

# Aviation Medicine

## Acceleration

### II: Short duration acceleration

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Acceleration may be of long or short duration. Though the distinction is arbitrary the effects of the two are different. Long duration acceleration produces physiological changes (see article 14 May, p 1557) whereas the effects of short duration acceleration are pathological and due to injury.

Abrupt decelerations commonly occur in accidents, whereas abrupt accelerations are more usual in military procedures—for example, ejection from aircraft. Both produce effects that depend on the mechanical strength of the body tissues. These effects have been investigated experimentally by the use of test rigs which produce controlled impacts. Because experiments on human volunteers must, however, be stopped before irreversible injury occurs much information depends on the investigation of accidents or on studies of animals and anthropometric dummies. Accurately measuring the accelerations is complicated and, ideally, triaxial linear and angular accelerometers should be used. In addition, the different densities and dynamic characteristics of the tissues imply that measured accelerations may differ greatly between various parts of the body. These factors, together with a wide range of individual variation and the importance of other variables such as body restraint, mean that tolerance limits should be interpreted with care.

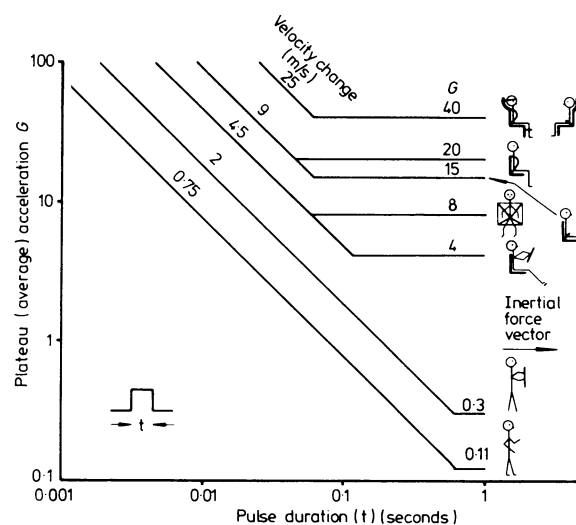
#### Assessing tolerance to impact

The criteria used to define tolerance clearly depend on the circumstances of the impact. For example, at one extreme survival after an aircraft crash—even with serious injury—would be acceptable, while at the other any injury would be unacceptable—for example, in a decision on the maximum force that an escalator may impart to a passenger's foot. Tolerance will also be affected if the impact is directed towards a particular area of the body. Thus a kick in the buttock is less damaging than an equivalent blow to the nape of the neck. In aviation medical research on impact, however, the prime concern is with the response of the whole body.

The injury potential of an impact is determined particularly by the induced velocity change so that as the duration of the acceleration is decreased higher peak acceleration levels may be tolerated.<sup>1</sup> This explains why in a forward facing impact ( $-G_x$ ) with adequate restraint of the upper half of the body tolerance is reduced from 45  $G$  for a duration of 0.1 s to 25  $G$  for a duration

of 0.2 s.<sup>2</sup> Short duration accelerations are also complicated by the rate of onset of  $G$  (jolt), because a higher jolt may lead to a dynamic overshoot with resultant increases in local forces. For example, Stapp found that a peak acceleration of about  $-38.6 G_x$  of 0.28 s duration produced no signs of shock when the jolt was 314  $G_s^{-1}$ , but at a peak of  $-38.5 G_x$  for 0.16 s severe shock was produced at a jolt of 1315  $G_s^{-1}$ .<sup>3</sup> In a rearward-facing impact ( $+G_x$ ) one of Stapp's group managed to survive a record voluntary insult of  $+40 G_x$  for 0.04 s at a jolt of 2139  $G_s^{-1}$ .<sup>3</sup> Thus body orientation appears to have an appreciable influence on tolerance because such an impact would not have been tolerable in a forward facing seat.

The importance of body orientation and restraint on human tolerance to horizontal impacts is outlined in the figure. When



Human tolerance to horizontal impact in attitudes and restraints indicated by the matchstick figures. The logarithm of acceleration has been plotted against the logarithm of the duration of the acceleration pulse, which has been assumed to be rectangular. (Though most impact acceleration pulses are shaped like an inverted V or U, a rectangular form is an acceptable compromise.) Below a certain pulse duration tolerance is determined by velocity change but beyond this point acceleration level ( $G$  levels on right of graph) becomes critical.

an upright subject is unrestrained tolerance—as defined by forward motion—is very low and depends on the subject's ability to maintain posture by muscular effort. Tolerance is increased in this orientation if a suitable immovable object can be gripped but it remains well below that in subjects supported by a seat. By bracing himself against the steering wheel an unrestrained driver may prevent forward motion up to a level of  $-4 G_x$ .

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Tolerance may be further improved only by applying passive restraint over as large an area as possible or to a portion of the body well adapted to tolerating high local pressure such as bone.

### Preventing injury

The simplest form of restraint, as worn by airline passengers, is a lap strap, which when correctly positioned should lie over the anterior superior spines of the pelvis. Though tolerance is increased the body may jack-knife over the belt so that the subject strikes structures in front of him. Indeed, deaths have occurred at otherwise survivable levels of impact simply because the head has struck sharp forward structures. In addition, submarining (rotation of the pelvis under the strap) may occur and increase the risk of injury to the abdominal organs and lumbar spine because of the high local loads. Jack-knifing may be eliminated by adding upper torso restraint to the lap strap, but submarining may be effectively overcome only by adding a negative G strap that runs between the legs to connect the centre of the strap to the seat.

Increasing the area over which the decelerative force is applied improves tolerance by reducing the load per unit area. This may be achieved by increasing restraint or more effectively by using a rearward facing seat. Such a seat with a lap restraint to prevent the subject from rebounding out of it may increase tolerance to levels only seen in forward facing impacts ( $-G_x$ ) when the head, arms, and legs are restrained as well as the upper half of the body.<sup>1-4</sup> Because of the higher loading on the seat back the seat and its floor attachments need to be strengthened.

For the past 30 years both the Royal Air Force and the United States Air Force have fitted only rearward facing seats in their transport aircraft, which has improved survival in accidents.<sup>5</sup> This idea has not been adopted by commercial airlines because of increased cost and weight and possible consumer rejection. Recently, however, stronger seats have been developed without imposing weight penalties, and passengers would probably not object to rearward facing seats.<sup>5</sup>

Lateral accelerations ( $G_y$ ) are usually less well tolerated than those in the x axis because neck injury may occur at quite low acceleration loads. If the head is fully restrained tolerance levels are similar in both axes.<sup>1-6</sup>

Aviation medical interest in short duration vertical accelerations was stimulated by the need for rapid escape from military aircraft. This is achieved by expelling the man on his seat by

explosive charges. The major factor limiting the acceleration profile imposed by the ejection seat is overloading of the spine with resultant compression fracture, most commonly of T12 and L1, where the cross sectional area is smallest.<sup>7</sup> Various degrees of spinal damage occur in up to half of ejectees, but these are acceptable when the alternative is to remain within a doomed aircraft.<sup>8</sup> Spinal injury may be reduced by engineering factors such as a reduction in jolt. This has been achieved by using multiple small explosive charges rather than larger ones and rocket motors to extend the time over which the force is applied.

In the final analysis the problem of improving tolerance to short duration accelerations has to be solved by the engineer with the knowledge of human limits and injury mechanisms gained by acceleration physiologists and pathologists.

Next week's article will cover the role of the special senses in flying an aircraft and how they may be impaired by the effects of flight.

We thank Air Commodore P Howard, commandant of the RAF Institute of Aviation Medicine, and Group Captain D Glaister for their constructive advice and help in the preparation of this manuscript. The figure is reproduced by permission of Group Captain D Glaister.

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*A woman of 33 had a hysterectomy two years ago for endometriosis. Her uterus was stuck to the pelvic colon. Since then she has had a definite cycle of quite severe abdominal trouble coinciding with what would have been the first day of her period. Her abdomen became hard, she was nauseated, and she had bad headaches with blurred vision. These symptoms would take a week to go. Eventually she was given norgestrol (Microgynon 30), which she takes continuously. Her trouble has gone, but is it safe to take this hormone continuously without any break?*

Cyclical ovarian activity continues after hysterectomy,<sup>1</sup> and if this patient's ovaries were conserved at operation two years ago it is possible that residual endometriosis continued to cause monthly abdominal pain. Her headaches and blurred vision may have been a reaction to this pain, or may more probably have been persistent symptoms of premenstrual tension, which can also continue after hysterectomy.<sup>1</sup> Cyclical ovarian activity is abolished by a combined oral contraceptive pill such as Microgynon 30 (which contains levonorgestrel and ethinyloestradiol), and the pill can cure endometriosis—though a high dose regimen of two or three tablets daily, taken continuously, may be required.<sup>2</sup> The pill may also improve the premenstrual syndrome. If this patient's symptoms are attributed to endometriosis the treatment should be continued for at least six months after her symptoms have disappeared: she may then stop treatment and see if her symptoms return. If they do continuous treatment may be restarted, observing the usual contraindications

and warnings regarding the pill<sup>3</sup>—for example, her weight, smoking habits, and blood pressure should be checked. Side effects are not a problem when the pill is used in a three month cycle by normal women,<sup>4</sup> and there is no evidence that after hysterectomy continuous use of the pill is any more dangerous than cyclical treatment.—JAMES OWEN DRIFE, senior lecturer in obstetrics and gynaecology, Leicester.

<sup>1</sup> Backstrom CT, Boyle H, Baird DT. Persistence of symptoms of premenstrual tension in hysterectomised women. *Br J Obstet Gynaecol* 1981;88:530-6.

<sup>2</sup> Hammond CB, Haney AF. Conservative treatment of endometriosis. 1978. *Fertil Steril* 1978;30:497-509.

<sup>3</sup> Andrews WC. Oral contraception. *Clin Obstet Gynecol* 1979;6:3-26.

<sup>4</sup> Loudon NB, Foxwell M, Potts DM, Guild AL, Short RV. Acceptability of an oral contraceptive that reduces the frequency of menstruation: the tri-cycle pill regimen. *Br Med J* 1977;iii:487-90.

*Might accidental spilling or spraying of BCG vaccine during mass vaccination of schoolchildren in an enclosed environment lead to them acquiring pulmonary tuberculosis through inhalation of vaccine droplets?*

BCG may cause generalised lesions in immune compromised hosts, but pulmonary lesions in healthy schoolchildren as a result of accidental inhalation of droplets may be discounted. So far as I am able to ascertain no such problem has ever arisen.—J MORRISON-SMITH, honorary consultant physician, Birmingham.