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REVIEW PAPER

An Overview of Protective Gloves with Regards to Hand Performance and the Evaluation Methods

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Abstract- **Many tasks are carried out with the use of hands in various environments and working conditions, so protective gloves are widely utilized by workers voluntarily or as needed. The present study aims to introduce the hand, its various parts, and the importance of protecting the hands, which are subjected to several mechanical and perceptive situations. Moreover, the literature introduces the types of protective gloves, their design and structure. The factors affecting the performance of protective gloves and their evaluation methods are also included. This paper contains two parts; the first part is allocated to overview the importance of protective gloves and the second part is assigned to the published researches in each field and their results are elaborated. By probing the results of the previously conducted researches on protective gloves, it was found that wearing protective gloves often reduced the strength capability of the hand, tactile sensitivity, manual dexterity and range of motion, while the discrepancy in the results of some functions, such as pinch or torque, was observable in the studied researches. Examination of hand performance measurement tasks also showed weaknesses and shortcomings in some methods, and this was one of the causes of contradictions in the results of studies.**

Keywords: **protective glove, strength, dexterity, sensitivity, muscle activity**

I. INTRODUCTION

Scientific advances in various fields have elevated the quality and merit of human existence. Although modern life is more comfortable and has brought welfare to humans, it may expose them to the risk of unknown physical, chemical, and biological hazards [1]. Various personal protective equipment such as vests, masks, hats, shoes and gloves are applied to protect different body sections such as the face and eyes, head, legs, hands, arms, and ears.

The human hand has the most complex anatomy in the body and it is more often used while doing different activities. Thus, hand injuries are the main sources of accidents, especially at work [2]. In developed countries, considerable range of damages is caused by occupation and the workplace [3]. According to reports by the US National Electricity Monitoring System, injured wrists and fingers are the most recorded injuries and it was declared that hand and finger troubles are more common compared to the other occupational injuries [4,5]. The risk of hand damage increases when working with tools and when joining pieces. It should be noted that the use of associated protective gloves considerably reduces the hand-related risks [6]. The use of gloves prevented injuries and significantly reduced the damages and also crush, fractures, avulsions, amputations, and dislocations [7]. Therefore, hand protection is necessary at the workplace for prevention of mechanical hazards (wear, cutting, compressing, breaking, piercing, and damaging), severe thermal hazards (heat and cold), radiation (nuclear, ultraviolet radiation, X-rays, and heat), chemical hazards, the transmission of diseases through contaminated blood, and also to provide protection against electrical hazards and vibration, and to reduce blistering, bruising and other various injuries [8].

Although wearing protective gloves reduces injuries, it may cause unwanted side effects and problems, such as getting stuck in a device during work or difficulties such as skin rash due to allergies [9]. Gloves also can affect hand performance abilities such as strength capabilities

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of the hand, range of finger and wrist movements, tactile sensitivity, manual dexterity, tiresome, and other problems during the work [10].

II. EFFECTIVE FACTORS IN THE APPLICATION OF PROTECTIVE GLOVES

Human hands may be exposed to harm or infection in the presence of many materials. One way to reduce the risk of such damages is to wear suitable protective gloves. Now, a wide variety of protective gloves are available, each of which protects hands and fingers against various dangers. It is noteworthy that the use of any kind of safety gloves would not be suitable for every work, because there are different risks associated with different jobs. Besides, it may have adverse consequences such as the transmission of contamination, causing skin problems, or affecting the correct performance of the wearer. To decide which gloves are suitable for a particular application, factors such as design, the user status, and working conditions at the workplace should be considered [11]. Factors influencing the selection of gloves cannot be considered single-dimensionally, while sometimes a combination of the criteria for the selection of gloves should be applied appropriately.

A. Design and Construction

The clothing which is regarded as a secondary skin will be appropriate to the human body, by consideration of the type of movement and its range, and in terms of ventilation and comfort [12]. Of course, it is usually more difficult to follow these tips for protective equipment, besides considering the protective function. For this purpose, the design of protective clothing should cover various factors which will be discussed below.

A.1. Thickness and Number of Layers

In some cases, gloves consisting of two or more protective layers may be designed and manufactured to improve wearers' performance. For example, astronauts' gloves which are designed to protect their hands from certain weather and environmental conditions are a set of three-layer gloves. As another example, people who are sensitive to latex may use an inner layer inside the gloves. The thickness of the materials and the design of gloves can be varied, as well. Thin and poor gloves have low protection against dangers, while thick gloves create greater resistance to chemicals or mechanical hazards. However, an increase in the thickness may result in a reduction of skill and sensitivity, thus reduces safety. Therefore, it is advisable that the thickness of the material and the number of layers used in various parts of the glove should be considered differently, depending on the situations that the hands are exposed to danger [13].

A.2. Type of Material and Its Physical and Mechanical Properties

Gloves are made from different materials depending on the type of hand protection that is anticipated, including the physical, mechanical, chemical, biological, and radiation protection. Various materials, such as cotton, nylon, leather, plastic, rubber, tarry or wire mesh, and aluminized fabric are used to make gloves. It is also possible to combine different fabrics such as woven or knitted blend fabrics, or composites of different fabric types that are produced by sewing, laminating, or bonding of different layers. Due to the required protection level, finishing operations may also be carried out on the fabrics. As an example, polyvinyl chloride, nitrile, and vinyl PVC fabrics can be mentioned [14]. The fibers used in protective gloves include elastomeric fibers such as lycra, natural fibers like wool and cotton, or regenerated fibers such as viscose rayon, flexible fibers such as nylon, silk, and polyester or non-flexible fibers such as glass or ceramic fibers. Physical and mechanical properties of protective materials such as the weight and thickness, shear strength, tear perforation and wear resistance, flexural strength, frictional properties, and pressure properties are among the important properties affecting the performance of protective equipment that should be considered [15].

A.3. Cuff

Many gloves continue to cover the wrists, so the style and length of the gloves are different depending on the purpose of the glove. To protect the hands and arms from chemical and toxic influences such as the large volume of liquid or dangerous objects that are likely to come into contact with hands, a longer cuff length for gloves should be utilized. Therefore, the length of the glove's cuffs may differ depending on the end-use of the glove.

A.4. Surface Characteristics

Most manufacturers offer flat or textured surfaces for gloves. Lumpy surface provides a better grip for hands, which is important when working in wet and oily conditions [16]. In cases where a glove with an appropriate level of friction is required, manufacturers should provide this friction with various materials such as latex or other rubbers.

A.5. Design

There are several types of gloves designed to protect the entire hand or part of it. For example, it is sometimes necessary to protect your wrists or fingers. Gloves structures consist of single and multi-layer gloves, which can be back-coated or open back gloves, gloves with one place for four fingers and one place for the thumb, double gloves, and gloves with a reinforcement pad in the palm or back of the hands or fingers [17]. Therefore, gloves are designed and constructed based on the area of the hand that needs protection and the type of work to be carried out.

A.6. Protective Properties

Depending on the different working conditions, the person may be exposed to risks such as fire, chemicals, radiation and, living organisms such as bacteria. Protective clothing can protect people from these dangers. Gloves are one of the categories of protective clothing that should be prepared and used according to the type of danger that threatens the hand. The type of utilized gloves varies depending on the hazards confronting the health of the hand. For example, in facing of chemical hazards, gloves should be compatible with hand-held materials to prevent gloves from being damaged. Additionally, the glove materials should be compatible with the skin and do not cause allergies. Another type of hazard that threatens the hand is physical hazards, including abrasion with hard and harsh parts, perforations, impacts, and heavy forces. One of the methods for increasing the protection against such hazards is to raise the number of layers in the glove, which has consequences such as diminishing the range of motion and the reduction in gloves' performance. In other words, the glove's protection level is usually in opposition to the comfort and working ability of the hand. Therefore, it is necessary to determine the level of optimal protection and provide solutions to improve the effectiveness of hands when using gloves [18].

A.7. Ergonomic Properties

The ergonomics of protective clothing is an important aspect, which needs to be considered while producing and using it. Ergonomics is a dynamic feature that is examined by considering interactions between humans and clothing [19]. The goal of ergonomics is to optimize the comfort, safety, and performance of humans when using protective clothing [20]. Clothing comfort is one of the important features of it [21]. Comfort includes the thermal, physical and, mental status and interactions between the human body and the environment. The comfort of protective clothing may change over time or under different environmental conditions. The importance of ergonomics is to minimize the loss of human performance when wearing protective clothing. The use of harsh and hard-wearing materials in the production of gloves or seams in contact with hands is one of the factors that affect the ergonomics and comfort of protective gloves. Furthermore, gloves should be made of safe and flexible materials to enable the wearer to accomplish the expected task. The weight of protective clothing is another determinant factor in its performance. The weight influences the level of muscle activity and fatigue of the individuals. In addition, it increases the energy consumption and thus heat generation. It is clear that the heat in cold climates is not troublesome, but it becomes a challenging issue in a warm, temperate, or humid environment [21].

B. Conditions for Glove Wearer

B.1. Glove Size

In the production of various protective gloves, the design features are important in determining their level of performance and protection. In this context, fitting the glove size on hand is the most important factor to keep in mind. Hence, the size of the hand and the gloves is proportional to the performance capability, comfort, and efficiency of the individuals. Fitting the size of the hand and gloves has a great impact on the performance, comfort and efficiency. In addition, gloves that are too small or large, restrict the hand movement and create fatigue in the hands and fingers. Tight gloves also cause skin problems, while very large gloves affect the hand grip. In order to prepare the suitable gloves, at the first stage, the measurements have to be done on the hand, and then the gloves must be selected with regards to the standard definition of sizes. Size can vary between manufacturers and among different types of gloves, so it is important to have a wide range of sizes available for each glove [17].

B.2. Skin Conditions

Wounds and skin lesions should be covered by dressings before wearing gloves. Skin conditions can affect the choice or use of gloves. People with eczema or allergies may need to use a thin layer of cotton inside the glove to prevent sweat irritation. People with latex allergies should not use latex gloves because of the high sensitivity to latex, thus the use of latex substitutes is recommended [17].

B.3. Comfort

Other functions aspects that should be considered while wearing gloves are their comfort or discomfort. Glove's comfort has two different aspects: one is feeling comfortable in the hands after wearing a glove, and the other is the hand condition after wearing the gloves. The comfort of the gloves affects the ease of performing a specified task. It should be noted that an optimal level of comfort and work tranquility should be made on gloves [10].

Generally, protective clothing decreases the heat dissipation and leads to consumer's discomfort. Therefore, the issue of heat and sweat is very important [22]. Manufacturers have proposed different measures for the disposal of heat and sweat from the protective clothing. For example, one of these processes is the combination of polyester and cotton fibers and the production of fabrics that have extraordinary properties in the repellency of heat and sweat. Another way to reduce and therefore regulate the heat is through using a battery or shape-memory materials. Chilled gases and liquid or phase-change materials are applied to cool the body, as well. However, using some of these materials may increase the weight and bulkiness of protective clothing and diminish the range of motion. Since comfort is a conceptual state that is sensed by individuals, it cannot be measured quantitatively, thus for this reason; researchers have proposed different ways to evaluate this feature. One of these methods is to use the convenience and discomfort assessment tables where the zero to five scales is used as below:

0=no discomfort, 1=very little discomfort, 2=low discomfort, 3=unpleasant discomfort, 4=you are upset, and 5=very severe discomfort

In addition, a five-point scale is designed to assess the ease of use, in which:

1=very easy, 2=easy, 3=normal, 4=hard, and 5=very hard

Besides, in some researches comparison method of the pairs is applied [13,23].

Time and continuity in doing work and rest periods between each job are the factors that clearly and inevitably influence all hand functions and in particular hand performance [23].

C. Working Conditions

C.1. Working Environment

The environmental and work climatic conditions may affect the performance and comfort of hands when using gloves [24]. In hot or humid weather conditions, wearing glove may lead to a lot of perspiration; however in cold weather conditions, it is necessary to observe the gloves' insulation. Therefore, when choosing a glove, it is necessary to pay attention to the climatic condition of the area, to make clear whether it is hot, dry, wet or cold. Moreover, the environmental circumstances of the workplace which can be muddy or dirty and slippery should be analyzed [24].

C.2. Kind of Work

The type of activity and the risks involved are very effective in choosing gloves. It should be noted that wearing any type of safety gloves may not be suitable for any kind of work, as it can have unpleasant consequences. Each glove is designed and manufactured for a specific activity that is capable of protecting the hands and fingers in the same range of work. Gloves are used in many industrial applications to protect the hands against dangers such as mechanical damages or thermal, radiation, biological, chemical, electrical, vibration, spark, and flame hazards [1].

C.3. Duration of Work

Most gloves are used for a long time by workers, engineers, etc. Therefore, the length of time periods of using gloves is very important. Long-time usage can change the effect of gloves and affect the performance, strength, comfort, and working skill of the wearer. The tests used to evaluate gloves are usually either sudden or short-term and performed only once. For all these reasons, these tests cannot measure the long-term effects of wearing gloves. In other words, assessing the effect of wearing gloves on hand performance with single-use tests and without considering time periods may have illusory results [13].

C.4. Type of Contact

Contact with objects and hazardous materials may occur by accidental or intentional contact. When the hand is not directly exposed to hazardous materials and for instance, it is exposed to discharge or leakage of materials, an accidental contact occurs. The intentional contact relates to tasks in which exposure to dangerous substances is inevitable. For example, immersing hands in liquids, directly handling an object, and treating materials that are coated or saturated with hazardous substances and direct handling of alive tissues are categorized as intentional contact. In accidental chemical contact, disposable gloves can be used but in intentional and long-term contact, in order to prevent attack and penetration of materials inside the gloves, re-useable gloves should be employed [1].

To select the appropriate glove for the desired activity, familiarity with the safety signs and warnings on them is necessary. In addition, the presence of a safety mark on the glove indicates that gloves can provide the minimum requirements for a specific purpose. It should be noted that the performance of protective gloves is significantly affected by burnout and durability. For instance, the level of performance after one year of the production of gloves is normally reduced even before it is used [25]. Therefore, the expiration date should be indicated on gloves and packaging. Since for every kind of protection, usually materials with a different protective level are provided, and along with the safety symbols, their functional level should also be specified [25].

III. SAFETY GLOVES INFORMATION

Protective gloves are usually prepared to protect the palm,

TABLE I
SELECTING GLOVES FOR PROTECTION AGAINST VARIOUS INJURIES [27-29]

Type of gloves and application	Materials and design
Aircrew gloves; these gloves are for keeping the crew's hands warm during the flight and must be flame retardant, water resistant and improve the ability to grasp and control objects and devices.	The materials used in the palms and fingers are leather and fire-resistant fabric.
Anti-vibration gloves; that are used to protect workers' hands when using vibrating tools such as drills and jackhammers, and It should have good resistance to puncture.	Largely composed of leather, polyester, nylon, polymer, spandex, or cotton. The glove palm may contain vibration control pads such as leather, foam or rubber.
Antistatic gloves; used to work with delicate components and destroy the electrostatic properties	Nitrile, nylon, and carbon fibers are the most common. Acrylic fibers or a polyurethane coating may be used.
Chainmail gloves; they have excellent protection against puncture and cutting. They are commonly used in food preparation and knife work.	Made of metal chains attached to leather or cotton fabric.
Tactical gloves; for use by the police and military to increase grip strength and range of fingers movement.	Made of leather, nylon, neoprene, spandex, Amara, Lycra, Kevlar, Nomex, and Spandura. Linings may include foam, microfleece, polyester, Thinsulate, Kevlar, or Nomex.
Chemical gloves; which are suitable for use in laboratory environments and chemical manipulations and should protect the hands against chemicals and abrasion. It has different thickness levels and may be disposable or reusable.	Composed of nitrile, neoprene, latex, vinyl, rubber or Viton, and other materials.
Electrical gloves; prevent electric shock, electric arc and explosion when working with voltage.	All of the electric gloves are made of natural rubber but may be included leather in the structure for comfort and resistance to tearing.
Firefighter gloves; have high strength and are flame resistant, heat resistant, waterproof, puncture and tear resistant and suitable for firefighting operations.	There are combinations of leather that can be covered with cotton or Nomex. Sometimes these gloves are double-layered, in which case they are made of aluminum or Kevlar.
Flame retardant gloves; that provide excellent protection against industrial processes. These are usually less durable than fireproof gloves and are more resistant to industrial work.	Leather, carbon fiber, Nomex, and Goretex are common materials. Gloves may be lined with fleece or cotton.
Cryogenic gloves; protect human hands and arms in very cold environments (liquid nitrogen, etc.). They offer good water resistance and flexibility.	Often made of nylon Taslan, PTFE, and silicone.
Garden gloves; are general, multipurpose gloves for landscaping, and terrain repair. They oppose abrasion while enhancing grip.	Leather, canvas, jersey, knit, cotton, latex, plastic, rubber, and vinyl.
Driving gloves; are used for better grip and control and driving gloves. They usually have an exposed knuckle and opisthenar for added flexibility.	Made entirely of leather
Medical gloves; are usually disposable and are used as a barrier between caregivers and patients.	Most prominently latex, but also nitrile, rubber, vinyl, and neoprene. Powdered cornstarch is sometimes used to keep gloves pliable.
Mechanics gloves; are made for use by machine repair workers. Abrasion resistance, air permeability and oil penetration resistance and flexibility are important parameters in these gloves.	Materials are not limited and various materials such as leather/suede, polyester, nylon, spandex, cotton, rubber, PVC, neoprene and Kevlar, along with foam, gel, and TPR padding.

fingers and wrist. Occupational hazards and environmental, recreational and aviation hazards are among the items, in which it is necessary to wear gloves in order to protect hands. Each glove is usually designed for specific end-uses, but may be suitable for other purposes as well. Therefore, it is important to assess the risks before selecting a suitable glove [26]. Since the design of gloves and the materials used in their preparation determine the application of each glove, Table I lists the most common protective gloves and materials and their applications.

IV. INTRODUCTION OF HAND PARTS AND THEIR PERFORMANCE

Since the current paper discusses the properties of protective gloves and also the hand protection against dangers, hence, the definition of damage and the various types of injuries have been presented. Moreover, various parts of the hands and their muscles and bones that are effective in their movement are introduced. In addition, a brief acknowledgment of their tasks has been carried out.

In medical science, any strike or injury to the body that has been imposed from the outside and the internal factors are not the cause of harm is a trauma [30]. In other words, trauma is any damage caused by increased input energy to the body and this energy may be shocks in the form of mechanical, thermal, chemical, nuclear or others. Damage to the body may occur as a result of the execution of any kind of external force. Considering that this damage is related to the soft tissue (muscle, skin, blood vessels, and nerves) or the skeletal tissue of the human body and its joints, it is divided into musculoskeletal or wound trauma. Muscle injuries result from the onset of force on the part of the body and it is an unwanted force that is injected through the body. Besides, a variety of skeletal injuries include fractures, luxation, torsion, cramps, and muscle spasm. The second type of injury is the wound, which is any kind of cleft or loss of connective tissue in the body, both inside and outside the body. The wounds are divided into two groups of open and closed wounds. Various types of open wounds consisted of slit wounds or cured sores, ripped wounds, scars, xystos and perforated wounds such as a gunshot. The common types of closed wounds can be described as bruises or crushing [31].

The human hand is a highly complex and multifaceted organ and is the last member of the mechanical leverage chain that begins at the shoulder [32]. The mobility of the shoulders, elbows, and wrists occurs on different planes and allows the hand to move in large volumes of space. Therefore, the hand is significantly movable and can change its figure to match the shape of objects, in order to move or touch them. In addition, the movement and mobility of 19 bones and 14 joints of the hand provide excellent hand function. The wrist is a set, consisting of eight parts of the bone. The soft tissues and structures around the bones are exposed to tendons that cross the joints and connect them.

The fingers and thumb are the basic parts of the hand. Each finger unit consists of metacarpal and three phalanges (two in the thumb) and joins to the middle of the hand. The fingers were named from the radial bone to ulnar which are called: 1) Thumb, 2) Index finger, 3) Middle finger, 4) Ring finger, and 5) Little finger, respectively. There are proximal joints (PIP) and distal joints (DTP) between the phalanges of the fingers that connect the two phalanges together, but the thumb has only one inter-phalangeal (IP) joint. The thenar area at the palmar side is formed by thumb muscles and another promontory hypothenar is located in the opposite direction. The third prominent part of the hand is the palmar, where it extends from the little finger to the index finger, similar to the pad. Fig. 1 shows the different parts of the hand.

Fig. 1. Important bones in the mobility of the hand.

The wrist set is surrounded by 10 tendons that are located at the edge of the bones. Three flexors and three extensors control the arched or crescent movement and the radial (abduction) and ulnar (adduction) deviation of the wrist. They also support the movement of flexion and extension of the wrist. The wrist has complex movements including the flexion/extension, radial/ulnar deviation, and the axial rotation of the supination/pronation; it is also possible to combine these movements. The types of wrist motion are shown in Fig. 2.

The wrist movement range for various complex actions are as follows: flexion 65°-80°, extension 55°-75°, radial deviation 25°-65° and the ulnar 30°-45° which vary depending on the individual ability.

The ranges of finger activities for four fingers and thumbs are described individually [33]. The joints in each of the four fingers allow the three axial movements of the fingers. Therefore, the fingers can perform flexion and extension; adduction and abduction; radial and ulnar. The flexion range of the fingers is from zero to almost 90°, but

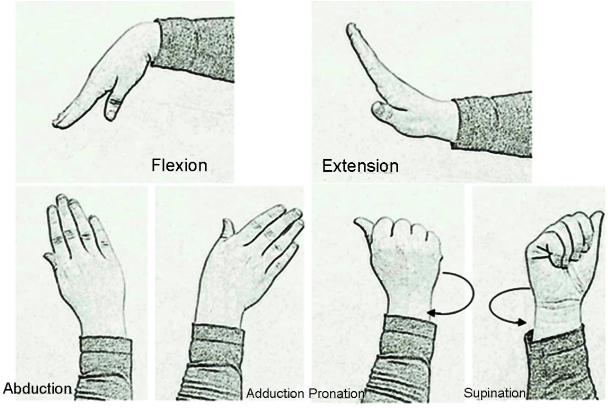
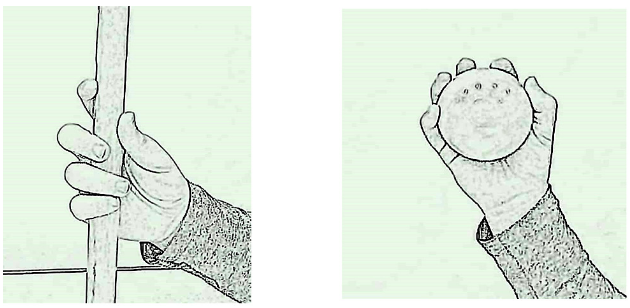


Fig. 2. Types of wrist movements.

this value varies among different fingers. The fifth finger has the most flexibility of about 95° and the second finger or the index finger's flexibility is 70°, approximately [33].

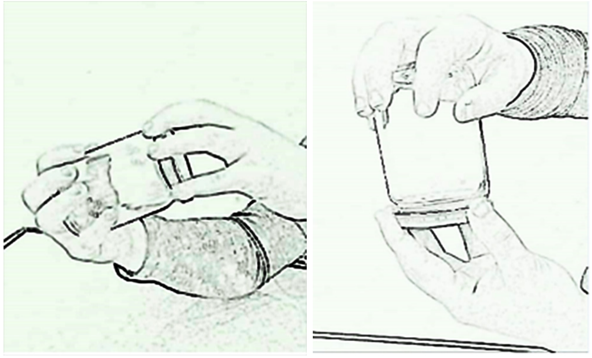
Opposition movement is the most important function of the thumb movement, in which the tip of the thumb moves towards the tip of the little finger [34]. In this movement, there is a change in the angle of thumb with the rotation from a normal position. The thumb flexion range varies considerably between different people, but the extension range of the thumb can be altered from zero position to 15°.

Many attempts were made to classify different patterns of hand performance. Hand function for most tasks can be categorized as grip (grasp), pinch, touch and manual dexterity. The grip performance can be divided into two distinct models; the power grip and the precision maneuver (taking the object along one axis). It is important that the basic needs of the operations with objects in both situations must be respected. Grasping or gripping is a powerful action that utilizes all the three-finger joints, so that the object is held between the finger and the palm, and by using the thumb to the palm, the object is safely placed in the palm of hand. In precision maneuver, the object positioned between the flexor of the fingers and the thumb and is pressed slightly. One of the important distinctions between the power grip and precision maneuver is the difference in the position of



(a) (b)

Fig. 3. Two fundamental patterns of hand function: (a) power grip and (b) precision maneuver.



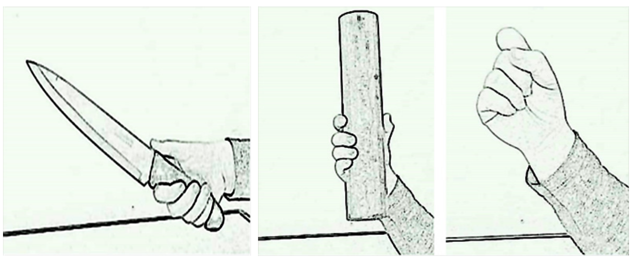
(a) (b)

Fig. 4. Unscrewing the lid of a tightly closed jar: (a) as the motion is begun and (b) as the lid loosens.

the wrist, such that they are carefully taken into practice to increase the touch of the fingers. In the precision maneuver, fingers have been drawn to increase the range of the touch. Another important difference between the power grip and precision maneuver is the fundamental difference between the thumb positions in each of the modes. In the power grip, the thumb is pulled in, but in the precision maneuver, the palm is pulled outward. The association between hand and forearm is also significant in these two tasks. In the power grip, the hand always diverges towards the ulnar and the wrist stays in a neutral state, so that the thumb axis is aligned with the arm; however, in the precision maneuver, the axis of the thumb is aligned with the object (Fig. 3) [34].

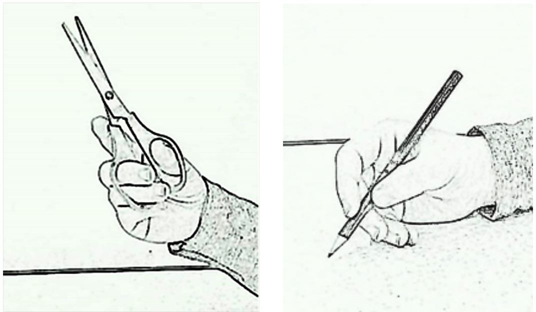
Daily tasks that are performed by hands often include both power grip and precision maneuver [34]. Moreover, a few examples of activities consist of a combination of different tasks. It is possible to point out the unlocking of the lid of a tightly closed jar which performs grip and torque action, simultaneously (Fig. 4).

For a different kind of power grip, one can hold objects and apply force with precision and strength [34]. In other words, this task is an element of power in which the element of accuracy also plays an important role (Fig. 5). The dynamic tripod is a kind of precise movement in which the thumb, index, and middle finger work together (such as scissors) to control the object, accurately;



(a) (b) (c)

Fig. 5. (a) The fencing grip, (b) the coal-hammer grip, and (c) bunched fist.



(a) (b)

Fig. 6. Dynamic tripod: (a) use of scissors and (b) a pencil.

while the ring and little fingers are doing the task of supporting and controlling (Fig. 6).

Pinch is referred to as the tiny touch of small objects. Pinch types can be categorized as two-point pinch (the object pinch between the thumb and index finger) (Fig. 7) and a three-point pinch (the object pinch between the thumb, index and middle finger and the middle pinch) (Fig. 8). The types of pinching are classified according to the finger phalanges that are used in activity on the object [34].

Torque is another strength capability of the hand. The difference in the grip of the handles and also considering the muscles which are involved during the operation has led to the classification of torque into different types [10]. The most common torque tasks, are: using wrist twist to turn a handle (as with a screwdriver), using wrist flexion to turn a handle (as with a motorbike throttle), using lateral force along a handle to turn it around a central axis (as with a car steering wheel), using pushing/pulling at right angles to a handle to turn it around a central axis (as on a wrench), and twisting a screw cap off a bottle (using finger pinch) [10].

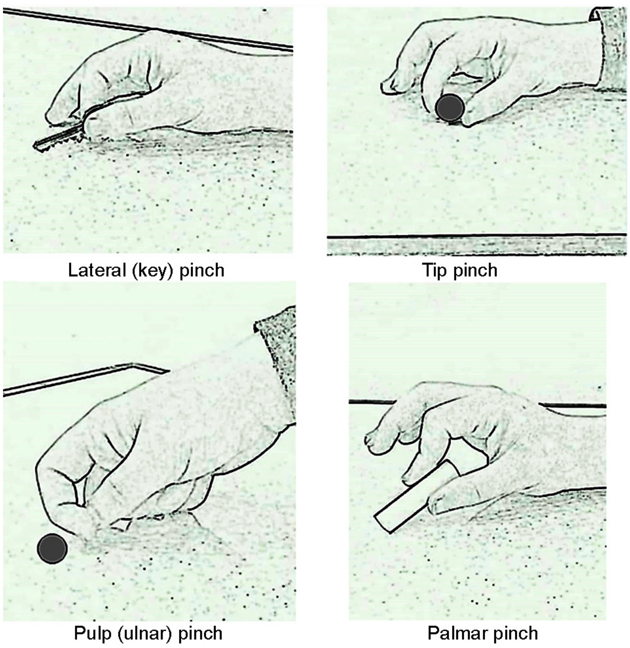


Fig. 7. Types of two-point pinch.

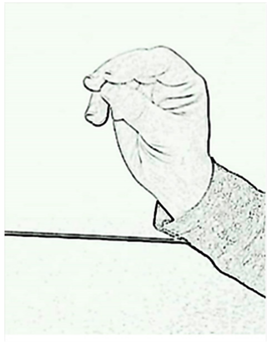


Fig. 8. Three-point pinch.

V. EFFECT OF PROTECTIVE GLOVES ON HAND PERFORMANCE

Effective factors in the selection of protective gloves and their design parameters that were previously stated (section III and IV) both affect the hand performance after wearing gloves. Therefore, various hand functions after wearing gloves should be evaluated. In order to provide the ability for hand to perform different activities, it should have both sensory and motor abilities. Motor functions include strength capabilities, range of motion, manual dexterity and muscle activity. In addition, the sensitivity and comfort of hand should be considered when wearing gloves. Hand functions can be classified into two dynamic and static, or one-dimensional and multi-dimensional groups. For example, the manual dexterity is a multidimensional test, because it influences strength, sensory function, comfort, range of motion, and many other factors. But because other performance capabilities do not affect the tactile sensitivity of the hand and finger, sensitivity is a one-dimensional function [10].

A. Strength Capabilities of the Hand

Muscle strength is one of the hand abilities in operating, which is generally referred to as grip and grasp, all kinds of pinches and forearm torque [10]. The muscle strength can be applied dynamically and statically, so the measurement of power is done both in a dynamic and static manner. When the hand enters the maximum compressive force, tensile strength or torsion torque, static strength occurs. While measuring dynamic power is more complicated than static power. When applying dynamic muscular force, the length of the muscles changes significantly, which is why the force applied when moving the body is known as dynamic power [10].

Various types of tools that have been reported in studies including the types of dynamometers [35] (i.e. the Jamar dynamometer, Rolyan dynamometer, dynamometer made by MIE Medical Research Ltd.), pinch gauges (B&L Pinch Gauge and Preston Pinch Gauge), or torque sensors (load cells, strain gauges, and torque sensors), are used to measure the hand power [35]. The strength capabilities of the hand, due to factors such as manual dexterity and range of motion are multidimensional tests. To evaluate and test the strength of the hand, the conditions of the test must be similar to the actual working conditions [35].

Many studies have examined various factors affecting hand strength after wearing gloves. Numerous studies have shown the negative impact of utilizing glove on hand power performance [36-45] while increased grip strength after using gloves has been reported in several studies [45].

Different test conditions, including climate, diameter and length of the dynamometer handle, hand and wrist position when applying force, the type of work required in the test process, and many other factors may be the cause of these conflicting results [46-48]. A number of studies have examined the effect of thickness, the number of layers and design of gloves on hand strength performance [49,50] and presented that increasing thickness has a negative effect on hand strength performance [23,49-54], but some studies also reported an increase in grip and pinch strength due to increased glove thickness [55,56].

The type of gloves and the physical and mechanical properties of the materials [59] used in the preparation of the gloves and their influence on the application of power by hand have also been considered by researchers. These factors affect the final force applied by the hand due to the impact on the friction [60-62] of the glove with objects, the stiffness of the glove and the feeling of fatigue of the hand. Application of gloves with proper size [59], force exertion by the dominant or non-dominant hand, the gender [63] and many other factors affect the force applied by the hand. The hand torque after wearing gloves was also tested by researchers [64-68] which found conflicting results in studies. Several studies have shown a positive effect of gloves on torque performance; however, some of them stated a number of negative effect or ineffective use of gloves on torque performance.

Research on the pinch performance was much less than that of the grip, but studies have revealed that gloves can reduce the performance of the pinch, but in some cases, researchers have reported an increase in the pinch strength due to the use of gloves [69-72]. Therefore, in general, the effect of using gloves on the power of pinch and torque is not very clear and requires further research.

B. Muscle Activity and Fatigue

The continuity of work and longtime activity can lead to symptoms that are sometimes painful and uncomfortable. In fact, fatigue is an unpleasant state that causes exhaustion in the muscles due to long period activities or applying vibratory and rhythmic powers. Environmental factors such as heat, cold or humidity, gloves design parameters such as flexural strength, material, comfort and many other effective factors can influence the severity of fatigue [10].

Fatigue may occur in static or dynamic operations. In static activities, a group of muscles are involved in a steady state and if the muscle is impacted by force during a long time, it is contracted without any movement. In dynamic activities, muscle movement, contraction and expansion accelerate the blood flow, consequently; less fatigue is observed in these activities than in static activities. One of the methods to measure muscle activity is using the electromyography device. In this method, muscle contractions can be perceived using electrodes that are mounted on the muscles. In this technique of the measurement, stronger contractions cause larger signals that result in fast muscle tiredness [10].

Summaries of previous studies on muscle activity and fatigue display that using gloves increases the activity of various muscles in the hand, resulting in earlier fatigue. But the efficiency of hand function is affected by factors such as the appropriate size of gloves, friction of gloves with objects, material, physical and mechanical properties of gloves. It should be noted that the position of the hand when doing work is also effective in fatigue [54,68,73-76].

C. Manual Dexterity

Manual dexterity is another skill in which nerves, muscles, joints and ligaments are involved [10]. The main aspects of manual dexterity are influenced by factors such as the range of motion of the fingers and wrists, the sensitivity and coordination of the hands. Therefore, this skill of the hand can be considered as a multidimensional performance. Manual dexterity has been measured by a number of standard tests such as the Bennett hand tool dexterity test, Minnesota rate of manipulation-turning or pegboard test [77], O'Connor dexterity test, Pennsylvania bimanual work sample assembly test, rope knotting test, block manipulation and nut and bolt test (the basis of most manual dexterity tests is to pick up and move objects and put each object in the right place) [78]. Due to the fact that the purpose is to measure one or two-finger dexterity or whole hand dexterity, the appropriate test should be selected.

But, despite all these common tests of dexterity testing, it is desirable to design a test to assess the performance of each glove by considering the work that is expected from the glove wearer. Therefore, when more factors such

TABLE II
STUDIES RELATED TO THE EFFECTS OF GLOVES ON STRENGTH, MANUAL DEXTERITY AND RANGE OF MOTION

Research	Method and tool	Hand condition	Influencing factor	Dependent variable	Result
Bradley (1969) [79]	Five types of control (push buttons, toggle switches, knobs, horizontally operable levers, and arid vertically operable levers)	Bare hand, wool glove, double glove, i.e., leather glove over wool glove	Type of glove, physical characteristics of the control, and type of control operation required	Control operation time	Wearing gloves has a negative effect on operation control
Taylor and Berman (1982) [85]	Pressing the keyboard	Bare hands, neoprene inner, cape leather flying, in conjunction with the inner glove	Hand conditions	Sensory feedback on keying	No significant differences between glove conditions
Plummer *et al.* (1985) [86]	Bennett hand tool dexterity test	Three single gloves and six double gloves combinations plus the bare hand condition	Hand conditions	Manual dexterity	Reduces manual dexterity after wearing double gloves compared to single gloves
Riley *et al.* (1985) [8]	Tension meter	No glove, one glove, and two gloves	Hand conditions	Maximum pull force, maximum push force, maximum wrist flexion torque, and maximum wrist extension torque	One-glove condition was superior to the conditions of no glove or double gloves for the forces and torques measured
Johnson and Sleeper (1986) [80]	O'connor and pegboard test	Bare-handed, chemical protective hand-wear, and headgear	Hand-wear and headgear	Manual dexterity	After wearing gloves manual dexterity is greatly reduced
Karis (1987) [92]	Control an airplane controller	No gloves, flight gloves, and a combination of three gloves worn simultaneously	Hand condition	Skill on motor control	Increased skill in controlling after wearing gloves due to increased friction
Chen *et al.* (1989) [59]	Cylindrical handle, electromyography	Bare handed and letters stand for leather, cotton, and rough deerskin	Glove size and glove material	Maximum torque exertion and small parts assembly	For the maximum exertion task, the size of the gloves does not affect the task, but the material is effective and for the assembly task size and the materials have a combined effect
Bellingar and Slocum (1993) [83]	Two tasks typical of pesticide applicators, two Locam cameras	Gloved and ungloved	Hand conditions	Hand movement	Kinematic motion of the hand appeared to decrease while wearing protective gloves
Bensel (1993) [87]	Minnesota, O'Connor, Cord and cylinder, Bennett hand-tool dexterity, and Rifle disassembly/assembly	Bare hand, three thicknesses of chemical protective gloves, 0.18, 0.36, and 0.64 mm	Gloves thickness	Manual dexterity	Manual dexterity is reduced by increasing the thickness of the glove

Research	Method and tool	Hand condition	Influencing factor	Dependent variable	Result
Nelson and Mital (1995) [52]	Texture identification test, two-point discrimination test, using scissors to cut out three different geometric shapes	Bare handed, Latex gloves of five different thicknesses 0.21, 0.51, 0.65, 0.76, and 0·83 mm)	Dexterity, tactility, grip strength and wrist flexibility, and penetration force	Thickness of the latex gloves	1. Increasing thickness has a negative effect on grip and sensitivity 2. Thickness had no significant effect on dexterity 3. Hand protection improved with thickening
Moore *et al.* (1995) [49]	Hand dynamometer, B&L pinch gauge	(1) Bare hand, (2) hand with a normal sized latex examination glove, and (3) hand with a tight fitting latex examination glove	Hand condition	Power grip strength, pinch strength, and manual dexterity	Latex gloves do not have an effect on strength, but inappropriate size reduces the manual dexterity
Bronkema and Bishu (1996) [61]	Standard hand dynamometer	Cotton, leather, and bare hand	Glove type, friction level, load lifted, trial, and gender	Grasping force and grasping control	Friction and load both affect the grasp force
Phillips *et al.* (1997) [23]	Texture matching, Point discrimination,Stereognosis with 2-D visual cue, Stereognosis without visual cue, Motor function-grip	No gloves, single latex glove, two pairs of latex gloves, latex-Repel-Lite®-latex, and latex-Lifeliner®-latex	Hand conditions	Grip strength, dexterity, and tactility	Thicker gloves reduce sensitivity and skill but do not have a multivariate impact on the motor tasks
Lowe and Freivalds (1996) [93]		Spectra, nitrile, and conventional thick cotton glove	Glove types, pinch forces shelf height, and handling strategies	Windshield glass handling	Gloves with higher thickness provide better performance
Tsaousidis and Freivalds (1998) [70]	A handle and two parallel metal bars was connected to a pressure transducer	A leather glove without lining and bare hand	Hand conditions	Pinch, wrist flexion, and grip force	No significant effect of gloves on pinch and torque and significant effect of gloves on grip strength
Chen *et al.* (1998) [82]	Monofilament test, O'Connor dexterity test, scissor cutting time, vibration test count, corneometer measure, borg's CR-10 scale measure, Grumman scale, and weight measurement	4 gloves with latex, latex with liners A, B, and C layers	4 gloves, two temperatures, and gender	Tactility and dexterity	The effect of gloves was significant but the temperature and gender were not significant
Muralidhar *et al.* (1999) [2]	Pegboard task, block manipulation, rope knotting, assembly task, grip strength with Jamar dynamometer, and algometer test	Bare hand, single glove, double glove, contour glove, and laminar glove	Hand conditions (different gloves design)	Grip force, dexterity, Pressure protection	Gloves decrease grip force, and hand dexterity but increases protection
Sawyer and Bennett (2006) [88]	Purdue pegboard test	Latex and nitrile safe skin gloves	Hand conditions and size	Hand and finger dexterity	The latex gloves provide better skill with greater thickness, but this difference was not very significant
Krausman and Nussbaum (2007) [89]	Wearable mouse and touch pad to enter text	Barehanded, gloves with thickness of 7, 14, and 25 mm	Glove thickness and mask use	Performance in entering text	1. Suggesting that thin protective gloves are more suitable than thicker gloves 2. Mask use did not affect task performance

Research	Method and tool	Hand condition	Influencing factor	Dependent variable	Result
Gnaneswaran *et al.* (2008) [91]	Jamar hand dynamometer, and pegboard test	Bare hand, latex with powder, latex without powder, vinyl with powder, and vinyl without powder	Hand condition, powdered and non-powdered	Grip and pinch strengths, dexterity, tactility, and manipulability	The latex gloves with powder are recommended over vinyl gloves but if a person (health care provider or receiver) is sensitized to latex allergen, then the use of vinyl gloves is suggested
Berger *et al.* (2009) [84]	O'Connor and purdue pegboard test	Nitrile Semper care and nitrile safe skin	Hand condition and dry and wet conditions	Finger dexterity	Reduced both gloves finger dexterity
Yalamarty *et al.* (2009) [48]	Grip dynamometer, (Takei company), pinch gauge (baseline), complete connection of electric power lines in the field	Bare-hand, electric utility lineman gloves	Hand conditions, four trials per task, and two-arm positions	Hand grip strength, pinch grip strength, an assembly task, and a rope knotting task	Decrease in grip strength and the time required to complete tasks due to wear glove
Drabek *et al.* [90] (2010)	Grooved pegboard test	Bare-handed, right size, too large, and too small	Size of gloves, the effect of time and fatigue	Manual dexterity	Wearing wrong size of gloves reduces the performance relative to bare hands and right size gloves
Dianat *et al.* (2010) [72]	Screw-driving task (MT8-3 biological telemetry system (MIE Medical Research Ltd., Leeds,UK), pegboard test, monofilament test, pinch gauge (B&L Engineering, Tustin, CA, USA), torque meter and a T-shaped handle	Cotton, nylon or nitrile gloves as well as barehanded	Hand conditions, shorter and longer duration effects of protective gloves, and hand conditions	Hand performance capabilities (muscle activity, dexterity, touch sensitivity, finger pinch, and forearm torque strength) and subjective assessments of discomfort and ease of manipulation	Wearing gloves significantly increased the muscle activity, pinch strength and discomfort but reduced the dexterity and touch sensitivity
Wells *et al.* (2010) [56]	Electromyographic (EMG) and hand grip dynamometer	Bare hand and five classes of gloves; 0, 1, 2, 3, and 4	Thickness and size	Electrical activity (EMG), performance times and ratings of comfort, fit and dexterity, and grip strength	Glove thickness increased: Performance decreased, effort and EMG amplitude increased and self-rated comfort, fit, and overall rating decreased
Dianat *et al.* (2012) [95]	Industrial assembly tasks involving pliers	Bare hand, cotton, nylon, and nitrile gloves	Hand conditions and duration of the task	Muscle activity, wrist posture, touch sensitivity, hand grip, and forearm torque strength	Gloves tend to increase muscle activity, wrist posture and discomfort and to decrease touch sensitivity, hand grip, and forearm torque strength
Yu *et al.* (2019) [44]	Calibrated metal goniometer, Jamar hand dynamometer, semmes–Weinstein monofilament test, purdue pegboard, and marble transport test	War-gaming glove and hiking glove	Fit of glove, physical and mechanical properties of glove materials, and type of gloves	Ranges of motion, grip strength, finger tactile sensitivity, finger dexterity, ability in holding and handling, and comfort	Active range of motion of fingers, finger tactile sensitivity, gripping strength and ability to handle pegs and marbles decreased with the use of gloves compared with bare hands

as the movement of the fingers together, movement of both hands together and movement of the eye and hand together are involved, the results will be closer to reality. Thus, multidimensional tests such as manual dexterity, strength capability or muscle activity may affect the choice of gloves and effective parameters on the design of gloves (explained in the previous sections), in addition to hand function characteristics.

Summarizing the results of published studies on the effect of gloves on manual dexterity performance presents that using gloves increases the working duration or the number of errors; thus, reduces hand dexterity [2,39,48,72,79-85]. Manual dexterity can be affected by the glove thickness and mostly reduces by increasing the thickness [23,52,56,86-89]. Also, using the right size of gloves can affect manual dexterity [49,90], because if the glove is too loose, it is weighty and it gets stuck around and becomes annoying. On the other hand, if the glove is too tight, the comfort is affected that leads to the reduction of manual dexterity. The materials used in the preparation of gloves are an important factor in the manual dexterity; harder and bulkier materials can negatively affect the manual dexterity [59,91]. Mutually, various studies have shown that thin gloves such as latex gloves have little effect on manual dexterity performance. However, improved hand skills after wearing gloves have been reported by increasing the friction between gloves and objects [61,92,93].

D. Range of Motion

The hands and fingers joints allow them to bend and move in different directions. The wrists and each of the fingers have their movements; however, the amount of their movement is different (Section II). Wearing gloves may change the movement of these joints and limit the movements. Limitation of hands and fingers movement reduces people's performance and increases muscle activity and also fatigue. The environmental conditions, the duration of the work cycle, the size of the glove and many other factors mentioned in Section III may also affect the movement angle. Hand-gauge measurement is performed using various tools such as manual and electrical goniometers and video cameras [17]. Few studies have been conducted on the effect of wearing gloves on the range of motion, but studies have reported that wearing gloves reduces the range of motion of fingers and wrist [8,39,44,83].

In order to overlook on the previous researches regarding the manual dexterity and range of motion, the details of the papers are gathered in Table II.

E. Tactile Sensitivity

The textures and grooves on the human hand make sensory and tactile sensations in palms and fingers. The tactile sensitivity is a feature that enables the hands and fingers to understand the shape, softness and roughness, material, size, and the texture of the objects. In other words, sensitivity to touch is perceived by the ability to recognize each of these features by the skin receptor on the hand. It is noteworthy that in addition to understanding all the touch elements such as material, shape and size, the time of understanding these features also affects the sensitivity of the hand. Usually, after wearing gloves, the sensitivity and perception of hands and fingers decrease due to the extra layers between the hands and fingers. Fess (1995) categorized the touch sensitivity test into three distinct groups consisted of: 1) Detection of the distance between two points, 2) Assessing the threshold of touch, and 3) Examining objects, shapes and textures. According to this category, each of these capabilities has been designed and built. Because of the pressure variation, size and diameter of the filaments, the monofilament test was a proper and accurate test for assessing the threshold of the touch, which presented a more logical and realistic evaluation. A two-point discrimination test is also used to recognize the distance between two points and another method for assessing the sensitivity is the shape-texture identification test. Despite all of these tests, the problem of time brings a large gap in the assessment of the sensitivity of the touch, which may result in mistakes. How long the pressure lasts, how it lasts and how long it takes to feel it are also important in sensitivity results that have not been taken into account so far. Another thing that has been overlooked until now is the ability to understand the roughness, softness, material, temperature, humidity and other factors changing by wearing gloves. Of course, in some cases, the purpose of wearing gloves is to reduce some sensory abilities, for example, when dealing with harsh or sharp objects or in contact with hot objects, the reduction of touch capacity is not a disadvantage of gloves [10].

Generally, several studies have shown that wearing gloves can affect the hand tactile sensitivity in a negative way, but some studies have reported that the use of gloves has no significant impact on hand sensitivity [13,39,44,45,56,72,81,95-97]. There are two possible reasons for this contradiction in results: one is the change in the characteristics of the tested gloves, and the other is the diversity of the type of tactile sensitivity test. Moreover, the gloves' characteristics, such as the thickness, flexibility, and stiffness of the gloves, are influential on the hand tactile sensitivity [23,98].

VI. CONCLUSION

Today, the importance of hand and body protection is more acknowledged than ever before, and for this reason, many studies have been conducted in this field. In this regard, products such as highly functional clothing with physiological comfort are produced and the use of methods such as nanotechnology, biotechnology, electrical technology in the field of manufacturing new protective equipment have been investigated [1]. From the past until now, new types of protective gloves such as anti-abrasive glove [99], anti-slip glove [100], multilayered glove [101], and double face glove [102], welding glove [103], cut resistant glove [104], utility glove [105], etc., have been produced and marketed. Also, new methods and materials for producing better and more suitable protective gloves are being proposed, continuously. This review paper includes the literature on protective gloves and its impact on various aspects of hand performance. As a result of previous studies, it was revealed that wearing gloves in most cases reduces hand dexterity, sensitivity, strength as well as increased discomfort, muscle activity and fatigue. However, there are contradictory results which could be due to the weakness in the methods of assessing the capabilities of gloves and lack of consideration of the actual condition of the gloves usage. The differences are due to the varieties in the experimental conditions, types of gloves, how the measurements were done, etc. In this case, the solution would be to develop or use standard test methods that provide an accurate estimation. Up to now, few studies have examined the design of gloves and how to improve each hand function by using design changes. According to the studies reviewed in this paper, it seems that there still exist some points that are necessary to be considered in the field of studying protective gloves including the use of gloves in long periods and real working conditions. Moreover, assessment of different features of hand performance with regards to the glove construction, and also the effect of glove's components physical and mechanical characteristics on the operative protection capabilities of gloves, are prominent aspects that are essential to be considered as the subjects of future researches on protective gloves.

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