ACCELERATION PROFILES FOR TASK PERFORMANCE IN HUMANS

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ABSTRACT

Upper body acceleration was recorded as subjects performed a series of well-defined tasks. Preliminary data analysis indicates that there are detectable differences in the acceleration patterns for the different activities. Further analysis is needed to examine inter-subject variability and determine whether or not a specific activity has a recognizable acceleration signature.

INTRODUCTION

In the assessment of human performance, there are many physiological and biomechanical variables that may be considered for measurement. One parameter that can be measured with currently available technology is acceleration. It has been shown that metabolic energy cost can be accurately estimated from whole body acceleration for level locomotion [1], but not for other activities, including household tasks and playing golf [2]. However, it may be possible to differentiate specific tasks from an acceleration profile of the body motion, and after calibration and including other information such as heart rate, estimate the energy cost for a specific task.

In this study, upper body acceleration was recorded for a set of well-defined activities. Preliminary analysis to differentiate the activities, based on the acceleration records, is reported

EXPERIMENTAL PROCEDURE

A human trial to collect upper body acceleration data for a set of specific tasks was run in December 2001. Thirteen male subjects participated in the study. The average age, height and mass of the subjects was 21.8±2.6 years, 177.8±4.2 cm and 76.4±6.4 kg respectively Each subject signed an informed consent form. Prior to testing, each subject's fitness level was assessed and maximum $\dot{V}O_2$ was estimated.

The testing consisted of two regimens: battle order (BO) testing and marching order (MO) testing. In BO testing, a triaxial accelerometer (Crossbow model CXL10LP3) was affixed at approximately the middle of the sternum. The accelerometer was mounted such that the X-axis was oriented left-right (positive to the right); the Y-axis was oriented vertically (positive upwards) and the Z-axis was oriented front-to-back (positive towards the back). The accelerometer was connected to an Embla data recorder[1], via a hardware interface. The data collection instrumentation was carried in a small backpack with a total weight of approximately 4 kg. Subjects were equipped with a military issue tactical assault vest (TAV), which weighed 4.5 kg, and helmet, and a model rifle identical in weight and size to rifles used by the Canadian Armed Forces. The purpose of the BO testing was to assess the integrity of the data collection instrumentation and to record an initial set of upper body accelerations. In MO testing, subjects were asked to carry one of two large backpacks, containing either a 15.7 kg (L) load; 24.455 kg (M) load or a 34.3 kg (H) load. A second accelerometer was fixed inside the backpack to the centre of the framesheet. MO testing was carried out over two sessions, with a minimum of 45 hours rest between trials. On day 1, subjects carried all three loads, in random order, in one of the two packs; on day 2 subjects carried all three loads, in random order, in the second pack. The purpose of the MO testing was to assess upper body acceleration for the three load conditions; to look for variations in the acceleration profiles over time; and to investigate the relative motion between the backpack and the wearer.

In each test regimen, subjects were asked to complete the standardized test circuit shown in Figure 1. At the beginning of each test, the subject ran (BO testing) or walked (MO testing) around the perimeter of the circuit. At the end of the run/walk, the subject was required to pass through the START position and then proceed to task 1 – balance beam and boulder hop. The subject was instructed to perform the task twice and then run/walk once around the perimeter. This was repeated for task 2 – over-under and fence climb (down and back), task 3 – shuttle run and up-down ramp, and task 4 – sidehill ramp. In the BO testing, a 20-m leopard crawl was added to the end of the circuit. In addition to the acceleration data, the subject's heart rate and the elapsed time were recorded each time the subject passed START.

[1] Manufactured by Flaga[hf], Reykavik, Iceland.

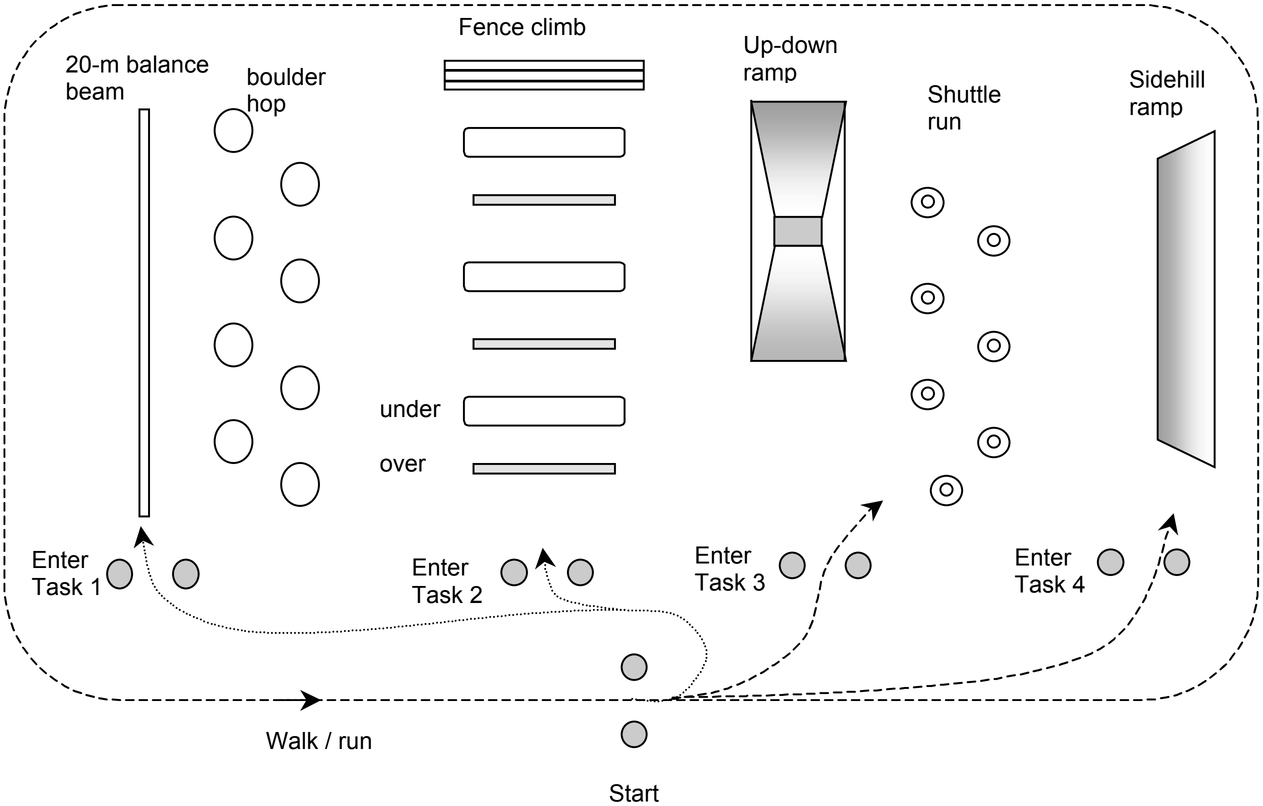

Figure 1: Standardized test circuit.

RESULTS AND PRELIMINARY DATA ANALYSIS

A full set of acceleration data was obtained for three BO trials and ten MO trials, involving six subjects. A preliminary analysis of one set of data (1BO) has been done. Representative acceleration curves for a running and a balance beam task, for the X-, Y- and Z-axes, are shown in Figure 2. Offsets for each of the curves in Figure 2 are given in Table I.

Table I

Run #1	**Offset**
X	−6.76 mV
Y	−184 mV
Z	59.2 mV
Balance beam #1	
X	0.415 mV
Y	−163 mV
Z	81 mV

The relative contribution of the X-, Y- and Z-axis signals was determined by calculating the mean square value per s for a 5-s signal segment from each task. (In the case of the up-down ramp, the task was completed in 4-s, thus the entire record was used.) This was done for 5 running, 2 balance beam, 2 boulder hop, 2 over-under, 2 shuttle run, 2 up-down, 1 sidehill ramp and 2 leopard crawl tasks. The mean of the data was subtracted before the mean square value was calculated to remove the gravity component. A plot of the mean square values for one instance of each task is shown in Figure 3(a). The pattern of mean square values in the X-, Y- and Z-axes is consistent for all trials of the same task, except in the case of the leopard crawl. Because the mean square values for the balance beam and leopard crawl tasks are considerably lower than those for the other tasks, mean square values for both samples of these tasks are shown in Figure 3(b).

DISCUSSION

One important issue in recording acceleration is the effect of gravity. A 1g acceleration due to gravity will be detected by one or more axes of the accelerometer, depending on its the orientation in the gravitational field. The calibrated sensitivity for each axis of the Crossbow accelerometer used in this study is: X-: 197 mV/g; Y-: 202 mV/g and Z-: 202 mV/g.

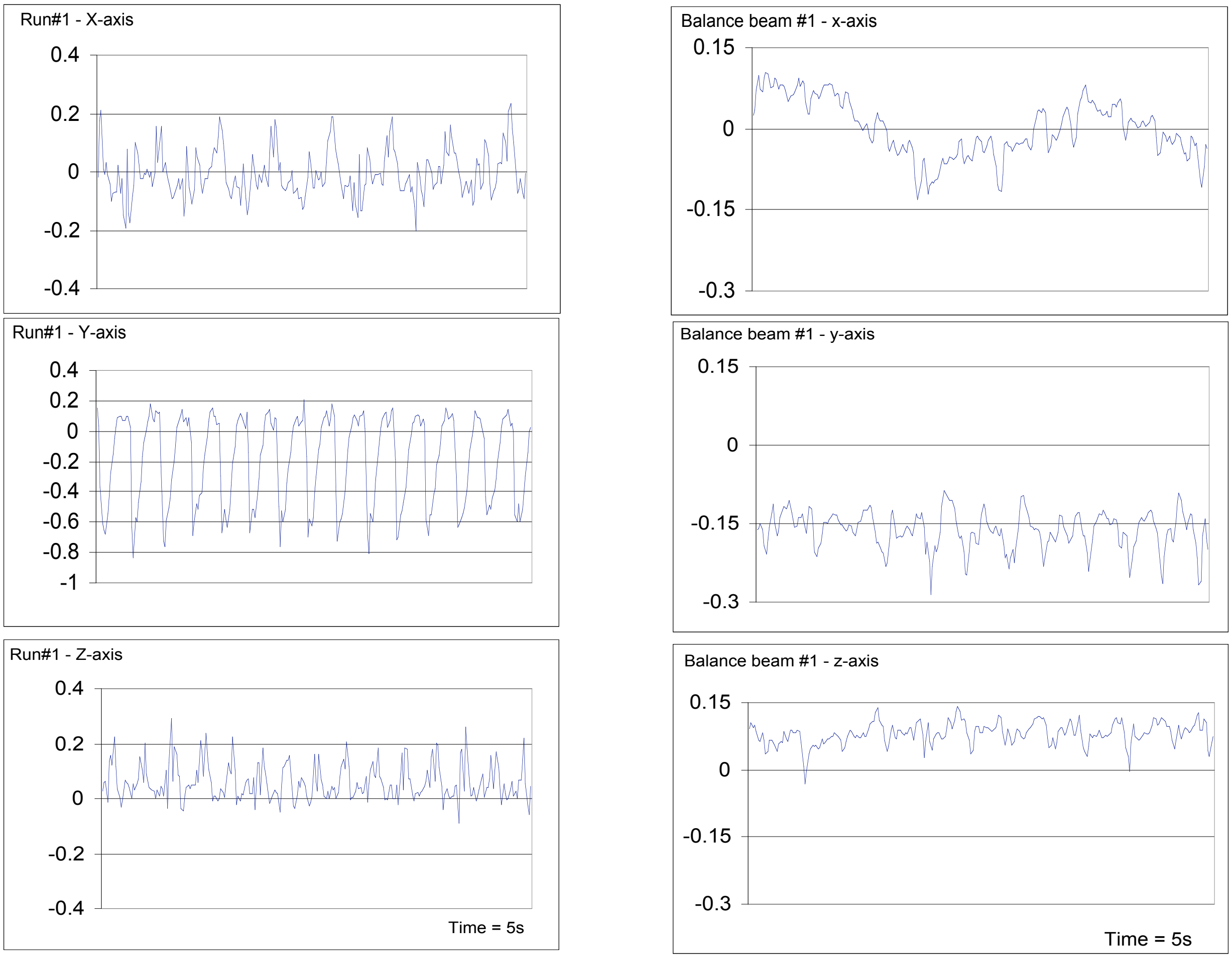

Figure 2: Accelerometer data for two tasks: running (left) and traversing the balance beam (right). The y-axis scale is accelerometer output in volts (note the scale for the accelerומenterY-axis for run#1 is different from the X- and Z-axis scales). The x-axis is time and the total time for each plot is 5s. X-axis represents side-to-side acceleration; Y-axis represents up-down acceleration and Z-axis represents forward-backward acceleration. Data are from trial 1BO.

(a) (b)

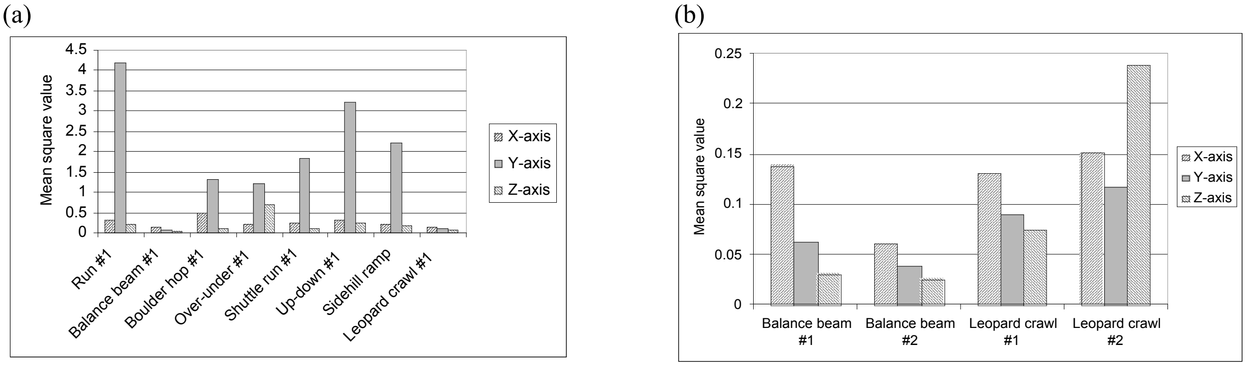

Figure 3: (a) Mean square values for one sample of each task; (b) mean square values for two samples of the balance beam and leopard crawl tasks.

From Table I, it can be seen that there are non-zero offsets on the Y- and Z-axes for the given tasks (running and balance beam). These offsets are due to the gravity vector, which is directed strictly downwards. If the accelerometer is tilted slightly backwards, the gravity vector will appear as a negative offset on the Y-axis and a positive offset on the Z-axis.

Visual inspection of the accelerometer data revealed that there are distinctive patterns for the different tasks of the standardized circuit. This is true for all recorded data files, but the discussion will focus on the 1BO subject data.

For the running task, the pattern of acceleration on the Y-axis is typical of the vertical sinusoidal pattern associated with gait. The predominant frequency in the signal is the step frequency, in this case approximately 3 cycles/s. Although the X-axis data is somewhat noisier, a predominant frequency of approximately 1.5 cycles/s is apparent. This is a reflection of the shift of the body's centre of gravity to be over the foot which is planted on the ground. The predominant frequency in the Z-axis data is again 3 cycles/s. This reflects the slight burst of acceleration which occurs with each forward step. (See Fig. 2(a)) The regular pattern of vertical acceleration associated with gait, is also apparent in the records for the shuttle run, the up-down ramp and the sidehill ramp, where the principle activity is walking or running upright.

The vertical or Y-axis pattern is altered in the balance beam, boulder hop, over-under and leopard crawl tasks, and in each case, the X- and Z- signals also show distinctive differences. For example, although the balance beam task involves walking upright, the vertical displacement is reduced in order to maintain balance. X-axis motion is significantly altered, showing a pattern of long-lasting side-to-side leans. The forward or Z-axis acceleration is decreased indicating a slower velocity with respect to running. (See Fig. 2(b))

Fig. 3(a) shows the relative mean square value per second of acceleration in the X-, Y- and Z-directions for each of the eight tasks. The same pattern of relative contribution was obtained for the other samples of each task, except the leopard crawl. The activities which principally involve walking or running upright, i.e. running, shuttle run, up-down ramp, and sidehill ramp, exhibit large vertical contributions and very small contributions on the other axes. The relative Y-axis contribution is decreased in the activities which require some agility (shuttle run and sidehill ramp) with respect to the mobility activities (running and up-down ramp). In the boulder hop and over-under activities, the vertical contribution still dominates, however in the boulder hop there is increased side-to-side movement and in the over-under task, there is increased forward-backwards movement. This is understandable, since the boulder hop involves lateral jumps onto the next "boulder" and the over-under task involves bending and straightening at the waist in order to go under and over the obstacles. In the balance beam task, acceleration on all axes is quite low and the greatest contribution is in the side-to-side (X-) direction. This is consistent with trying to maintain balance on a narrow beam. The leopard crawl is the most variable activity. In this case, the Y-axis represents forward crawling motion; X- represents side-to-side motion and Z- represents up-down movement of the upper body. The two samples were taken from early and late in the leopard crawl, and the change in relative contribution may be due to a refinement in the crawling technique or to fatigue.

CONCLUSIONS

Upper body acceleration profiles were recorded as subjects performed well-defined tasks in a standardized test circuit. Preliminary analysis of the data indicates that it is possible to separate some tasks based on the acceleration characteristics. Future data analysis will concentrate on looking at the relative contributions of accelerations on the X-, Y- and Z-axes for all subjects and examining inter-subject variability, and analysing the frequency content of the recorded signals.

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