Ergonomics and human water carrying

Ben Page, UK

THE SIMPLEST AIM of many water projects is to reduce the distance that people carry water because that task is tiring, time consuming and has negative long term effects on health. However, there are places where the point of water collection cannot be brought closer to the user. In these circumstances it is necessary to focus attention onto the carrying task itself. Ideally in such situations humans should not have to carry the whole burden of the water but should use simple wheeled devices or animal haulage. However, these may not always be available in which case humans will be left carrying water in the traditional way: in some kind of container, supported on some part of the body.

The aim of this paper is to describe a set of laboratory experiments comparing water carrying devices and to set out a simple methodology for further field studies. First, however, the general principles of good carrying will be established.

General principles of good carrying

Physiologists and ergonomists have been studying the way people carry things since the middle of the last century. They have looked at a variety of jobs (soldiers, factory workers, waiters and porters) and established the main variables to be considered. These can be separated into three categories. Firstly, those relating to the task (the weight of the load, the distance carried, the speed and duration of the journey, the type of terrain covered and the gradient). Secondly, those relating to the worker (age, gender, nutritional intake, size, fitness and training) and thirdly the type of carrying device used. These different variables have been studied at length examining the metabolic cost to, and subjective preferences of, different workers engaged in different tasks.

From these studies the following list of good carrying principles can be gleaned:

- Keep the load close to the trunk both for stability and because it minimises the change in the centre of gravity and so minimises the muscular action necessary to balance.
- Maximise the use of large muscle groups and spread the load between muscle groups.
- Allow arms and legs free movement; the gait should be as normal as possible.
- Minimise any inhibition of ventilation or constriction of the chest.
- As far as possible the load should be distributed symmetrically, to minimise muscular work keeping the body vertical.
- Maximise the use of those points of contact (such as the hips) which are less sensitive to the pressure of belts and straps.
- Distribute the load across as wide an area as possible at the points of contact. Eliminate fabric wrinkles and chafing points.
- Minimise static muscle effort (such as supporting the load with a hand) as this can be particularly tiring.

A laboratory comparison of different water carrying devices

With these principles in mind three water carrying devices were designed, constructed and compared experimentally with a round earthenware Tigrayan water pot carried in the traditional way (low on the back, supported across the chest by a rope). The devices were a wooden backframe (a modernised chee-geh) holding a plastic water container; leather webbing strapping the water container to the back, and a uPVC plastic pipe frame frontal yoke from which two water sacks were hung. The volumes of water were all identical. Though clearly the devices were different weights. A no-load control was also used in the experiments.

Four healthy young British females undertook five twenty-five minute step tests at a self-selected speed over a period of five days, using one device each day selected in a random order.

The first aspect of the test looked at the different metabolic costs of the different devices. The number of steps each subject took per minute was recorded as the speed. The pulse was also recorded during the tests, and this was converted into a figure for oxygen consumption based on the subject's individual relationship between the two which had been calculated before the experiments began. A uniform distance climbed was then set at 100m so that the oxygen consumption could be compared between the different carrying devices, and this comparison was also corrected for subject bodyweight. The test showed a statistically significant improvement for all three new devices when compared to the Tigrayan Pot. That is to say: for the same task more oxygen was used when carrying the pot. Most of this can be explained by the extra weight of the pot, but it also contradicts many other principles of carrying. The second aspect of the experiments looked at the subjective preferences of the individuals for the different devices. Various standard scales were used during the step tests to assertion the subjects perceived exertion (Borg's scale) and specific body pains (Corlett and Bishop's Bodymap) and different points during the test. The results from these tests were not statistically significant but the pattern matched that of the metabolic cost studies in that a clear improvement can be seen between the three new devices and the Tigrayan pot.

Finally the subjects pace length and gait was measured after the step test using each device. This revealed that the pace and gait were significantly abnormal when using the Tigrayan pot and Frontal yoke, which is indicative of an unstable and awkward load.

In conclusion the experiments showed that it is potentially possible to improve on existing carrying techniques by building devices which accord more carefully with the principles of good carrying and which weigh less. Whilst it is impossible to differentiate statistically between the three new devices the extra stability afforded by the backframe seems to have offset the extra weight. The advantage of the yoke is that it distributes the weight symmetrically but the materials were weak and the device was unstable. The flexibility of the pipe which some authors have proposed is advantageous since it acts as a compliant suspension system, proved to be inconvenient in this case.

Table 1. Mean differences between four carrying devices for metabolic cost, subjective preference and pace (standard deviations in brackets)

	Back-frame	*Back-strap*	*Frontal Yoke*	*Tigrayan Pot*	*Control*
Pulse (Beats min.)	142.9 (9.9)	143.1 (6.3)	147.1 (12.9)	146.1 (11.0)	123.0 (7.3)
Speed (Steps/ min.)	18.6 (1.3)	17.7 (1.7)	17.6 (1.1)	14.0 (1.9)	22.0 (2.1)
0_2 cost	0.72 (0.06)	0.77 (0.07)	0.80 (0.02)	0.95 (0.15)	0.47 (0.08)
Perc. Exert.	13.7 (1.3)	14.6 (2.6)	15.4 (1.0)	16.4 (0.8)	10.9 (1.8)
Pain	11.3 (2.9)	25.8 (7.9)	23.3 (8.8)	31.5 (14.0)	-
Pace (mm)	350 (15.6)	341 (42.5)	282 (72.8)	270 (63.9)	353 (17.0)

Note: The 0_2 cost is measured in litres of oxygen consumed during a 100m climb per kilogramme bodyweight

A field methodology

One of the major weaknesses of this laboratory study is that the English subjects are not an effective analogy for real water carriers from around the world. It is necessary, therefore to repeat the experiments in the field. The only equipment used in the laboratory that would not be suitable for field work is the bicycle ergometer and oxygen mask that was used to find the individual relationship between oxygen consumption and pulse for each subject. This information can be ascertained using step tests and data on bodyweights and monographs published in various work physiology textbooks (e.g. Astrand and Rodahl, 1971). Alternatively formulae have been published (Pandolf, 1979) which allow you to calculate oxygen consumption from data on the task (length, speed, grade, load weight etc).

An appropriate sample size would be selected and the time taken for them to perform the daily water carrying task with different carrying devices over a period of days could be measured. Since the journey is fixed speed will be the only variable. There are problems with self-selected speed as the key variable, for example some people speed up when they are in pain which would give a misleading result. The subjective preference tests should also be repeated. The main difficulty - anticipated in this is the influence of past experience, which might mean that one device appears to stand out not because it is better but because it is what people are used to.

Discussion

It is important to emphasize that improving the way that people carry water is a far less satisfactory strategy than improving the actual task by bringing the point of water collection closer to the user. Nevertheless water is still carried by humans in many different settings around the world and an ergonomic examination of this task is, therefore, worthwhile. There is currently a very healthy respect for indigenous knowledge, and there is usually a reason why the people in a certain place carry water the way they do. Furthermore, the most common way to carry water around the world is on the head which is a very effective way of carrying things. Having made these caveats it does however, seem sensible to at least consider the technical knowledge derived from studies by ergonomists working in different contexts such as rucksack design to see if improvements could not be made in water carrying devices.

There is, of course, a huge gulf between identifying a potential improvement in a device and the relevant community adopting that technology and changing the way that they have been carrying out the water carrying task since childhood. Where there is an easy improvement to be made, communities have very often; made it already anyway (for example using plastic containers which are lighter than clay pots). So, even though the experiments that would test devices are relatively straightforward the application of any changes deriving from their results are less so.