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Research Article

INVESTIGATING THE EFFECT OF CARRYING BACKPACK AND WEAPON ON THE GROUND REACTION FORCE AND MOVING THE CENTER OF PRESSURE IN THE ISLAMIC REPUBLIC OF IRAN'S ARMY SOLDIERS

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ABSTRACT

Carrying loads and military equipments is one of the most important aspects of military personnel both at peace and war times. In the present study, we intend to investigate the effect of carrying backpack and weapons while walking on the movement of COP, and GRF parameters.

The present study was done in the format of pre and post clinical trial. The statistical population of this research was the IRI Army soldiers who are required to carry backpacks and weapons during marching and battles. The studied population in this study was the soldiers of Army Medical University. We used non-random convenient sampling. Based on the previous studies, we determined the sample size to be 15. People with dominant right leg were selected for the study. The weight of all these people was beyond 70 kg.

In this study, 15 soldiers of IRI Army, with mean age of 20.4 ± 1.45 years participated. The mean BMI in these soldiers was obtained to be 25.2± 2 kg/m^2 (Range 22.9-28.4). It was observed that in all of the test modes, there are statistically significant differences ($p<0.05$) in V force, magnitude of AP or ground reaction force, magnitude of ML force and movement of anterior and posterior COP. Mean of V, AP, and ML parameters while carrying weapon was significantly higher than base mode (Mode 1) ($p<0.05$). Mean of COP movement in both AP and ML directions while carrying the weapon, had a statistically significant increase compared with the base mode.

Carrying weapon and backpack brings about changes in GRF forces and movements of COP to sustain COM and the person's balance. The findings of this study indicate the need for further attention to the more appropriate, ergonomic, and accurate design of military equipment's to minimize or reduce the injuries to the military personnel and soldiers.

Keywords: *Ground Reaction Force, Center of Pressure, Carrying loads, Weapon*

INTORDUCTION

Carrying loads and military equipment's is one of the most important aspects of military personnel both at peace and war times. Depending on the needs and conditions, military personnel need to carry weapons or special equipment's. Because of this, the recognition of the effects left on the soldiers by carrying these weapons and equipment's is of great importance (Majumdar and Pal, 2010). The significance of this issue is further highlighted when we know that in many cases, these personnel need to carry loads which reach up to 60 percent of their body weight for long periods of time. This issue can give rise to different complications and injuries including stress fractures, generalized fatigue, biomechanical and postural problems (Majumdar and Pal, 2010, Knapik *et al.*, 1997). The factors which contribute to these injuries and complications include the amount of load, excessive fatigue, training and practice, their boots and the distance taken (Majumdar and Pal, 2010, Knapik *et al.*, 1997). In 18th century, the infantry used to carry 15 kg of equipment's. However, with the passage of time, and along with increased use of advanced technologies for improving safety and protection, fire power, mobility, and soldiers' communication, this load has had a dramatic increase (Knapik and Reynolds, 2004)

Sustaining balance and stability is one of the most important functions for doing many human activities particularly walking and standing. Upright stance, is an essentially unstable position whose stability and balance features can be investigated via studying the movement of center of pressure (COP), ground reaction force (GRF), which follow the movements of center of gravity (COG). In some studies, the movement of COP has been defined as a model of a random movement or emissions of a suspended matter within a liquid (Collins and DeLuca, 1993 Rougier and Caron, 2000).

Ground Reaction Force (GRF)

In physics in general, and in biomechanics in particular, GRF is a force which is exerted by the ground on an object in contact with it. For example, a person standing on the ground exerts a force, equal to his/her weight on the ground. On the other hand, ground exerts an equal force on the person as well, but in the opposite direction. The term 'reaction' has been employed based on Newton's Laws. In the present study, GRF was measured using force plate machine. Figure 1 demonstrates a sample of these measurements.

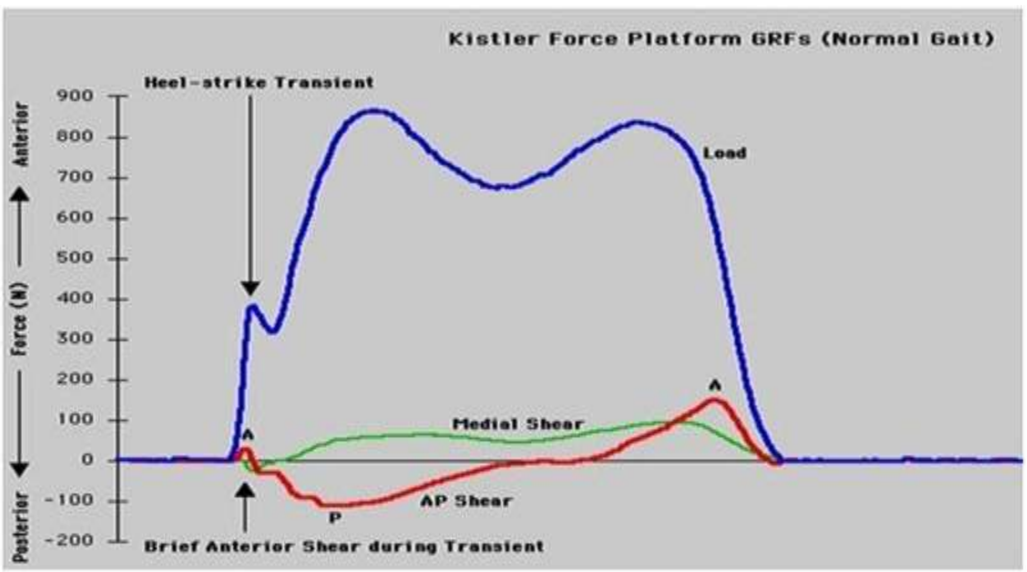

Figure 1: Measurement and analysis of GRF in a gait

Center of Pressure (COP)

Is the point on which the sole touches the ground, and at any moment all the forces on the sole are exerted on it. In other words, this point is the point on which the outcome of total forces exerted on the sole. As demonstrated in figure 2, the total forces between the foot and ground can be aggregated and create a single GRF vector. In the present study, the position of COP was determined by force plate machine. Balance and stability in upright stance is sustained by keeping COP on the base of support. The integrated data which is collected from a feedback system including the vestibular, Proprioceptive, and vision will result in keeping COP on the base of support (Gauchard, *et al.*, 2001). A number of external and clinical factors can influence the mechanisms of balance and stability and reduce their power of control. One of these factors is carrying a load by the person which has shown to be able to move COP (Chow 2010).

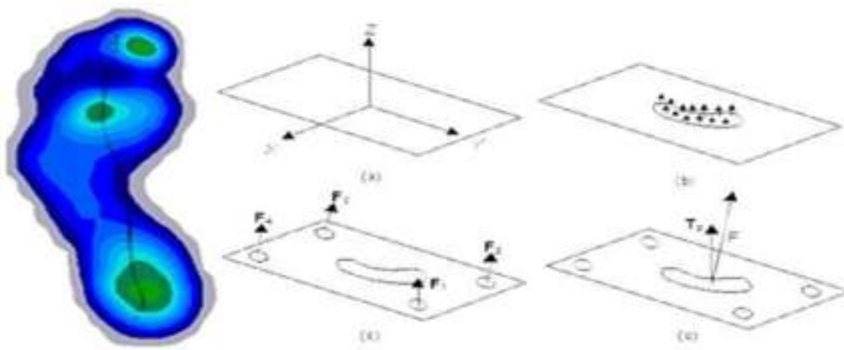

Figure 2: Centre of Pressure (COP)

A variety of factors can influence a person's ability in carrying load. One of the most important of these factors is the anthropometric features of the person including his stature, weight, length of limbs, composition. These factors tend to be different in various human societies (Attwells, 2006, Haisman, 1988, Knapik, 1996). Using measurement systems in different societies (eg, size Thailand, size Mexico, size USA, size UK) indicate that these features need to be considered in studying gait and load carrying (Majumdar, Pal, 2010). Considering this, it can be said that so far no study has investigated this issue among Iranian soldiers who are anthropometrically unique and carry specific weapons and equipments. It is clear that through further and better recognition of biomechanical effects of load and weapons carrying on the posture and gait of soldiers, the results of the present study may effectively contribute to designing better backpacks for I.R.I army soldiers which can provide better and further freedom of movement and designing boots which can reduce the detrimental effects of load carrying. In the present study, we intend to investigate the effect of carrying backpack and weapons while walking on the movement of COP, and GRF parameters. GRF study while carrying load can provide useful information about the gait mechanisms and the amount of forces exerted on the lower limbs. On the other hand, it can be beneficial in recognition and prevention of damages and injuries to the lower limbs (Birrell, *et al.*, 2007).

MATERIALS AND METHODS

The present study was done in the format of pre and post clinical trial. The statistical population of this research was the IRI Army soldiers who are required to carry backpacks and weapons during marching and battles. The studied population in this study was the soldiers of Army Medical University. In this study, we used non-random convenient sampling. Based on the previous studies, we determined the sample size to be 15.

Instrumentation, Data Collection, Reliability and Validity of Data

Force plate or force platform is a machine which is used to measure the ground reaction force created because of standing or walking on it to investigate gait, and other biomechanical parameters. The most common use of this machine is in sports and medical studies. The precision of the data obtained from the machine was completely dependent upon the calibration of the machine. Hence, before the test, the machine needed to be calibrated. Because of this, all of the data was collected by a specialist and through a primary test to cross check the accuracy of the calibration. After having the proposal confirmed by the Research Council of Army Medical Sciences University, the research started and the necessary coordination was arranged for participation of human resources. In addition, the necessary backpack and weapons were prepared. The volunteers were first examined and a form of their general health was filled out. In this study, people with full health participated and participants who were suffering from any sort of cardiovascular, kidney complications, systemic disease, or any other deformities were excluded from the study. In addition, people with dominant right leg were selected for the study. The weight of all these people was beyond 70 kg. The participants were asked to consciously sign a consent form prior to the study.

To do the study, the participants were required to walk a 10 m route in the middle of which the machine was placed. This distance was considered to help present a natural gait, so that the effects of increase and decrease of acceleration be reduced in the beginning or end of walking gait.

The test was done in 4 different modes, and participants walked at their own convenient pace. The four forms of test were:

1. Base condition: wearing standard boots of IRI Army,
2. Wearing boots and carrying an organizational weapon weighing 4.2 kg (Figure 3),

Figure 3: Type of Weapon carrying in current study (Adopted from Birrel *et al.*, 2007)

3. Wearing boots and carrying a backpack weighing 12 kg (Figure 4),

Figure 4: Type of backpack carrying in current study (Adopted from Birrel *et al.*, 2007)

4. Wearing boots and carrying a backpack and the organizational weapon.

Each person repeated each condition of the test 10 times. A test was considered successful and accurate if all the foot was placed in the impact area of the machine and the gait pattern was not adjusted or manipulated. The participants were allowed to take the route as many as they wanted to get accustomed to the conditions. To prevent early fatigue, the participants had a 10-minute rest between various test modes. The data was collected through 100 Hz frequency. It is important to note that despite taken efforts, it was not possible to carry the real weapon because of the security and safety reasons. Eventually, the test was done by making a simulation of a metal piece which simulated the weight and dimensions of a real weapon.

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Having collected the data, they were tabulated in Microsoft Excel 2007. Initially, using the same software the mean of V, AP, and ML and the mean of movement of COP in the two directions of AP and ML in each step was measured. Then, these numbers were inserted into SPSS 16.0 software. Since the data did not have normal distribution, non-parametric statistical tests were used for analyses. For comparing and contrasting the four test modes, Friedman test and for comparing two test modes with each other, Wilcoxon test was used. The significance level of the test was considered to be 0.05.

RESULTS

In this study, 15 soldiers of IRI Army, with mean age of 20.4 ± 1.45 years participated. The mean BMI in these soldiers was obtained to be 25.2 ± 2 kg/m^2 (Range 22.9-28.4). The sample participants had no history of surgery in musculoskeletal system, neurologic diseases or deformities. Since based on the kulmogrof-smirnov test, the variables under study did not have a normal distribution, the data in different test modes were compared using Friedman test. It was observed that in all of the test modes, there are statistically significant differences ($p<0.05$). In the study of V force, it was observed that the magnitude of this force had a significant increase from base mode (wearing boots) to mode 4 (wearing boots and carrying the backpack and weapon) ($p<0.05$).

The magnitude of AP, or ground reaction force, similar to V parameter, had a significant increase from base mode (wearing boots) to mode 4 (wearing boots and carrying the backpack and weapon) ($p<0.05$). The magnitude of ML force while carrying the weapon was significantly higher than the mode of carrying the backpack and the weapon and significantly lower when compared to the mode of carrying the weapon and the backpack ($p<0.05$).

The movement of anterior and posterior COP had a significant increase from mode 1 (wearing boots) to mode 4 (wearing boots and carrying backpack and weapon). However, the movement of COP in the internal-external direction while carrying the weapon was significantly higher than the mode of carrying backpack and wearing boots, and lower than the mode of carrying both backpack and the weapon ($p<0.05$).

We have compared and contrasted different modes and for this end, we used Wilcoxon test whose results are presented as follow:

a) Comparing the Base Mode (Wearing Boots) With Weapon Carrying Mode

a. In this case, we observed that the mean of V, AP, and ML parameters while carrying weapon was significantly higher than base mode (Mode 1) ($p<0.05$). In addition, it was observed that the mean of COP movement in both AP and ML directions while carrying the weapon, had a statistically significant increase compared with the base mode (wearing boots only) ($p<0.05$).

b) Comparing The Base Mode And Backpack Carrying Mode

Similar to the previous set of results in a, all the parameters had statistically significant increases in backpack carrying mode compared with the base mode (wearing boots only) ($p<0.05$).

a) Comparing the base mode with carrying backpack and weapon mode

In this case, similar to a, and b, all parameters experienced a statistically significant difference in the backpack carrying mode with the base mode ($p<0.05$).

b) Comparing the weapon carrying mode and backpack carrying mode:

In this case, we observed that the magnitude of V, and AP forces while carrying the backpack was significantly higher than the time when the person is just carrying weapon ($p<0.05$). However, the ML force magnitude while carrying weapon was significantly higher that while carrying backpack ($p<0.05$). In comparing the COP movements, it was clear that the AP movement while carrying backpack and ML movement while carrying weapon has been greater ($p<0.05$).

c) Comparing the weapon or backpack carrying mode with simultaneously carrying both

In these two comparisons we observed that when the person is simultaneously carrying both the backpack and weapon, all the under study parameters have a statistically significant increase when compared with modes in which the person is just carrying one of them ($p<0.05$).

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DISCUSSION

Since the purpose of our study is investigating the biomechanical effects of carrying backpacks and weapons and not the neuromuscular matching, the momentary effect of carrying load was assessed. It is worth mentioning that carrying backpack and weapon can leave its effects from the beginning by exerting mechanical forces.

Effect of Carrying Weapon on GRF

Majumdar *et al.,* (2010) investigated the cinematic changes in Indian Army while carrying military equipments. In this study, soldiers' gaits while not carrying any load and when they were carrying 4.2 and 17.5 kg were investigated. They concluded that significant changes in the range of hip and wrist motion and increase of trunk forward bending while carrying loads can impose injuries on the joints. As a result, the design of such military equipments and backpacks should be changed and improved (Majumdar and Pal, 2010).

Haslam and Birrel (2010) investigated the synthetic effects of load distribution due to carrying military equipments by Load Carriage System (LCS) among British military personnel. They came up with the result that while the amount of load carried is the most influential factor in creating changes in gaits and damages because of them, conducting scientific tests and improving carriage systems can reduce these risks and improve the situation (Birrel and Haslam, 2010).

Haslam and Birrel (2008) in another study, investigated the effects of carrying weapon on the soldiers' gait and declared that their findings indicated that weapon can increase the range of motion of center of gravity of body by limiting the natural swing of hands, and therefore, influences the exerted forces (Birrel and Haslam, 2008).

Birrel *et al.,* (2007) in a study studied the effects of carrying military equipments on GRF. They stated that the increase of vertical force is one of the main reasons of overuse injuries. Hence, the analysis of biomechanical effects of load carrying to earn proper recognition of injuries due to carrying military equipments is pivotally indispensable (Birrel *et al.,* 2007).

Attwells *et al.,* (2006) investigated the changes in gait and posture in response to the load increase carried by military LCS. They stated that intense muscle contractions to tolerate such changes in gait and posture will bring along injuries, muscle strain, and joint problems and complications (Attwells *et al.,* 2006)

Heler *et al.,* (2009) investigated the effects of carrying a backpack among women to study the postural sway, and finally concluded that carrying a military backpack leads to increased postural sway and this might contribute to increased possibility of fall or injuries (Heller, *et al.,* 2007).

Zultowski *et al.,* (2008) surveyed the effect of load magnitude, load positioning, and the dimensions of base of support in the upright stance while carrying a backpack. They arrived at the conclusion that attention needs to be paid to the manner of load carriage to improve posture control and prevent unnecessary pressure (Zultowski *et al.,* 2008).

Sako *et al.,* (2004) studied the effect of magnitude of load and position of the load on the body swing in the upright stance and carrying a load. They concluded that the study of COP in a static condition can contribute to better recognition of individual characteristics' effects and magnitude and position of the load on the body's swinging (Sako *et al.,* 2004)

Schiffman *et al.,* in their study in 2006 studied the effect of the load carried by soldiers on their postural sway. They came up with the conclusion that increase of load can endanger the balance of the person and military personnel have to exert a higher controlling force on the load to sustain their balance and stability (Schiffman *et al.,* 2006).

The design of this study was in a way that it could investigate the effect of carrying weapons on the parameters related to sole (COP and GRF). To make enquiries about the effect of carrying weapons, the magnitude and value of parameters while carrying weapons was compared and contrasted with the base mode (wearing boots only). It was observed that while carrying weapons all three parameters of GRF increased.

Birrel *et al.*, in two different studies observed that carrying weapons causes an increase in impact peak (GRF vertical parameter while heel s) and AP and ML forces. On the other hand, these researchers noted that the thrust maximum (GRF vertical parameter while toe-off) and force minimum (GRF vertical parameter while midstance) decreases, and consequently, unlike our study, the total magnitude of vertical parameter stays constant while carrying weapon (Birrel and Haslan, 2010, Birrel, *et al.*, 2007).

In general, carrying weapon leaves its effects in two different ways. First, increasing the load of anterior trunk which is caused by carrying weapon, and second, it limits the arms swinging while walking which influences the movement of COP. It has previously been shown that the movement and swinging of arms while walking can adjust the movement of COP in vertical and horizontal alignments (Elftman, 1939, Murray, 1967, Hinrichs and Cavanagh, 1981). Accordingly, it can be assumed that restricting the arms swinging can disrupt the harmony of movement of COP over the vertical axis. As a result, COP needs to take a larger range of movement and it experiences bigger swinging. Another important point is that the previous studies have shown that carrying load around hips or in a front pack can increase impact peak parameter because of further movement of COM forward and increase of proportion of load on the leg which is in stance phase (Birrel *et al.*, 2010, Hsiang and Chang, 2002). Since our purpose in the present investigation was not real-time study of vertical GRF, and only its total was measured, we cannot speak about its increase and decrease in the different periods of stance phase. Due to the fact that the increase of force is repeated in each step, and even if it is a negligible amount, it can exert a considerable force on the limb of the individual. Body is responsible for absorbing and neutralizing these forces. Now how clinically important this increase of force is requires conducting further research and is not known to us. Feltner *et al.*, and Lees *et al.*, indicated that the arms swinging at the times of vertical jumps considerably increases the ability of the body to pull the trunk up (Feltner *et al.*, 2004, Lees, *et al.*, 2004). The last point to mention is that if arms swinging were not effective in thrusting the body forward, in the present study and that of Birrel *et al.*, no significant difference would be found in the magnitude of AP parameter between times at which arms were free to move, and times at which weapons were being carried. In our study, similar to the one of Birrel *et al.*, the ML force increased while carrying weapons (Birrel and Haslan, 2010, Birrel, *et al.*, 2007).

The Effect of Carrying Backpack on GRF

In this study we observed that carrying a backpack can create important changes in GRF. In fact, as shown in various other studies, load carriage in our study has led to increase of GRF parameters, particularly its vertical parameter (Birrel *et al.*, 2007). Have investigated different load carriages in different systems including backpack. They observed that from among 3 parameters related to V parameter (impact force, force minimum, thrust maximum), only changes observed in the thrust maximum were statistically significant. This parameter significantly decreased with carrying load [(Birrel and Haslan, 2008). These researchers in a different study observed that, similar to our study, upon carrying load, the V force will increase in a linear fashion (Birrel and Haslan, 2010, Birrel, *et al.*, 2007). It is said that increase of V force includes impact force such as time of carrying or running, an important risk factor is overuse injuries (Birrel and Haslan, 2010). The increase of V force can raise the possibility of stress fracture, tibia, metatarsus, and related problems and complications of knee joint (Polcyn, 2002, Knapik, *et al.*, 2001).

In the present study, as previously observed, the magnitude of AP force increased with carrying backpacks. The important point in this area is that the increase of cutting/shear forces in AP axis can create blister in the sole of the feet, which is the most complication of load carriage, and can be extremely painful and debilitating at times (Knapik, *et al.*, 1997). Knapik *et al.*, suggested that load carriage, increases the pressure on the skin and through creating bigger AP forces, can cause more movements between feet and boots and therefore increases the possibility of blistered foot (Knapik, *et al.*, 1997). In our study, we observed that the magnitude of ML force increases by carrying a backpack. Unlike our present study, some researchers have noted that the changes in the ML force parameters while carrying a weapon is negligible, and some of them have totally ignored this issue (Knapik, *et al.*, 1996, Birrel and Haslam, 2008, Polcyn, 2002). On the contrary, Birrel *et al.*, in their study observed that, similar to our study, ML parameter is increased by carrying a backpack. However, this increase was not statistically significant.

The Effects of Carrying both Backpack and Weapon

In the present study, it was observed that the GRF parameters and COP movement increased in both directions. In other words, simultaneous carrying both the weapon and backpack, through limiting the arms swinging, leaves more fundamental and important effects on COM and as a result, GRF and COP.

The Effect of Carrying Load and Weapon on the Movement of COP

We observed, in our study, that carrying weapon and backpack separately and simultaneously has led to increase in the movement of COP in two directions of AP and ML. it is clear that this increase indicates the reduced body stability and on the other hand, efforts of stability and balance mechanisms to maintain control of the body.

Like all other studies, our study suffered from a number of limitations. The most limitation of our study was that we dealt with GRF parameter in a total and not detailed manner. There was not real-time analysis of GRF in different phases of gait. In fact, in this study, due to the restricted facilities, we lacked the ability to analyze the gait using the infrared cameras. Another limitation of our study was that we analyzed only one type of backpack with a fixed amount of load, while it is possible that with the increased load of the backpack, the observed changes prove to be drastically different.

Conclusion and Suggestions

Carrying weapon and backpack brings about changes in GRF forces and movements of COP to sustain COM and the person’s balance. These changes, although trivial, because of being repeated can cause various harms to the body of people. In a study, it was mentioned that sometimes military personnel walk a distance around 11 km which causes exertion of 9000 hits to their lower limbs. Because of this, the ability to accurately predict forces created while carrying heavy loads within long distances might prove very beneficial. In addition, the findings of this study indicate the need for further attention to the more appropriate, ergonomic, and accurate design of military equipment’s to minimize or reduce the injuries to the military personnel and soldiers. This, however, requires detailed and numerous investigations. In fact, we need to review the shape of backpacks and weapons, and to use lighter weapons to prevent such problems as much as possible and improve the speed, mobility and agility of the military personnel. Suggestions are:

1. In addition to force plate, gait analysis system equipped with infrared cameras be used to study the real-time forces in different phases of gait.
2. The effect of magnitude of load be investigated on the force and COP movement.
3. The long-term effect of carrying military equipment’s be analyzed on the person’s gaits.
4. More participants or samples be used.

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