic drills that vibrate far less than traditional machines.
The vibration amplitude of the tool decreases with:

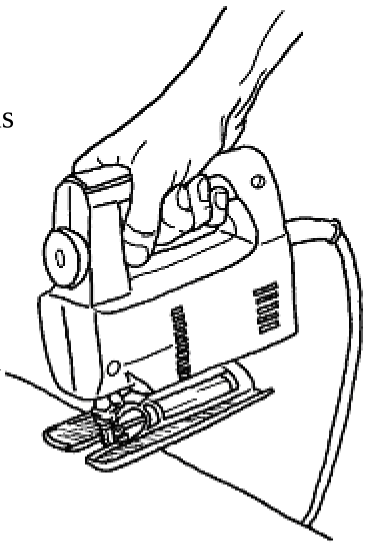


Figure 5. Correlation between vibrations from power tools and vibration exposure in the user’s hand-arm.

Handles

Since users generally hold the handle, it’s the part of the tools that have the greatest impact on the ergonomic conditions. Therefore handles are devoted a separate chapter.

Handle profile

The optimal profile of the handle for a tool depends on the tool type. A circular profile on the handle is often preferred for tools that the user may wish to rotate in the hand, such as screwdrivers. An ellipsoidal (oval) profile is, however, preferred for hand tools that should not be rotated in the hand and when the direction of the tool is critical, as for axes. An ellipsoidal profile is also preferred for tools, like wrenches, for which the user may need information about the angle of the jaws in relation to the work-piece. Rectangular/triangular profiles should be avoided, because the edges can cut into the user's hand. If rectangular/triangular profile for any reason is used, the edges should be well rounded.

Handle material

What is the best material on the handle of the tool depends on the type and conditions of use. But generally, the material:

- Have low electrical and thermal conductivity, for safety and comfort reasons (Mital A and Kilbom Å 1992 Part 1 & 2).
- Provide high friction, since increasing friction reduces the gripping force needed to hold the handle. This is particularly important for tools, such as screwdrivers, with which torque is to be transferred.
- Have low density, to minimize the weight of the tool.
- Not contain nickel, since prolonged contact with nickel-or nickel-plated hand tools can cause nickel allergies and even hand eczema.
- Be able to withstand rough handling without deformation.
- Prevent sharp metal pieces and the like gets embedded in the handle, since that may harm the user and/or make the handle uncomfortable.

For certain tools the handle the material should be slightly compressible, because it distributes the pressure better in the hand (GL Fellows and Freivalds A 1991; Mital A and Kilbom Å 1992 Part 1 & 2). This reduces the risk of developing disorders caused by high pressure against spots in the hand (se below). A compressible material also absorbs shock better and it can also to some extent dampen vibrations (Björing G, Johansson L and GM Hägg 1999). But a very compressible material has the following disadvantages from an ergonomic point of view (Mital A and Kilbom On 1992 Part 1 & 2):

1. The user may need to use more gripping force, to hold the tool.
2. Some very compressible materials (like foam rubber) absorb fluids, like for instance solvents, which can be annoying and increase the risk for allergies.
3. Sharp particles, such as metal pieces, can easily be embedded in the handle.
4. The durability is often low.

Handle surface

The optimal surface texture on the handle depends on the circumstances under which it is used. But generally, a uniform or finely patterned surface is more comfortable than a coarsely patterned surface with for instance grooves. Deep grooves can cause high pressure on point in the hand, which in turn can cause problems (se below).

Moreover high friction between the hand and the handle is often desirable, because the higher the friction is, the lower gripping force is needed to keep the tool in a steady grip. Regardless of if the hand is dry or sweaty, a fine patterned surface provides higher friction than a completely smooth surface, or a surface with ribs. But if the handle was soaked in contaminants, such as oil, ribs would improve the friction.

High pressure against the palm and/or fingers can cause pain (Tichauer ER and Gage H 1977) and blisters (if shear forces are involved) (Sulzberger MB 1966). The pressure level is due to the gripping and/or feeding forces the user applies and the profile/length/size and surface conditions of the handle/trigger/shanks. The highest pressures arise, of course, when the tool is gripped with high force. Sometimes it’s hard to do anything about because the job requires high gripping forces, such as when cutting sheet metal with manual shearers. But some tools (like small pliers) have such small shanks that even if they are not gripped with particularly high force, the pressure will be high on some spots of the hand.

Finger shaped handles should be avoided on standard tools. This is because the notches are designed to fit the "average hand" and it can make the handle unnecessarily uncomfortable for a those user whose hands are not suitable for the grip (figure 6). It also reduces the user's ability to vary the grip.

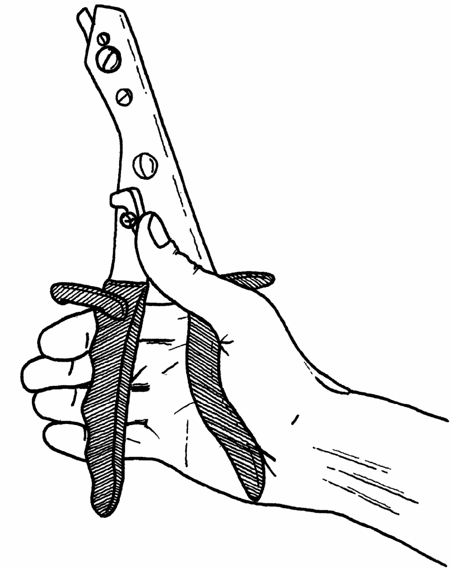


Figure 6. Shanks with notches for the fingers, which do not suit the user.

Handle length

If the handle is too short, the end of it will cut into the user's hand, thereby making the tool uncomfortable. In the preliminary European standard for tool design it says that tools which the user must keep a firm grip, the handle must have a minimum length of 125 mm. In some cases (such as regarding large knives), the user may want to push the thumb against the handle to press it down on the work-piece and in that case, the handle should be long enough to make it possible.

Placement and orientation of the handle

The placement and orientation of the handle affects the posture and it also has a major impact on the transmission of vibrations from the tool to the user. Furthermore extreme wrist postures reduce the maximal gripping force (Grant AW and Hallbeck MS 1997, Terrell R and Purswell JL 1976). The optimal placement of the handle is dependent on the tool type, and the working height of the item in question.

When large feeding-/press forces shall be transmitted, such as when drilling in steel, a pistol grip is preferable. But it is important to note that the tools that are designed to fit for work in one direction at a working height can be far from optimal when working in a different direction or on another working height. On tools with pistol grip handle, the angle between the handle and the rest of the tool usually is between 100-110°. The angle is optimal if the tool is used primarily on vertical surfaces and if the work performed at elbow height or below (figures 7 and 8). But if the tool is usually held above the elbow and/or if the tool is often directed towards horizontal surfaces, a 90°angle is better. If the work is only performed on horizontal surfaces at elbow height straight tools is, however, usually better. Finally, the handle of tools, such as circular saws, which are most frequently used under elbow height, should have an angle that is larger than 110°.

On most pistol grip tools, the handle is positioned in the back, but some have the handle in the middle. The advantages of the latter are that the balance is better and that some of the tool's weight burden is carried by the arm instead of the hand.
For straight tools, such as screwdrivers, the distance between the handle and the cutting edge is important for the position of the upper arm (figure 9).
In the case of strong rotating tools, like nut runners, the distance (torque arm) between the centre of rotation and the hand important for the ability to counteract the torque.

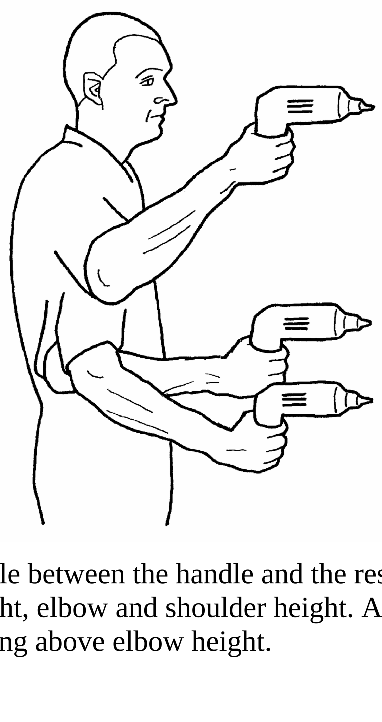


Figure 7. Pistol handles with an angle between the handle and the rest of the tool of 110º and 90º used when machining a work-piece at waist height, elbow and shoulder height. As seen in the figure the 90º angled handle gives a better posture when working above elbow height.

Figure 8. Pistol handle with an angle between the handle and the rest of the tool of 110º and 90º and a straight tool used when processing of a horizontal surface of a work-piece lying on a workbench. The straight tool provides the best working position and 110º gives the worst.

Figure 9. A screwdriver which is not suitable for the task, since it forces the user to lift the upper arm outwards.

Right-/left hand handles and gender differences

Often the users wants to hold the tools with the hand that they have the most control over, which for about 90% of us are the right one. But to allow the user to switch between right and left hands, and also to improve for those who are left-handed, tools should be designed so that they can be used with both.

There are differences in hand length between males and females, but the average difference is less than 10%, and it does not justify making tools with different handle sizes. However, the average difference in grip strength is 30% and this can affect the design of the handles. Furthermore, the difference in length between men with long hands and women with short ditto may be bigger than 30%.

So if it was possible from an economic standpoint, it would be beneficial if some tools were available with different left-and right-hand grips and/or handles in various sizes.

Specific requirements for the handle on some types of tools

Electric and pneumatic tools, the main handle

A majority of all hand-held electric or pneumatic tools with pistol grip (as drilling machines and circular saws) has a more or less ellipsoid handle. A common size of the profile is 50 x 35 mm. But for tools with great weight imbalance, such as large hammer drills, it may be appropriate to have a smaller size of the profile, in order to increase the possibility of holding the tool in a power grip.
The trigger should not have any sharp edges because it can cut into the user's hand. The trigger should also not be so short that one of the fingers is pressed against the bottom of the trigger. Finally, the distance between the fingers that actuates the trigger and the rest of the fingers shall not be longer than what is absolutely necessary, because it makes the handle uncomfortable.

Generally the trigger force should be as low as possible. However, if the trigger force must be high, two or four finger triggers are preferred. The appropriate length of the trigger depends on the width of the user's fingers and it is not possible to give any general recommendations.
When a tool is pressed with high force against a work-piece it can create high pressure on the skin between the thumb and forefingers, which can lead to redness and even blisters. It is therefore important that the part of the handle which is in contact with this part of the hand is appropriately designed.

The most common handle material is plastics. But there are also tools that have aluminium handles. A minority of all tools have handles that are more or less covered with rubber. Rubber handles probably has some advantages, as it reshapes after the users hand and thus distributes the pressure better. Also it to some extent dampens the vibrations. Finally, the rubber and plastic tool isolates thermally and electrically, so that they feel less cold and the risk of electric shock is reduced.

Some tools (like angled nut runners) have a circular profile on the handle. This is because these are kept different depending on whether the user is tightening a horizontal or a vertical screw. Straight tools often have a circular profile on the handle. The optimal diameter of such handles is for most people 30-40 mm. On straight tools it is advisable to have a bolster at the beginning of the handle, as it reduces the gripping force that the user needs to develop in order to achieve the correct feeding force. The bolster will also prevent the user from sliding on the handle.

Electric and pneumatic tools, support handle

The handle should be designed so that it can be used with either the left or right hand. On electric or pneumatic tools, such as an angled grinders, that handle often vibrates with higher amplitude than the main handle. Therefore, it is important that the support handle dampens vibration.

Screwdrivers

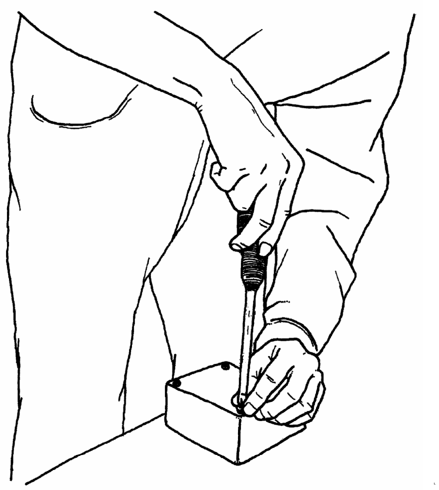
There are many different types of handles for screwdrivers. The profile varies from squared to circular. Generally circular profile is preferable because the user may want to rotate the screwdriver in his hand. But also because a square profile with edges can cut into the user's hand.

In the initial phase of the screwing the user fits the edge of the screwdriver into the recess of the screw head. It is a precision task. When the precision task is performed most users likes to hold the handle in a precision grip (figure 10). Afterwards many users changes from precision grip to "quick screwing grip". In the end many user changes grip again, to hold the screwdriver in a firm in order to tighten the screw.

The ability to rapidly rotate the screwdriver reduces with the diameter of the handle. While the ability to produce high torque increases with the diameter of the handle up to a maximum of about 50 mm, hereafter it decreases.

Regarding screwdrivers made for small screws, the precision and quick screwing phases are more important than the high torque one. Therefore, the diameter of the handle should be small. But not smaller than 6 mm, as smaller handles often cut into the user's hand, and it also makes it more difficult to control the screwdriver.

When screwing larger screws, it is important to be able to produce high torque. Therefore, a diameter of 32-38 mm is preferred. Some screwdrivers have a bolster or a "finger stop" at the beginning of the handle, which can reduce the need to grip the handle when the screwdriver pressed against the screw. Many large screwdrivers also have a "waist" at the beginning of the handle. This is to increases the efficiency in the precision and fast driving phases.
The rear end of the handle must be rounded, large and uniform. This is because the user may want to push one of his hands against it or hit it with the palm.
The friction between the hand and the handle is important, partly to reduce the force that is used to hold the screwdriver and partly to increase the possibilities to produce high torque. Finally, the handle should be long enough for the entire hand to fit around it. A minimum length of 114 mm is recommended. For extremely large screwdrivers, it is advisable that the handle is so long that the user can grip it with two hands.



A B C

Figure 10. Using a screwdriver, A. precision phase, B. "fast-screwing", C. tightening.

Tool that is reciprocated, as files

Round files should have more or less circular profile on the handle. While flat files should have a more squared profile, because it will make it easy to maintain the alignment of the file's surface. Files should have a waist or a bolster at the beginning of the handle. This because it will reduce the gripping force which the user must develop to provide the desired feeding force. Waist or bolster will also prevent the user from slipping over the handle. Large files should have a long handle so that it is possible for the user to press the thumb against the handle to push the file against the work-piece.

Knives

The most important feature for knife handles is that they prevent the user from sliding from the handle over the blade. This is accomplished through a bolster between the handle and the blade or by designing a part of the handle like a bolster. The bolster should protrude at least 16 mm. For knives that are designed to transfer high feeding forces, the handle should be so long that the user can push with the thumb against the back of the handle. Generally, the handles of knives should have ellipsoidal shape. But there are a large number of knives for different purposes and general recommendations for the size of the handle can not be given.

Striking tools, such as hammers and clubs

Most striking tools are intended to be used in one direction and they should have an ellipsoidal profile on the handle. If large impact forces is to be produced the handle should be designed to minimize the risk that the tool slipping out of the user's hand. It is therefore important that the user's fingers can completely encircle the handle. Generally, the handle of a hammer, should have a width of 25-40 mm. The handle should be shock absorbing, to prevent a certain circulatory problem in the hand, which can be caused by mechanical shocks against the hand.

"Cutting" tools, such as pliers, wire cutters and scissors

The shanks should have a half ellipsoidal profile, as it reduces the risk that there will be high pressure on points in the hand. The larger forces the tool is designed to transmit, the wider the shanks should be. Many small pliers and the like have pretty thin shanks, which can cut into the user's hand. If the shanks are too short (usual on for instance small pliers), the outer end cuts into the user's hand, making the handle uncomfortable. The preliminary version of the European standard for tool design states that the shanks should be 50-80 mm. For tools (such as scissors), where a finger is inserted into the handle, the handle should be designed so that there is enough room for the finger. The handle of these tools are often specially designed for right-handed people, because it greatly improve the situation for the majority of users. But it makes the tool inconvenient for left-handers (approximately 10% of us).

"Push and pull tools", such as hand-powered lawn mowers

When using "push tools" large shear forces are transmitted between hand and handle. These shear forces can cause blisters in the hand. To reduce the risk of blisters the handle should be very compressible.

Tools with a high trigger force, such as manual staplers and spray guns

These tools are often characterized by that large gripping forces has to be used, which may result in that there is high pressure on spots in the user’s hand. Therefore, the handle (and trigger) should have well a rounded half ellipsoidal shape. Furthermore, the handle profile and trigger profile should harmonize with each other. On some tools, like spray guns, there is often a heel on the front of the handle placed so that it is to be between the middle finger and ring finger. The advantage of this heel is that a part of the weight of the tool can be carried with the ring finger. The downside is that if the heel is too thick and/or the distance between the bottom of the trigger and the bottom of the heel is big, the distance between the middle finger and ring finger will be so big that the handle becomes uncomfortable to hold.

Wrenches and similar

For handles on wrenches and the like, it is important that the user can obtain the desired torque with as little grip force as possible. Furthermore, the handle must distribute the surface pressure as evenly as possible in the hand, and it shall prevent the tool from slipping out of the hand. A square or ellipsoidal handle shape is preferable to a round ditto, because they can give the user information about the position of the shanks. An important feature in the event that the tool is used as a counter part at the back of, for instance, an engine block.

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