

CIVILIAN FOOTSTEPS

Forces exerted on the ground by civilians during everyday activities

landmine action
THE CAMPAIGN AGAINST LANDMINES

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Comments on the contents of this report are welcome.

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The full data set acquired for this report is available from Landmine Action (a charge may be made for production and postage).

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1 Introduction

The 1997 Ottawa Convention banned the use, development, production, stockpiling and transfer of anti-personnel mines. Unfortunately, distinctions between mines designed to kill or injure people and mines labelled anti-tank or anti-vehicle are not always clear.

A recent report (Landmine Action/GIBL, 2001) identified a number of 'anti-vehicle' mines that can be activated by pressures of between 2.2 kg and 100 kg. One US military source is reported as stating in 1971 that 130 kg to 180 kg of pressure was needed to activate common anti-vehicle mine pressure fuzes, but that the activation pressure may be modified to produce detonation from lighter pressure, such as soldiers, civilians running or light vehicles.

In March 2001 a meeting of international experts was convened by the International Committee of the Red Cross in Geneva to discuss anti-vehicle mines (AVM). Attention was focused during those meetings on a **minimum initiation pressure** in order to achieve the military objectives of the weapon while posing no foreseeable or avoidable threat to non-combatants. Some experts favoured a prescriptive approach, suggesting that a minimum pressure be imposed by international convention, while others argued that this could encourage the wide-scale manufacture of AVMs capable of initiation at the lowest legal pressure as the norm. One suggestion, favoured by a number of delegates, was for a minimum pressure of 150 kg.

Landmine Action consider this to be a matter of some concern because there appears to be a lack of objective evidence to show that 150 kg is a 'safe' minimum pressure.

International attention has been focused on the landmine because of its potential impact on non-combatants and on post-conflict rehabilitation. It is perhaps surprising therefore that no trials appear to have been published showing landmine initiation pressures that would not result in casualties among people involved in normal civilian activities. One possible explanation for this lack of data is the international focus on weapons which possess such low pressure thresholds that non-combatants are always vulnerable.

There is no widely accepted or legal definition of an anti-vehicle mine. This may contribute to uncertainty as to what constitutes acceptable minimum pressure thresholds to enable AVMs to achieve their military purposes without the risk of causing disproportionate incidental effects. Some sources consider the term anti-vehicle mine an alternative name for an anti-tank mine, while others point to the military imperative to destroy lighter vehicles. Although it is clear that the targets of such weapons are vehicles, there is a wide range of vehicles in military use, including Main Battle Tanks weighing in excess of 40 tons and lighter armoured personnel carriers. Soldiers routinely use four-wheel drive vehicles, and in some cases bicycles.

From a military perspective it is clearly wasteful and uneconomic if an AVM, designed and intended to destroy or immobilise a high value target, is vulnerable to initiation by a soldier on foot. From a humanitarian and legal standpoint an AVM which can be accidentally initiated by a person innocently engaged in a normal activity would, by definition, be an anti-personnel mine and therefore subject to the relevant landmine Conventions.

1.2 Study concept

It would be a major task to perform tests across the full range of existing AVMs. Such tests may in any event have little direct relevance to current and future AVM developments.

This study, therefore, set out instead to determine the pressure exerted on the ground by humans in the normal course of their daily lives. This provides both landmine designers and legislators with the

baseline data necessary to draw a safe line of demarcation between landmines capable of initiation by persons travelling on foot and mines only capable of being detonated by a vehicle.

Landmine Action commissioned the Sports Biomechanics Research Group at Loughborough University to conduct a series of independent experiments designed to measure the forces exerted by humans while engaged in a range of activities common to communities worldwide. The tests included:

- A series of baseline activities – walking and running on level ground and on uphill and downhill gradients. Each of these tests was conducted both in footwear and with bare feet.
- A series of trials designed to replicate activities common to most population groups in most countries, ranging from children's games to various work-related carrying activities. A number of experiments were carried out with the subject dropping to the ground from varying heights, to replicate a person alighting from various forms of transport. This latter activity was of special relevance since the act of dismounting from a vehicle on a road or verge is commonly a time when the pedestrian may intuitively be expected to exert a greater amount of pressure than might be considered normal, on areas of ground which could be most likely to contain AVMs. Heights for this test took into account that, in many communities, it is common for civilians to travel in the rear of large commercial trucks.
- A number of additional experiments were included to establish the force exerted by two light vehicles; a loaded wheelbarrow and a bicycle ridden by an adult. In addition a series of basic tests by a subject representing an infantryman in combat marching order were included as a useful point of reference and comparison.

There are many other occupation-related tasks which could have been added, such as hoeing, hand-ploughing and road repair activities but this project was designed to offer a wider understanding of ground pressures which might innocently be exerted and thus assist the international community in efforts to reduce the risk of non-combatant and post-conflict casualties resulting from the use of anti-vehicle mines.

2 Tests: forces exerted on the ground during everyday activities

2.1 Introduction

Whenever a human body is in contact with the ground there are equal and opposite forces acting between the body and the ground (Newton's Third Law). The vertical force exerted by a body on the ground is equal to the sum of the weight of the body and the vertical acceleration of the body multiplied by the body mass (Newton's Second Law). Therefore both of these factors need to be considered when interpreting the forces exerted on the ground.

For an individual, bodyweight and mass are constant over the time it takes to take a step, jump up, drop down or sprint. However, the accelerations during these movements change rapidly and hence the forces exerted can change considerably. A human can change the acceleration of the body while in contact with the ground by changing the technique used (changing muscle activation time histories). In addition the accelerations of the body are also effected by the accelerations and movements of the ground. This is most obvious when mats or sprung floors are used to cushion landings and when spring boards or trampolines are used to enhance the forces produced for jumping. These interactions can be complex as the forces may be attenuated by the physical properties of the ground. The ground will tend to attenuate the force by absorbing, reflecting and redirecting energy. The extent to which this occurs is dependent upon its viscosity, elasticity, layering and geometrical configuration of its component particles.

Forces are measured in Newtons and denoted by the symbol N, where 1N equals the force produced when a mass of 1 kg experiences an acceleration of 1 m.s^{-2} (Newton's Second Law). An alternative notation for expressing force is in terms of bodyweights of the person producing force, where one bodyweight is equal to the vertical force exerted on the ground when the person is standing still. It is often helpful to express force in terms of a person's bodyweight as it allows a meaningful comparison between subjects of different sizes. Using bodyweights is particularly useful when looking at relative forces as opposed to absolute forces. Another common method of describing the magnitude of a force is to use the units of mass, Kilograms (abbreviated to kg). One Kilogram of force is equal to 9.81 Newtons and is more correctly termed a Kilogram weight. The difference between force and pressure should also be noted. Pressure is the force per unit area and is measured in Pascals, where 1 Pascal is equal to 1 Newton per square metre. This report will express the force data in the units of Newtons and where helpful also express the results in terms of bodyweights and Kilograms (kg).

Movements with large accelerations are usually referred to as dynamic activities e.g. running, jumping and landing. These movements can produce very large forces on the ground when compared to just standing or walking (Hamill and Knutzen, 1995, Hamill et al, 1983 and Muro et al., 1987). In extremes of dynamic movement, forces exerted through one leg onto the ground have reached 11770 N in long jumping (Hay, 1986) and 10000 N in triple jumping (Hay, 1992). Furthermore, Stacoff et al. (1988) showed that landing from a volleyball block with drop heights of 65 cm resulted in peak forces in the range of 8 to 9 bodyweights. Pain (1999) demonstrated that two footed landings from a drop height of 0.43 m can produce forces of over 14500 N (18 Bodyweights). In these situations humans have the ability to withstand a large range of forces without injury. At the other end of the spectrum, humans require a minimum level of forceful interaction to maintain healthy bones and other tissues. Probably the most noted cases are of bone loss in astronauts on long duration space flights (Holick, 2000). Typically humans therefore have a tendency to perform their daily functions within a window that provides the necessary stimulation but avoids acute injury.

The forces exerted on the ground by a human body are commonly measured using a force plate. This can be thought of as a very versatile and sophisticated measuring scale which records force in all directions at once. The force plate detects the force exerted using force transducers which convert the force into an electrical charge proportional to the force applied. The electrical charge can then be

amplified, converted to a voltage and measured by an electrical system, commonly a computer. This gives a time history of the forces applied for the interaction between the human and the force plate.

The purpose of this study is to quantify the magnitude of forces exerted on the ground by a representative group of individuals performing everyday activities using a force plate. The effect of body mass, type of activity, ground composition and ground depth, on the forces that are exerted on the ground will be investigated.

2.2 Methods

A force plate (Kistler 9281-B12) was used to record ground reaction force data produced during a broad range of everyday activities. The force plate data were sampled via an analog to a digital convertor at 1000 Hz.

Test subjects

Five subjects were invited to take part in the study (Table 1, page 13) and signed informed consent forms; in addition for subjects 3 and 4 a parent counter signed each consent form as the subjects were under the age of 18. Subjects 1 and 2 were chosen as representative male and female adults, subjects 3 and 4 were typical male and female children and subject 5 was chosen to represent a military soldier.

Activities

The activities performed were split into three groups:

- a group of baseline activities performed by subjects 1-4
- a number of specific activities which appropriate subjects performed
- some basic activities on different surfaces performed by subject 1.

The first group of tests were used to provide some quantitative data on the forces produced during everyday movements by a range of subjects. The second group of tests were used to demonstrate the forces produced during some specific tasks and the third group of tests were used to demonstrate the different forces exerted on the plate when different materials and different depths of material were placed above it. Figure 1 (page 11) shows the experimental set up with one of the subjects performing a drop landing. The top left corner of each image shows the vertical force trace up to the instant in time shown in the corresponding image.

Baseline activities

The baseline activities were walking, running, running uphill and running downhill for shod (wearing their own shoes) and unshod (barefooted) conditions. The walking trials consisted of each subject walking at their own pace with one foot contacting the force plate during each trial. For each running trial the subjects were asked to run at a pace similar to them 'running to catch a bus' with the horizontal velocity of each trial measured using an array of photo-electric cells attached to a digital timer. Running uphill was replicated by the subject's foot contact on the force plate being 0.13 m higher than the previous foot contact on the ground. Running downhill consisted of the subject's foot contact on the force plate being 0.12 m lower than the previous foot contact on the ground.

Specific activities

The specific activities were chosen to replicate typical actions by children and adults. Subjects 3 and 4 performed the following activities; skipping on the spot, jumping on the spot, hopping on the spot, stamping on the spot, hopping forwards, a running jump, a drop landing from a height of 0.45 m, kicking a football (support leg in contact with the force plate), playing 'tig' for 20 seconds and play

fighting (wrestling) for 10 seconds. In addition subject 4 simulated a child carrying a baby by carrying a 6.75 kg (15lb) mass while walking. These activities were chosen as they represented a broad range of activities that are frequently performed by children. Subject 2 simulated an adult carrying firewood or fertiliser by walking over the force plate while carrying a 15 kg bag of wood chips. Subject 5 simulated typical military activities by walking, running and drop landing from a height of 0.45 m with a 30 kg backpack.

Activities on different surfaces

Subject 1 performed the following activities on seven different surfaces: running, a running jump, jumping on the spot and drop landings from heights of 0.80 m and 1.18 m. The seven surfaces used were the force plate:

- with no covering
- covered with 0.04 m of sand
- covered with 0.12 m of sand
- covered with 0.04 m of gravel
- covered with 0.12 m of gravel
- covered with a 0.04 m thick judo mat
- covered with three 0.04 m thick judo mats.

The sand and gravel surfaces were contained in boxes secured to the force plate to ensure that all the force exerted on the surface of the sand or gravel was transmitted to the force plate. The trials with the judo mats allowed the force exerted to be transmitted to the ground surrounding the force plate as well.

Data collection

Each subject repeated each activity five times to provide an indication of the variation in forces exerted; each was also given a few trials to become familiar with the activity and contacting the force plate correctly. Any trials in which the subject partially or completely missed the force plate were repeated.

Data analysis

Forces in all three directions were recorded. However, only the vertical force was used in this study, as this is the dominant force in all the activities performed and is commonly collected in isolation in other studies. For each trial the peak vertical force was determined. The mean and standard deviation were then calculated for each group of five repetitions.

2.3 Results

Baseline activities

The peak vertical forces (mean \pm SD) for the baseline activities are shown in Table 2 (page 13). The peak vertical forces for shod walking (velocity: subject 1, $1.5 \pm 0.1 \text{ ms}^{-1}$, subject 2, $1.7 \pm 0.1 \text{ ms}^{-1}$, subject 3, $1.5 \pm 0.1 \text{ ms}^{-1}$ and subject 4, $1.3 \pm 0.1 \text{ ms}^{-1}$) were found to be in the range 1.2 to 1.5 bodyweights. The peak vertical forces in shod running on the flat (velocity: subject 1, $4.9 \pm 0.1 \text{ ms}^{-1}$, subject 2, $4.5 \pm 0.1 \text{ ms}^{-1}$, subject 3, $3.8 \pm 0.2 \text{ ms}^{-1}$ and subject 4, $3.6 \pm 0.2 \text{ ms}^{-1}$), increased to be in the range 2.5 to 3 bodyweights. These data for running and walking are in good agreement with data from the literature (Hamill and Knutzen, 1995). Peak vertical force increased in a similar fashion for all subjects for shod running uphill and running downhill (comparable speed to running on the flat). This

increase in peak vertical force was due to the increased accelerations required for the body to rise up against gravity or brake the step down.

For the unshod trials the subjects performed at very similar speeds as in the shod trials but had some variation in technique which can be seen in the results in Table 2. The peak vertical forces increased for all activities for subjects 3 and 4 and increased for most activities for subjects 1 and 2 when compared to the equivalent shod trials. For the unshod trials similar changes in the peak vertical forces exerted were observed for the four different activities.

The highest mean force from these baseline trials of 2813 N is greater than four bodyweights and equivalent to a 280 kg person standing on the force plate.

Specific activities

Tables 3 and 4 (pages 13 and 14) demonstrate that dynamic movements produce much higher peak forces than activities such as walking with heavy loads or wrestling. This is because the force due to the acceleration of the body is much greater than the force due to bodyweight. In the walking trials with added loads the peak force increased when compared to the unloaded walking. Peak force in walking with the 30 kg backpack was over 1.5 bodyweights. Subject 5 considered the drop landing height to be quite modest yet peak forces of over 6000 N were produced.

Figure 2 (page 12) shows typical force traces (line graphs) for some of the specific activities. These curves show a wide range of forces with the peak forces of a child performing a very dynamic activity (figure 2c) greater than that of a much larger heavily loaded adult male performing a less dynamic activity (figure 2d). The children performing dynamic activities were both able to produce peak forces in certain activities of over 3500 N or the equivalent of 350 kg.

Activities on different surfaces

Table 5 (page 14) shows the peak vertical forces (mean \pm SD) for subject 1 performing a range of activities on different surfaces. In the running and running jump activities all the surfaces reduced the peak force from that measured directly onto the force plate. However, the peak forces were all still within the normal range of expected forces with values between 2.6 and 3.1 bodyweights. Figure 3 (page 12) shows some example traces for characteristic activities performed by subject 1 in this section of activities.

For sand and gravel the deeper the covering of material the lower the peak force. This was as expected due to the damping effect of the sand and gravel since it compresses during the foot contact. A single mat reduced the peak force by more than any other surface but surprisingly having three mats actually increased the peak force of the subject running above the level of one mat. This was due to the peak force occurring during the active push off phase of the run and not during the impact phase (when three mats were used). The large compression of the mats required the subject to exert extra force with extra time to generate a larger force to push himself off the compressed mats. For the running trials on the three mats the foot was in contact for 0.21 seconds whereas for the other trials the foot was only in contact for 0.18-0.19 seconds.

For the drop landings no real trend can be seen in how the surface altered the peak force for drops from the same height. For all but the three mats covering the plate the lowest mean peak force was recorded in the trials directly onto the force plate. This would appear to be quite the opposite to what would be expected, but can be explained by considering the fact that the subject has intelligent, active control of how he lands. This is clearly demonstrated by the dropping trials directly onto the force plate from a height of 1.18 m. The first trial performed resulted in the single highest force recorded, 10087 N, however, the four subsequent trials from that height had a mean peak force of 6325 N (a 37 per cent reduction in the peak force). To achieve this the subject adapted his landing technique during trials 2-5 so that the landings were more comfortable.

These drop landing trials demonstrated that the technique chosen by the subject was dominant and determined the level of forces produced. It can therefore be suggested that the peak forces observed should be representative of the forces produced over a wide range of different surfaces. When the force plate was covered with three mats for the drop landings the peak forces were lower than in any other surface conditions. This is due to the mats deforming to a large extent while still having the potential to compress further. The surface was therefore dominant over the technique of the person in attenuating the peak force when three mats were used. These results from the force plate covered with one mat and three mats are important to consider as they were judo mats designed to reduce forces in landings and also allow some of the force to be transmitted to the surrounding floor away from the force plate. However, with a single mat a peak force of over 10 bodyweights was recorded compared to the highest peak force of 12 bodyweights when drop landing from 1.18 m.

There was a decrease in the peak force observed when the covering was increased from 0.04 m to 0.12 m for the vertical jumping trials. In these trials the peak force occurred as the subject was actively braking and pushing back up. In addition the vertical jumping trials with the mats covering the force plate showed the highest forces as in the running jump.

3 Summary of results

Running and walking trials on a flat surface produced peak forces comparable with other studies with peak forces up to 1.5 bodyweights in walking (a maximum of 997 N), and 3.1 bodyweights in running (a maximum of 2132 N). Running uphill and downhill increased the peak force by approximately one bodyweight, for the gradients used in this study, to a maximum of 2813 N. In the specific activities it is important to note that the children were able to produce high peak forces, greater than 4000 N (equivalent to 400 kg) when performing very dynamic activities. These forces are actually higher than those of a large adult running or even jumping.

The highest forces produced were in drop landings by an adult with a single trial reaching a peak force of over 10000 N. The drop landings from different heights onto natural ground coverings ranged from 5800 N to 8200 N on average. The drop landings onto different surfaces indicated that the technique of the subject was dominant in determining the peak forces. The subject was quite capable of repeatedly performing landings that had peak forces of over 10 times his bodyweight on a number of surfaces.

Humans can produce very high peak vertical ground reaction forces many times greater than their bodyweight while performing normal active tasks.

4 Conclusions

It should be of serious concern to armed forces and non-governmental organisations alike that a person, dropping from a height equivalent to dismounting from the rear deck of a cargo truck, may exert a ground force many times in excess of his or her own bodyweight. But perhaps of more concern is the fact that a child can quite easily, while skipping for instance, exert downward forces in excess of a common AVM initiation pressure of 150 kg. This study has shown that a child weighing less than 40 kg can produce forces in excess of 450 kg by dropping from a height of less than half a metre, the equivalent of jumping from a garden wall or out of the back of a light goods vehicle. This is obviously worth careful consideration by those interested in safe initiation thresholds.

Although one of the tests conducted, a drop landing by a man weighing 90.2 kg carrying a 30 kg backpack, could be described as extreme, this test was included to replicate a military activity and war is a scenario where extreme situations are common. This particular experiment may be viewed as important in illustrating the vulnerability of the civilian over the trained soldier in the context of the additional finding that, when repeating physical tasks such as drop landings, the subject will adjust technique to reduce the impact on the body and, therefore, the ground pressure exerted. A trained soldier would be likely to exert less downward force than a civilian who was only occasionally called upon to perform more extreme tasks.

These results may assist in the development of an improved understanding of the interface between military utility and the vulnerability of non-combatants.

5 Recommendations

- States Parties to the Ottawa Convention should transparently review the initiation thresholds of all anti-vehicle mines in existing stocks and in development, reporting this promptly under the existing Ottawa Convention reporting framework. As part of such reviews, States Parties should provide convincing technical and field information, making it available to independent observers such as specialist non-governmental organisations, that demonstrates anti-vehicle mines are not capable of being initiated by the forces exerted by civilians on foot.
- States parties should give due consideration to the findings of this research in efforts to determine 'safe' pressure thresholds.
- Interested parties should institute a wider and more comprehensive study of the vulnerability of non-combatants to anti-vehicle mines during military operations and in post-conflict environments.

Figures

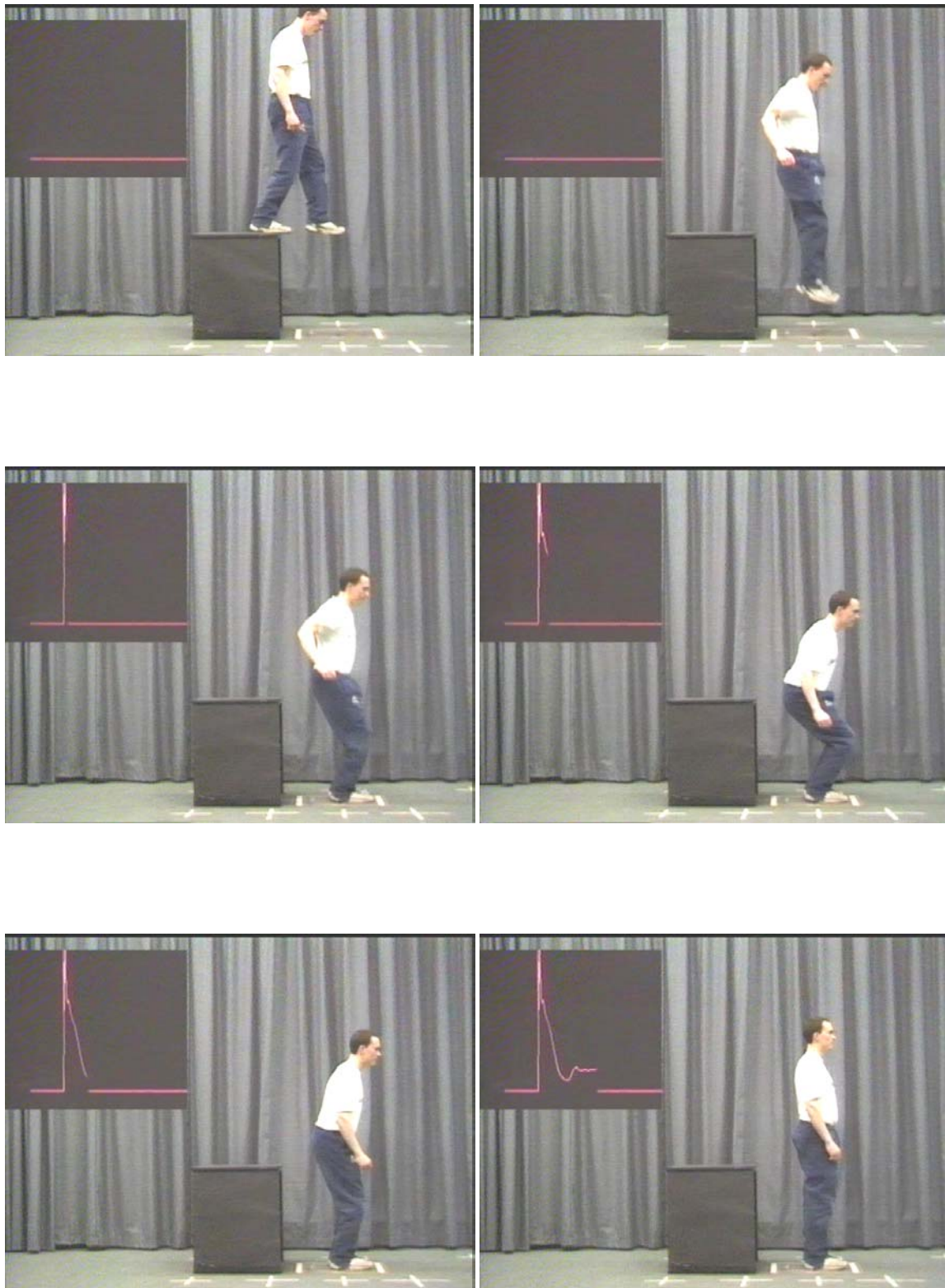


Figure 1. Example of a subject performing a drop landing.

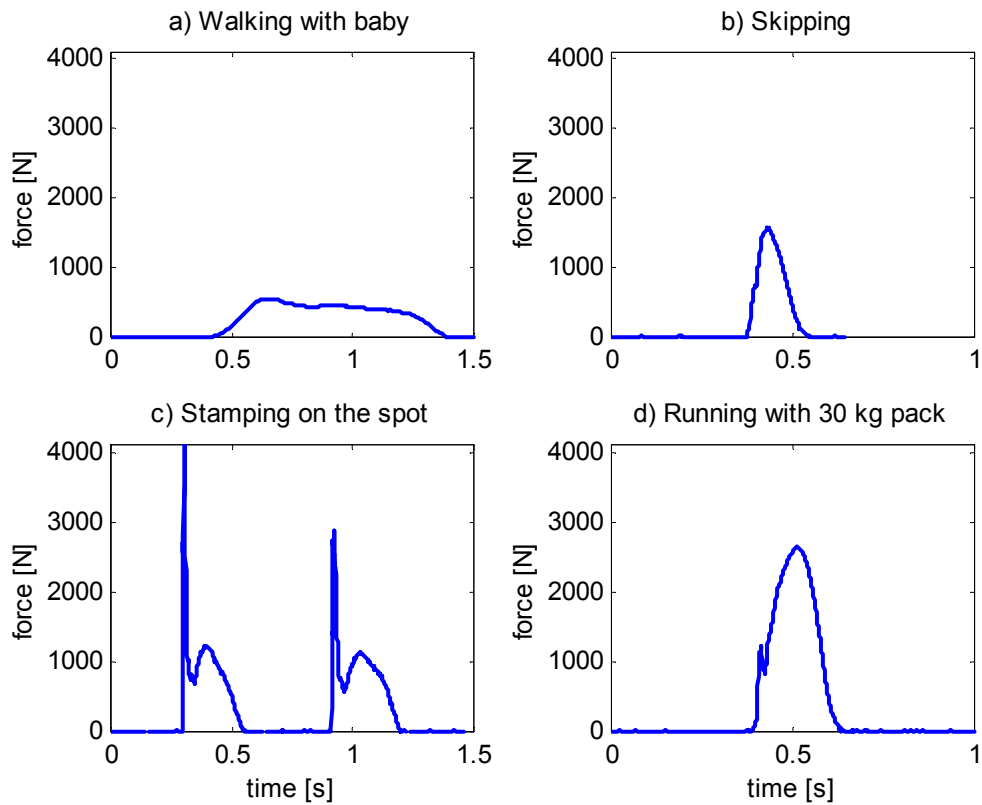


Figure 2. Vertical ground reaction force traces for subjects 3 (figure 2b), 4 (figure 2a and 2c) and 5 (figure 2d) performing a range of the specific activities examined.

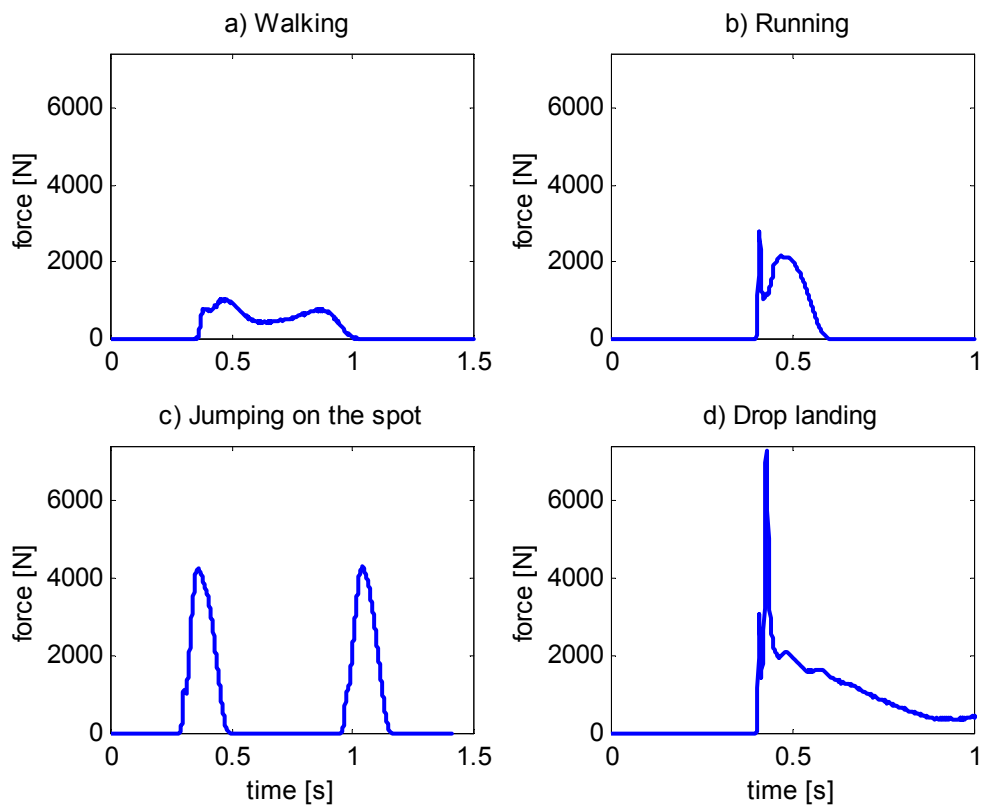


Figure 3. Vertical ground reaction force traces for subject 1 performing a range of the activities examined. Peak force range: (1020 N in figure 3a to 7310 N in figure 3d).

Tables

Table 1. Gender, age, mass and height of the five subjects.

	Gender	age [years]	mass [kg]	height [m]
subject 1	male	24	70.7	1.75
subject 2	female	24	69.9	1.70
subject 3	male	8	30.2	1.34
subject 4	female	9	39.2	1.45
subject 5	male	29	90.2	1.75

Table 2. Peak vertical ground reaction force data (mean \pm SD, measured in Newtons) for the baseline activities performed by subjects 1, 2, 3 and 4 (shod and unshod).

	subject 1	subject 2	subject 3	subject 4
shod walking	997 \pm 20	884 \pm 43	470 \pm 37	498 \pm 41
shod running	2107 \pm 88	2132 \pm 107	889 \pm 48	982 \pm 29
shod running uphill	2492 \pm 114	2513 \pm 294	1324 \pm 100	1300 \pm 150
shod running downhill	2696 \pm 197	2562 \pm 177	1434 \pm 164	1344 \pm 121
unshod walking	956 \pm 19	938 \pm 54	560 \pm 18	505 \pm 49
unshod running	2027 \pm 63	2130 \pm 43	994 \pm 149	1237 \pm 324
unshod running uphill	2663 \pm 303	2813 \pm 459	1630 \pm 309	1421 \pm 271
unshod running downhill	2730 \pm 377	2113 \pm 287	1740 \pm 377	1645 \pm 322

Table 3. Peak vertical ground reaction force data (mean \pm SD, measured in Newtons) for the children's activities performed by subjects 3 and 4.

(shod trials)	subject 3	subject 4
skipping on the spot	2209 \pm 409	1391 \pm 75
jumping on the spot	1183 \pm 181	2457 \pm 690
hopping on the spot	1228 \pm 328	1383 \pm 109
stamping on the spot	3237 \pm 109	3886 \pm 652
hopping forwards	1668 \pm 331	1783 \pm 181
a running jump takeoff	958 \pm 82	1315 \pm 184
drop landing from 0.45 m	4004 \pm 536	4527 \pm 1338
kicking a football	1003 \pm 41	826 \pm 111
subject 4 carrying a baby	-	598 \pm 58
subjects 3 and 4 playing 'tig'	1007 \pm 256	
subjects 3 and 4 wrestling	751 \pm 65	

Table 4. Peak vertical ground reaction force data (mean \pm SD, measured in Newtons) for the specific activities performed by subjects 2 and 5.

(shod trials)	Peak vertical force
subject 2 carrying 15 kg bag	1112 \pm 92
subject 2 riding a bike	485 \pm 13
subject 2 pushing a loaded wheelbarrow (total mass 110 kg)	1061 \pm 8
subject 5 walking with 30 kg backpack	1845 \pm 178
subject 5 running with 30 kg backpack	2709 \pm 96
subject 5 drop landing with 30 kg backpack	6252 \pm 447

Table 5. Peak vertical ground reaction force data (mean \pm SD, measured in Newtons) for activities performed on different surfaces by subject 1.

(shod trials)	force plate	0.04 m sand	0.12 m sand
running	2107 \pm 78	2096 \pm 78	1889 \pm 145
running jump	3003 \pm 114	2714 \pm 356	2441 \pm 103
drop 0.80 m	4497 \pm 284	5827 \pm 664	6253 \pm 154
drop 1.18 m	7077 \pm 1765	8213 \pm 965	7812 \pm 811
vertical jumping	3838 \pm 136	3912 \pm 370	3422 \pm 79

Table 5 (continued).

(shod trials)	0.04 m gravel	0.12 m gravel	0.04 m mat	0.12 m mats
running	2086 \pm 101	1866 \pm 97	1794 \pm 68	1932 \pm 27
running jump	2798 \pm 331	2560 \pm 197	3158 \pm 167	2897 \pm 203
drop 0.80 m	6026 \pm 1039	5950 \pm 987	5672 \pm 458	3862 \pm 295
drop 1.18 m	7872 \pm 1252	8247 \pm 1155	7111 \pm 1180	5243 \pm 279
vertical jumping	3730 \pm 567	3446 \pm 79	4234 \pm 148	3932 \pm 184

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