ANALYSIS OF HANDGRIP FORCE-TIME VARIATIONS FOR ATHLETES AND NONATHLETES

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Abstract

Measurements of single and combined fingers grasping forces of athletic and nonathletic subjects (males and females) have been carried out. Results show that the maximal fingers grasping forces of males are higher than the corresponding forces of similar female groups. The maximal single or combined fingers forces decrease with time. Their endurance times vary from group of study to another and are affected by the athletic activity and the sex of the subjects. The percentage of males capable of applying forces up to specific percentage of their maximal fingers grasping forces are higher than the corresponding percentage of females except for $F_2$ forces. The endurance times ($T_F$'s) of keeping grasping forces up to 90% of the maximal values are higher than the corresponding values of $T_M$'s. The rise time ($T_r$) values for nonathletic female groups are higher than the corresponding $T_r$ values for males. The $T_r$ values of $F_1$, $F_2$, $F_3$, $F_9$ for athletic females are higher than the corresponding $T_r$ values for athletic males while the $T_r$ values of $F_4$, $F_5$, $F_6$, $F_7$ for athletic females are less than the corresponding $T_r$ values for athletic males.

Nomenclature:

- $F$: Female Subject.
- $F_1$, $F_2$, $F_3$, $F_4$: Grasping Forces of Little, Ring, Middle and Index Fingers Respectively.
- $F_5$: Grasping Forces of Ring and Middle Fingers together.
- $F_6$: Grasping Forces of Ring and Index Fingers together.
- $F_7$: Grasping Forces of Middle and Index Fingers together.
- $F_8$: Grasping Forces of Ring, Middle and Index Fingers together.

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Grasping Force of Little, Ring, Middle and Index Fingers together.

Male Subject.

Statistical Package for Social Sciences.

Indurance Time for Female Subjects.

Indurance Time for Male Subjects.

Rise Time.

Introduction:

The complexities of anatomy and function of the human hand have been reported (Landsmeer, 1963). A variety of occupational risks associated with wrist disorders have been reported (Armstrong et al., 1982; Mayer et al., 1985) that hand strength is used as a major factor for employment and physical fitness assessments. Handgrip injury statistics in U.S.A (Ayoub et al., 1975) have shown that tools handling caused 9% of all reported disabling injuries and 75% of these are due to manual tools. However, the main functions of the human hand have been divided (Landsmeer, 1963) into (a) power grasping and (b) precision handling (pinch). Power grasping is a force action of flexed fingers such that the object is held between the fingers and palm, while the thumb acts as a stabilizing element. Pinch is handling of small objects in a fine manner between the finger and the thumb.

A two-dimensional mathematical force analysis of human fingers during pinch has been carried out (Smith et al., 1964), in which the tendon and joint-contact forces have been calculated. As the movements of the human wrist and the metacarpo-phalangeal (MCP) joint is three-dimensional (Tolbert et al., 1985; Linscheid, 1986), the two-dimensional analysis is insufficient to provide realistic data for the purpose of reconstructive hand surgery. The direction of moments about the longitudinal axis of the hand and the forces generated at the finger tips have been carried out (Nathan, 1992). It has been found that the stability and the elasticity of the wrist joint soft tissue may significantly affect the direction of the joint moment vector. A three-dimensional analysis of the finger tendons and joints have been carried out (Chao et al., 1976). In this study a statically indeterminate problem was solved by using constraint conditions based on electromyography (EMG) and physiologic assessments. The models used in the analysis of the wrist movements have been carried out either by using equivalent screw displacement axes (Evans et al., 1986) or by using Euler’s angle (Youm and Yoon, 1976). Finger motions investigation has been conducted (Small et al., 1992) by using the three alignment-
based system (Floating, Euler and Cardan Axes) and the results of the three systems were found to be identical.

Muscle forces can be determined experimentally by using the EMG (Án et al., 1983; 1984). This requires collecting EMG data about the muscles involved in joint torque production which in turn form enough EMG relations which creates a statically indeterminate problem. Buchanan et al. (1993) estimated the forces of five muscles acting at the wrist by using EMG signals and found that the force of an individual muscle at the wrist can be determined with considerable accuracy.

In general, handgrip measurements (Trombly, 1983) create a baseline from which improvements can be assessed and adjustment of realistic treatment objectives. Mathiowetz et al. (1984) reported that the data of handgrip strength which have been obtained (Kellor et al., 1971) are the most commonly used in therapy clinics. Even though, they took the age and sex into consideration, they did not show a standard procedure of testing (i.e. test position, instruction, etc.).

For economical reasons and convenience, the Stoeling Handgrip Dynamometer (Type TKK Model 1201) has been widely used by physicians and therapists in field studies of adults and children (Vanswearingen, 1983). The authors of this paper (Qassem and Al-Kurdi, 1994) have used a hand dynamometer (manufactured by Lafayette Inst. Co.). They found that the middle and little fingers apply the highest and lowest single grasping forces respectively, and the hand grasping force is higher than the grasping force of any fingers combination. Some investigators have found correlation as high as 0.8 between such data and overall measures of isometric strength (Jackson et al., 1980) or isokinetic torque (Kofsky et al., 1983). The isometric handgrip force of 67 elderly men and women have been measured (Shephard et al., 1991) and found that the handgrip force decreases by 6-8% per decade.

Some of the previous investigators (Clarke, 1964; 1965) have reported a force-time (F-T) curve on university students (either males or females). In these studies, small muscles of the hand and of the elbow flexors have been tested. Even though, most of these studies have given the force in pounds or kilograms, they did not show the force as a percentage of maximal voluntary isometric contraction (MVC). The rate of force has been reported (Teeple and Massey, 1976) and found that production is independent of maximum force. The force-time components of MVC for wrist flexors and handgrip of college men and women have been investigated by using a
load cell assembly (Morris et al., 1983). The results were reported in ratios of MVC. Significant difference between the response of males and females have been found and females can reach full MVC faster than males.

Even though, the previous studies provide valuable information, the rate of MVC decrease with time among various groups of subjects is still not reported. Therefore, the purpose of this study is to investigate the time relationships of MVC of handgrip among various groups of professional college students athletes (males and females). A particular aim is to investigate the average values of single and combined fingers grasping forces. This aspect has not been considered in pervious investigations.

**Experimental Setup:**

Figure (1) shows the block diagram of the experimental setup used for measuring the maximal grasping force of handgrip as a function of time. The setup consists of a hand dynamometer, signal processor, and an xyt plotter.

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![Diagram](image)

*Fig. (1): Block Diagram of Handgrip Measuring System*

The hand dynamometer is a load cell, LCD, (0-400) capacity that converts mechanical tension caused by grasping the handle into an electrical signal which is proportional to the exerted force. This electrical signal is picked up by the "Jackson Evaluation System" (manufactured by Lafayette Inst. Co.) Model 32528. It is a signal processing system used to measure the strength of grip, arms and back. Strength is measured as:

1. Average strength displayed on an LCD output.
2. Peak strength displayed on an LCD output.
3. Instantaneous strength which can be obtained as an electrical signal from the output at the back of the system called "x-ducer analog output". The output is usually 1mV/1lb.
This study deals with the instantaneous strength value. Therefore the xducer analog output has been used and fed directly to the xyt recorder (manufactured by Phillips Co. Model No. PM 8271).

**Subject and Experimental Data:**

Human fingers grasping forces of 58 professional athletic (30 males and 28 females) and 30 nonathletic (15 males and 15 females) university students aged 17 to 23 years have been investigated. Two athletic group subjects of this study where, (a) group games - basketball players-, and (b) single games athletes such as throwing, running and jumping, racket, gymnastics and swimming. All subjects accepted the task of this study before measurements have been carried out. Jackson Evaluation System connected to xyt recorder has been used to measure the maximum grasping forces of single and combined fingers (see fig. 1). The subjects were instructed to apply the maximum grasp while the line of action of the investigated finger force acts along the axis of Jackson Evaluation System. The subject under investigation was instructed that his fingers not to touch the dynamometer handle and therefore they do not contribute to the measured forces. Each subject was also instructed to apply the force as long as he can when his arm is in the extension position (see fig. 2). SPSS software program has been used to analyze the data. Analyses include mean value, correlation factor, significance, and their variations with time (see figs. 3-5 and tables 1-3).

**Discussion:**

The average grasping forces of males and females of various single and combined fingers are presented in table (1). It shows that the average grasping forces of females fingers are lower than the average grasping forces of males corresponding fingers. Moreover, athletes fingers grasping forces are higher than the nonathletes corresponding fingers grasping forces. These results are in agreement with Qassem and Al-Kurdi (1994) previous findings. For athletic males, throwing and running and jumping athletes have the highest and lowest ring and index single fingers grasping forces respectively. Moreover, basketball and running and jumping athletic males have the highest and lowest little and middle single fingers grasping forces.

For females, throwing athletes can apply the highest single fingers grasping forces. Moreover, the basketball athletic females have the lowest little and middle single fingers grasping forces, while the racketball athletic females have the lowest ring and index single fingers grasping forces.
Fig. (2): Human Subject Applying Force

In male subjects, throwing and gymnastic athletes, the index fingers have the highest single finger grasping forces followed by the middle, ring and little fingers. Moreover, for running and jumping, basketball, racketball and swimming, athletes and nonathletes have the highest single fingers grasping forces of middle fingers followed by index, ring and little fingers.

In females subjects (throwing, running and jumping, basketball and gymnastic athletes), the highest single finger grasping force is due to index finger followed by the middle, ring and little fingers. Moreover, for racketball and swimming athletes and nonathletes, the highest grasping forces is due to middle fingers followed by the index, ring and little fingers.
Table 1: Single and Combined Fingers Average Grasping Forces (lb) for Athletes and Nonathletes, Males and Females.

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* All t-tests (P ≤ 0.05) are significant.
Table (3): t-test Results for the Difference between the Means among Sex for Maximal Grasping Forces Rise Time (sec)

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* All t-tests (P ≤ 0.05) are significant.
** t-tests (P ≤ 0.005) are highly significant.
Fig (3) Characteristic Curves of Male Subject Fingers Grasping Forces
For throwing and running and jumping athletic males, \( F_6, F_9 \) are the highest and lowest combined grasping forces respectively. For basketball, racketball, gymnastic, swimming athletic males, \( F_6, F_8 \) are the highest and lowest combined grasping forces respectively. However for nonathletic males, \( F_5, F_9 \) are the highest and lowest combined grasping forces respectively.

In females, (a) for basketball, swimming and gymnastic athletes, \( F_9 \) is the highest combined grasping force, (b) for racketball and running and jumping athletes, \( F_8 \) is the highest combined grasping force and (c) for throwing nonathletes, \( F_7 \) is the highest combined grasping force. Moreover, (a) for basketball, swimming, racketball, \( F_6 \) is the lowest combined grasping force and (b) for gymnastic, throwing and running and jumping athletes and nonathletes, \( F_5 \) is the lowest combined grasping force.

Fig (3) shows the characteristic curve of fingers grasping forces as a function of time. It shows that human fingers ability of applying grasping maximal forces decreases with time. Such variations vary from finger to finger and depend on sex and activity as shown in fig (4). It shows that in all cases, the percentage of males who could keep applying forces up to specific percentage of their maximum grasping forces is higher than the corresponding forces of females, except for \( F_2 \), where 90% of males and 92.9% of females could keep applying force up to 80% of its maximal values. It is clear that 100% of subjects could keep applying forces \( (F_1,F_2,F_4,F_5,F_6,F_7,F_8,F_9) \) up to 90% of their maximal values. Moreover, 100% of males and females could keep applying the forces of \( (F_4,F_6,F_9) \) for males or female and \( F_1 \) for females only) up to 80% of their maximal values. In addition 100% of \( F_6, F_9 \) of males and 100% of \( F_6 \) of females could be kept up to 70% of their maximal values.

Fig (5) shows that the maximal grasping forces of finger decrease with time. This could be due to muscle fatigue as has been concluded by Royce (1962). It is obvious that the endurance time \( T_f \) of keeping grasping up to 90% of the maximal force values for the case of females is higher than the endurance time \( T_m \) for the corresponding fingers of males. Moreover, the endurance time \( T_f \) of keeping grasping up to 80% is higher than the endurance time \( T_m \) of the corresponding fingers grasping force value except for \( F_2,F_9 \). For 60% and 50% of the maximal grasping forces it is found that \( T_m > T_f \) for the grasping forces of all fingers and their combinations.
Fig. (4): Percentage of Males and Females who could Apply Forces up to (90%, 80%, 70%, 60%, and 50%) of Their Maximal Values.
Fig. (5): Indurance Time (sec) of Applied Forces up to (90%, 80%, 70%, 60%, and 50%) of their Maximal Values for Males and Females.
**Fig. (6):** Grasping Forces Rise Time $T_r$ (sec) of Male and Female Athletic and Nonathletic Groups
Fig. (6) shows that all F's rise time $T_r$ (time needed to reach maximal grasping force) of nonathletic females is higher than the relevant rise time for nonathletic males. However, the rise time of $F_1,F_2,F_3,F_9$ for athletic females are higher than the relevant rise time of athletic males, while the rise time of $F_4,F_5,F_6,F_7$ for athletic females is less than the relevant rise time for athletic males. Moreover, all F's rise time for nonathletic females is higher than the relevant rise time for athletic females, while all F's rise time for nonathletic males is less than the relevant rise time for athletic males.

A comparison of the rise time of various male athletic activity groups shows that throwing athletes has the highest rise time for $F_1,F_2,F_6$ and the running and jumping athletes has the highest rise time for $F_3,F_5,F_7,F_8,F_9$. For female athletic groups, it is found that throwing, running and jumping and basketball athletes has the highest $F_1,F_6$, and $F_5$ rise time respectively. Moreover, gymnastics athletes has the highest $F_2,F_3,F_9$ rise time while swimming athletes has the highest $F_4,F_7,F_9$ rise time.

In table (2) the t-test showed that t-values between the forces of fingers between males and females vary from one athletic group to another. That is $F_5,F_8,F_9$ of all subjects (athletes and nonathletes) in general are significant at 0.05 significance level (0.008, 0.043, 0.02) respectively and $F_1$, is highly significant at 0.005 significance level (0.0001). Moreover for group games athletes the results are significant for $F_8$ at 0.05 significance level (0.012) while for single games athletes $F_1,F_2,F_4,F_6$ are significant (0.006, 0.008, 0.022, 0.011), while for gymnastic players $F_7,F_8$ is significant (0.021, 0.009). Moreover for nonathletes $F_9$ is significant (0.038).

In table (3), t-test among sex shows that t-values between rise time of all grasping forces vary from group to another. At 0.05 significance level and 0.005 highly significance level it is found that $T_2,T_7$ of all athletes are significant (0.03, 0.02) and $T_2,T_4,T_8$ of throwing athletes are significant (0.04, 0.03, 0.05). $T_2$ of racket games athletes is significant (0.01), $T_2$ and $T_9$ of swimming athletes are significant (0.01, 0.02) while $T_9$ of gymnastic athletes is highly significant(0.001).

**Conclusion:**

It is evident from the results of this study that sporting events need different levels of fingers strength, depending on the technique of executing the event. In
addition to this it is difficult to define some absolute quantity of muscular strength needed to perform such events.

It is also important to point out that it is impossible to draw a firm conclusion, not only due to variations in the strength of single and combined forces but due to the variations in fingers strength required during the execution of the event. In shot-put event, the shot is held in the palm of the hand at the beginning of the event, while at the release stage the applied force to shot is produced due to fingers (index, middle and the ring) flexion. Similarly in the case of javelin throwing the athlete grips the javelin by index and middle fingers at the beginning, whereas at release the spinning about the long axis of the javelin is produced from the middle finger which means the highest strength should be due to this finger.

Moreover, in basketball players catch the ball by hand i.e all fingers are involved in producing force, whereas in the delivery stage the index, middle and the ring fingers are involved in the production of the force. However, this is not the case in the Gymnastic events when a Gymnast swings on the horizontal bar, he grasps the bar firmly, that is, Gymnast should have strength in all fingers.

Although in track events, such as running, the objective is to cover a given distance in minimum time, the success in running requires the athletes to combine the action of legs, arms and trunk. Thus, developing the internal forces in the segment of the human body such as the hand is important due to the fact that the arm segment forces development is needed to balance the leg action during the stride phase. In jumping (pole-vault) event, the objective is to obtain a maximum displacement of the athlete center of gravity. The amount of energy stored in the pole is a function of the pole material and the vaulter force exerted on the pole which is transmitted via his hands. In swimming, the exerted force by the hands is necessary to react the resisting force of water.

Even though the number of examined athletes in this study is low, due to limited number of available professionals at this age (17 to 23 years) in such a small country like Jordan, still the obtained results are important. Therefore, further studies are needed in which higher number of professional athletes should be included.
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