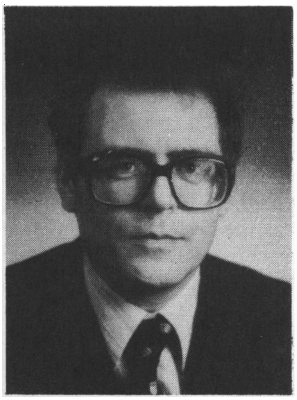
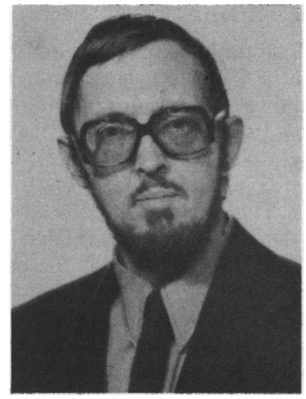
Brit. J. Sports Med. - Vol. 15, No. 3, September 1981, pp, 151-158



A. Hammer

Ann-Louise Schwartzbach



P.-E. Paulev

TRAMPOLINE TRAINING INJURIES — ONE HUNDRED AND NINETY-FIVE CASES

A. HAMMER, MD, Ann-Louise SCHWARTZBACH, MD and P.-E. PAULEV, MD, DSc

Department of Orthopaedic Surgery, Glostrup University Hospital and Institute of Medical Physiology B, University of Copenhagen

ABSTRACT

In 198 people 201 trampoline injuries are analysed. All except three adults were re-examined, following an observation period of one to four years. School children (145) represented the major part of the 195 persons re-examined. Handling the large trampoline injured 21 of the 145 school children and six children at clubs. Injuries of a permanent nature were found in 49 of the 195 who were re-examined.

The biomechanics and physiology of trampoline jumping is evaluated. Mismatch of a multitude of sensory impulses (visual, tactile, others) with impulses from the vestibular apparatus converging towards the orientation centres of the brain, may result in disorientation and then in the inadequate motor reactions actually seen at the time of the trampoline accidents.

A G-induced split second loss of consciousness is another possible explanation of the trampoline accident.

More secure procedures than trampolining as a school-sport and recreational activity are recommended.

Key Words: Trampolining. Acceleration. Black-out. Disorientation.

Correspondence and proofs:
Anders Hammer & Poul-Erik Paulev,
University of Copenhagen,
Institute of Medical Physiology B,
71 Raadmandsgade,
DK-2200 Copenhagen N,
Denmark

INTRODUCTION

Trampoline jumping has become increasingly popular during the last decades. In Denmark and other countries the growth of trampolining has been greatly increased by its introduction to the physical education lessons in schools.

The incidence of severe injuries during trampoline training has always been high (Bosco, 1970; Clarke, 1977; Schultz and Olesgaard, 1978; Steinbrück and Paeslack, 1978; US Consumer Product Safety Commission, 1973; US Consumer Product Safety Commission, 1976; and Zimmerman, 1955). Some of these accidents have killed the young victims or resulted in permanent damage and invalidity such as tetraplegia (Bosco, 1970; Clarke, 1977; Ellis, Green et al, 1960; Evans, 1979; Frykman and Hilding, 1970; Krawitz, 1978; Rapp, 1978; Steinbrück and Paeslack, 1978; US Consumer Product Safety Commission, 1973; Zimmerman, 1955).

However, precise information is not available at present, because a reliable reporting system does not exist. We do not know which trampoline activities cause most injuries, to whom most injuries occur, and which type of injury is most common.

The object of the present report is to elucidate these problems and to re-examine people previously injured during trampoline training. Our ultimate goal is to reduce the number of trampoline accidents, but without discouraging its use in a responsible manner.

MATERIAL AND METHODS

A population group of 250,000 persons (including 55,000 school children from 86 schools) on the western outskirts of Copenhagen is served by the Glostrup Amtssygehus district hospital. At the time of counting, 66 out of 86 schools, with a total of 46,000 pupils used trampolines in their physical education lessons. The majority had both types of trampoline, the large and the mini. Twenty schools with 9,000 pupils had neither.

The casualty department of the hospital serves the whole area. Over the three years 1976 to 1978 the casualty department accepted 141,347 casualties, and we have analysed all casualty reports. Trampoline training was involved in 201 injuries in 198 persons, since three children were injured twice. The children of this study were aged between six and 19 years, and the adults between 20 and 45 years at the time of accident. Nine out of the 19 adults were gymnastic teachers who were also qualified trampoline instructors. Three adults could not be contacted, so the total number of persons injured during trampoline training and re-examined by an orthopaedic surgeon (together with four colleagues) was 195 in our series. Follow up examinations were after one to four years after injury. Re-examination involved X-rays where necessary, and included an interview of the children and their parents.

None of the 195 persons were tired, sick or uncomfortable, or had any associated injury on the day of the accident. The girl/boy ratio was 0.95 for all age classes in the population of the area, as for Denmark in general (Statistical Yearbook Copenhagen, 1978). The total number of girls was 120 and there were 75 boys.

Two types of trampolines were used: The large trampoline (approximate size of frame: 5 x 3 m with a bed of 4 x 2 m), and the mini-trampoline with a horizontal or oblique bed and mostly used as a springboard.

All our patients were injured during trampoline training at one of the 66 schools or at the trampoline clubs in the area. There are no uncontrolled public trampolines in the area. Only two of the accidents took place during the summer holidays (two children at a club in July). The number of X-rays taken primarily was 148 out of 201 injuries.

SCHOOL CASUALTIES

The age distribution at the time of accident is shown in Fig. 1. The 145 injured school children consisted of 88 girls and 57 boys. Three school children were injured twice. Careful safety instructions for the trampoline training of Danish school children have been followed as strictly as possible. The trampoline training has been headed and controlled by a teacher with gymnastic and educational experience and with a special course of at least 20 hours in the trampoline training of school children. Only in 14 of the accidents had the teacher not been through the trampoline course.

The 145 school children indicated the height at the jump in which the injury occurred, which was from 0.3 to 1 m.

CLUB CASUALTIES

The age distribution is shown in Fig. 1. One girl was also injured at the school two years before, so only 34 other children are involved. Out of the 35 children 27 were girls and only eight were boys, probably reflecting the trampoline's greater popularity among girls as also indicated by the school casualties.

After leaving school most give up trampoline jumping. Only 16 adults (plus three men not re-examined) were injured in clubs — six women and 10 men. The total number injured in this group came from 12 different trampoline and gymnastic clubs.

All club members were trained by experienced

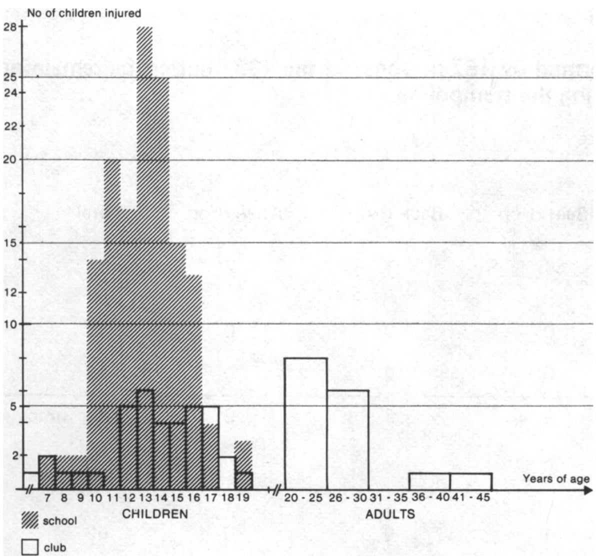


Fig. .1. Age distribution of 179 children (with 182 injuries) and 16 adult trampolinists with 16 injuries.

trampoline instructors, who had attended courses sponsored by the Danish Trampoline Association.

The 50 persons from the clubs indicated the height at the jump of injury from 0.5 to 4 m.

PHYSICS OF TRAMPOLINING AND ASTRONAUTICS

A vertical, hypothetical axis (Z) through a man standing on the earth surface is defined as positive in the upward direction (+Z). According to Newton's third law on action and reaction the man is affected by a force from the earth surface, which may be looked upon as "action", whereas his influence on the earth in the opposite direction may be considered "reaction" or popularly his "weight". A man's "body weight" is thus a "Gravity reaction" (G reaction). Since the "action" is positive upward in the Z-axis, the G-reaction becomes positive in the downward direction. As long as the man is standing on the earth he is influenced by an upward (positive) force and a downward (also positive) G-reaction in the Z-axis. Near the surface of the earth its magnitude is 9.8 metre/second^2, but small variations with latitude and elevation make it practical to use the term: $+1G_Z$.

This physical system is in accordance with Ganong's use of "positive G forces" (or "headward accelerations") as directed along the axis of the body (Z-axis) in the head to foot direction and "negative G forces" (or "feetward acceleration") directed in the foot to head direction (1979). Burton (1972) uses "positive G" for forces directed toward the feet (and counteracted by use of an anti G suit).

An immediate fall in the arterial oxygen saturation was observed in eight healthy air breathing persons upon exposure to 4.5-5 G continuous acceleration in the "human centrifuge" at Karolinska Institute (Barr, 1962; Barr, 1963).

Parabolic aircraft flight or trampoline jumping, have been used to test and select potential astronauts. Weightlessness in itself is not a problem, but when the astronauts start to move they get kinetosis (Baumgarten, 1977). Although head movements aggravate the symptoms of kinetosis, the austronauts seem to be virtually immune against stimulation of the vestibular apparatus by the so-called labyrinthe Corioli forces (Graybiel, Miller et al, 1974). This is a "spin phenomenon" in astronautics with violent, disorienting vertigo when a set of semicircular canals is suddenly "stimulated" zero, while another set is stimulated as forcefully as possible. "Mismatch" of such impulses with visual, tactile and other impulses converging towards the orientation centres of the brain, may result in disorientation (Baumgarten, 1977) and then in the inadequate motor reactions actually seen at the time of injury.

There are many other possible explanations for the injuries. Jumps with rotation may change the cerebral blood flow thus causing acute cerebral insufficiency.

RESULTS

All types of jumps are involved in the injuries (Table I). The simple feet bounce is the main culprit. Landing on the bed of the large trampoline covers more than 50% of its 107 injuries. More than 50% of the injuries following jumps from the mini-trampoline were due to a fall on the safety mattress (Table II).

The pelvis, hip and thigh regions were not damaged in any of our 195 persons, but obviously all parts of the human body can be damaged from trampolining, the cranium and spine in particular (Table III).

Of the 198 injuries, 169 occurred during jumping, and 29 while handling the trampoline (Table III). Handling the large trampoline injured 27 children, —21 at school, and of these six children had after-effects. Four of the school children and one of the club children, aged 11 to 15 years, suffered from a displaced forearm fracture, all jammed in the frame when the children were assisting in unfolding and folding the large trampoline.

Handling the mini-trampoline injured two children in school (Table III).

Only three injuries could be related to a defect in the apparatus.

Injuries of a permanent nature (i.e., after-effects) were found in 49 of the 195 persons re-examined, forty children from school, four children from clubs and five adults (Table III). The dominant after-effects were painful joint instability (ankle, knee, shoulder and wrist), permanent back pain and growth disturbances (Table IV).

Significant injuries were defined as injuries needing more than one day of treatment. They constitute approximately 40% of the 198 injuries (Table IV). The rest of the injuries were contusions and sprains.

Epiphyseal plate lesions, fractures and other bone injuries constitute 25% of the 198 injuries (Table IV).

TABLE I

Types of trampoline exercises involved in the 169 jumps performed by 167 persons. Of the 198 injuries the remaining 29 took place during handling the trampoline.

LARGE TRAMPOLINE	Somersault	Feet bounce	Stomach drop	Seat drop	Back drop	Knee drop	Total
Children School	13	32	3	4	1	2	55
Children Club	4	7	2	0	0	0	13
Adults	5	5	0	0	2	0	12
	22	44	5	4	3	2	80 jumps
MINI TRAMPOLINE							
Children School	26	42	0	1	0	0	69
Children Club	7	9	0	0	0	0	16
Adults	2	2	0	0	0	0	4
	35	53	0	1	0	0	89 jumps

TABLE II

The site of accident in relation to the trampoline for the 198 injuries in 195 persons.

	LARGE TRAMPOLINE	MINI TRAMPOLINE
On the bed	56	10
On the frame	11	18
On the mattress	0	53
On the floor	13	8
Handling	27	2
	107 injuries (104 persons)	91 injuries (91 persons)

Concussions (Table IV) from the large trampoline were partly due to a collision between knee and face and partly due to a fall with the head leading. All except two of the concussions from the mini-trampoline were due to a fall on the safety mattress head first.

Dislocations include torn menisci and ruptured ligaments. They occurred in six children (two shoulders, two elbows, one knee with a torn medial meniscus and a ruptured anterior cruciate and a ruptured medial collateral ligament, and one subluxation in the cervical spine at level 2/3) and one adult with a dislocated metacarpophalangeal joint in the left thumb combined with a ruptured radial collateral ligament.

We found 12 children with lesions of the epiphyseal plate. Seven of these children developed growth disturbances such as premature cessation of growth in one of two paired bones (radius) and cessation of growth in one area of the epiphyseal plate with continuation of growth in the remainder, leading to angulation (proximal tibia, distal humerus and phalanges). Two of the lesions of the epiphyseal plates occurred in the two children with dislocated elbows. Neither of the children needed reconstructive surgery. We did not see any avascular necrosis of the bony epiphysis (Table IV).

DISCUSSION

Biomechanics and physiology

Trampoline biomechanics (quantitating the effects of the trampoline on the human body) is only available in internal reports (Grossmann, 1974; Riehle, 1971) and in an excellent, cinematographic analysis (Vaughan, 1980).

The following is a description of a typical jump (feet bounce) based on Vaughan's report (Vaughan, 1980). At the peak of the jump all energy is potential and the vertical (Z-axis) velocity is zero. As the man falls toward the bed his velocity along the Z-axis changes from zero to –5 m/s at touch down (Fig. 2) and his kinetic energy

TABLE III

Location of the injuries and the fraction of injuries of a permanent character (after-effects) in 195 persons (with 198 injuries) during trampolining.

	Jumping		Handling		Total
Location	Large trampoline	Mini-trampoline	Large trampoline	Mini-trampoline	
Face, nose, eyes and teeth	4	8	1	0	13
Cranium and spine	18	16	0	0	34
Trunk, shoulder and upper arm	10	4	1	0	15
Elbow and lower arm	4	5	8	0	17
Wrist, hand and fingers	13	8	12	1	34
Knee, shin and calf	4	9	0	0	13
Ankle	19	19	0	0	38
Foot and toes	8	20	5	1	34
	80	89	27	2	198 injuries
After-effects	20/77	22/89	6/27	1/2	49/195 persons

TABLE IV

Number and character of serious trampoline injuries and after-effects of 195 injured persons (198 injuries).

Serious injuries	Large trampoline	Mini-trampoline
Concussion (all children)	5	8
Sutured wounds (all children)	1	7
Dislocations	3	4
Volar plate lesions	3	0
Lesion of epiphyseal plates	3	7
Greenstick fractures	4	1
Avulsions (mainly ankles)	5	7
Fractures (mainly forearms)	13	4
	37	38
		75/198 injuries
After-effects		
Recurrent dislocation (shoulder)	0	1
Growth disturbances	4	3
Permanent back pain	9	7
Footpain when walking	1	4
Painful joint instability	12	7
Scar (ugly lip)	0	1
	26	23
		49/195 persons

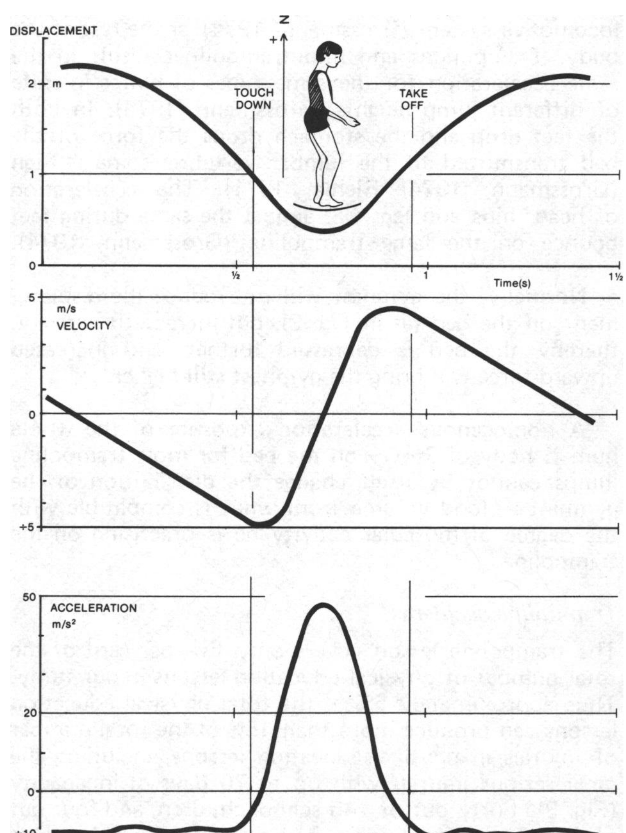


Fig. 2. Vertical displacement, velocity and acceleration (+G_Z) curves for a trampoline jump (feet bounce) performed by a 71.8 kg man (modified from Vaughan, 1980).

increases accordingly. The sum of potential and kinetic energy remains constant, while the man is in the air. In contact with the trampoline bed most of his kinetic energy is stored in the elastic elements of the trampoline in the form of strain energy, though some is dissipated as heat. The man's second jump is not as high as his first (Fig. 2). The acceleration stabilised around $-9.81\ m/s^2$ (or $+1G_Z$) before the gymnast made contact with the trampoline. The linear acceleration on the bed (Fig. 2) and the man's body mass were used to calculate the peak vertical force exerted upward by the trampoline on the man. The peak force varied between five and seven times his "body weight" (i.e., 5 to 7 G in the Z-axis or – calculated – 3500 to 5300 Newtons).

Grossmann (1974) had obtained similar results with accelerometers on 12 trampoline jumpers. He examined three large types of trampoline, the Nissen ½ inch, the Nissen ¼ inch, Eurotramp, and the Nissen minitramp. For all trampoline types, jumping types and persons, the peak acceleration varied around 6 to 7 G. The choice of trampoline does not influence the stress of the human locomotive system (Grossmann, 1974) or the rest of the body. Trampolines and mini-trampolines result in the same acceleration for the same types of jumps in spite of different jump heights (Grossmann, 1974). In both the feet drop and the stomach drops the force of the bed transmitted to the lumbar vertebral spine is high (Grossmann, 1974; Riehle, 1971). The acceleration of head, hips and legs was almost the same during feet bounce on the large trampoline (Grossmann, 1974).

Normally, the gymnast will not reduce the displacement on the bed (as in Fig. 2), but increase it actively, thereby the bed is depressed further, and increased upward force will bring the gymnast still higher.

A homogenous acceleration exposure of the whole human body of 7 $+G_Z$ on the bed for most trampoline jumps cannot by itself change the distribution of the gymnast's blood volume from what is compatible with the degree of muscular activity he is practising on the trampoline.

Trampoline accidents

The trampoline lesson covers only five per cent of the total number of physical education lessons in our study. Thus approximately 5% of the total physical education lessons can produce more than 15% of the total number of injuries in physical education lessons, including the most serious injuries with up to 70 days of incapacity (Fig. 3). Forty out of 145 school children, and four out of 34 other club children had permanent injuries. Five out of the 16 adults had permanent injuries. This is rather a high frequency, but reasonably related to the forces involved in trampoline jumping.

Now, what could be the cause of the trampoline

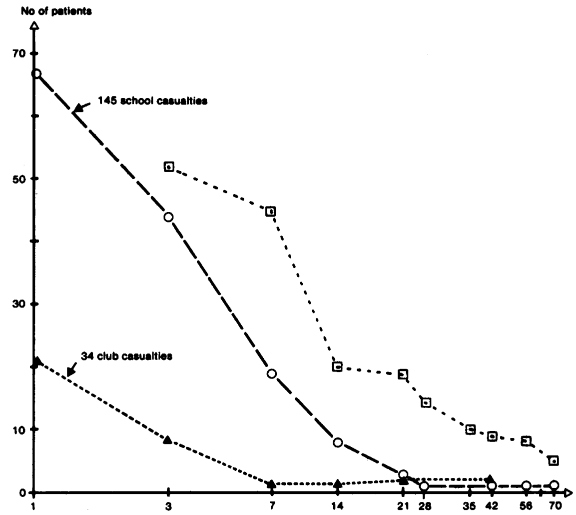


Fig. 3. The period (in days) of school absence following the trampoline injury in 145 school casualties (o) and in 35 club casualties (Δ).
The total duration of incapacity of the 180 children is shown in the upper curve.

accidents? Half of the injured children failed to recognise why the jump went wrong (on both types of trampolines). These children reported a short black-out or dizziness.

Baumgarten's hypothesis of "mismatch" of sensory impulses is compatible with the biomechanics (1977). A G-induced split-second loss of consciousness is another possibility (Whinnery and Shaffstall, 1979), which may not be recognised by the person (Whinnery and Shaffstall, 1979).

The most important difference between the bones of children and of adults is the cartilaginous epiphyseal plate, which is weaker than bone, tendons, ligaments and the fibrous joint capsule (Salter and Harris, 1963). Any lesion of the epiphyseal plate might lead to growth disturbances, even to avascular necrosis of the bony epiphysis (Bisgard and Martenson, 1937; Dale and Harris, 1958; Harris and Hobson, 1956). Shearing and avulsion forces might lead to a lesion of the epiphyseal plate (Salter and Harris, 1963).

Trampolining increases the height from which the child falls. The energy, which has to be absorbed by his bones, results in lesions, especially of the epiphyseal plate.

The force projected up through the spinal column from the bed of the large trampoline can result in permanent X-ray findings such as degenerative changes in the intervertebral discs and disturbances in the ossification of the vertebral bodies causing lower back pain (Riehle, 1971; von Schwerdtner and Fohler, 1974). This is found without a specific accident — just as a consequence of jumping, an overuse injury (Riehle, 1971).

Serious injuries to the head and spine are more frequent with the trampoline than with many other sports (Zimmerman, 1955). Injuries often happen during advanced exercises on the trampoline and exercises without the supervision of a trampoline instructor (Zimmerman, 1955). Our study showed that serious accidents also occur during simple exercises under careful supervision.

The line between transient discomfort during trampolining and neurological disaster at times is thin. A fatal outcome is possible in a skilled person even with supervision (Ellis, Green et al, 1960). The most dangerous part of the large trampoline remains the centre of the bed (Ellis, Green et al, 1960) — a fact also substantiated in our study.

In the USA the National Electronic Injury Surveillance System (NEISS) based on daily reports from 119 hospital emergency rooms across the country estimates that each year approximately 19,000 people are injured from trampolining (US Consumer Product Safety Commission, 1976). In 1973 another NEISS survey showed that an estimated 50 cases of severe injury to the spinal cord occurred yearly (US Consumer Product Safety Commission, 1973). The best of safety mattresses do not provide substantial protection from the mini-trampoline accident that leads to quadriplegia (AAHPER, 1978).

In Germany more than 7,000 school children are reputedly injured from trampolining annually (Steinbrück and Paeslack, 1978). In the 10 years from 1968 to 1978, 25 cases of severe trauma with quadriplegia appeared with increasing frequency (Steinbrück and Paeslack, 1978). Among these were nine children aged 14 to 19. Twelve of the 25 persons died.

Frykman and Hilding (1970) in Sweden described three cases of severe cervical spine injuries in elite trampolinists and suggested a ban on trampolining in school lessons.

American children could not improve their cardiorespiratory fitness by trampolining as shown by the half-mile-run (Gabbard, 1980).

We support the statement from the American Academy of Pediatrics, which late in 1977, took a public position that the trampoline was posing an undue risk of serious injury and therefore warned that it should not be utilised as a competitive sport nor as an activity within physical education (AAHPER, 1978).

CONCLUSION

The large number of injuries and of severe after-effects from the use of trampolines, in spite of a very high safety level, forces us to recommend less dangerous procedures than trampolining as a school sport and as a recreational activity.

ACKNOWLEDGEMENT

Excellent assistance was provided by: Hanne Ben-Shalom, Margit Hartyani, Maj-Britt Jellingdal and Noveko Ollinger Petersen.

REFERENCES

American Alliance for Health, Physical Education and Recreation (AAHPER). Position Statements on Trampolines, 1978. "The use of trampolines and mini-tramps in physical education". J.Phys.Educ. 49: 14.

Barr, P.-O., 1962 "Hypoxemia in man induced by prolonged acceleration". Acta Physiol.Scand. 54: 128-137.

Barr, P.-O., 1963 "Pulmonary gas exchange in man as affected by prolonged gravitational stress". Acta Physiol.Scand. 58: suppl. 207.

Baumgarten R. von., 1977 "Problems of vestibular function in the weightlessness environment". Proc.Intern Union Physiol.Sci.Abstr. of Lectures and Round Tables 12: 718.

Bisgard, J. D. and Martenson, L., 1937 "Fractures in children". Surg.Gynecol.Obstet. 65: 464-474.

Bosco, J. S., 1970 "Research and fitness in gymnastics". Mod.Gymnast.12: 21-22.

Burton, A. C. Physiology and biophysics of the circulation. 2nd ed. 1972.

Clarke, K. S., 1977 "A survey of sports-related spinal cord injuries in schools and colleges, 1973-1975". J.Safety Res. 9: 140-146.

Dale, G. G. and Harris, W. R., 1958 "Prognosis of epiphyseal separation". J.Bone Joint Surg. 40-B: 116-122.

Ellis, W. G., Green, D., Holzaepfel, N. R. and Sahs, A. L., 1960 "The trampoline and serious neurological injuries". JAMA 174: 79-82.

Evans, R. F., 1979 "Tetraplegia caused by gymnastics". Br.Med.J. 2: 732.

Frykman, G. and Hilding, S., 1970 "Hop pa Studsmatta kan orsaka allvarliga skador". Läkartidningen 67: 5862-5864.

Gabbard, C., 1980 "Trampoline training and cardiorespiratory fitness among 8 and 9 year olds". J.Phys.Educ. 77: 94-95.

Ganong, W. F. Review of Medical Physiology 9th ed. 1979.

Graybiel, A., Miller, E. F. and Homick, J. L., 1974. The Proceedings of the Skylab Life Sciences Symposium. NASA Publ. TMX-58154, 1: 169-198.

Grossmann, O., 1974 "Erschütterungsmessungen Beim Trampolin- und Minitrampolin Springen". Diplomarbeit, Zürich.

Harris, W. A. and Hobson, K. W., 1956 "Histological changes in experimentally displaced upper femoral epiphysis in rabbits". J.Bone Joint Surg. 38-B: 914-921.

Krawitz, H., 1978 "Problems with the trampoline: too many cases of permanent paralysis". Pediatr.Ann. 7: 728-729.

Rapp, G F., 1978 "Safety suggestions for trampoline use". Pediatr.Ann. 7: 730-731.

Riehle, H., 1971 "Über die Beanspruchung der Wirbelsäule beim Trampolinturnen". Diplomarbeit, Deutsche Sporthochschule, Köln.

Salter, R. B. and Harris, W. R., 1963 "Injuries involving the epiphyseal plate". J.Bone Joint Surg. 45-A: 587-622.

Schultz, A. and Olesgaard, P., 1978 "Skader opstaet ved trampolinspring". Ugeskr.f.Laeg. 140: 3128-3129.

Schwerdtner, H. P. Von and Fohler, N., 1974 "Wirbelsäulenschaden beim Trampolinspringen". Sportarzt und Sportmed. 8: 182-186.

Statistical Yearbook 1978, Danmarks Statistik, Copenhagen, 1978.

Steinbrück, K. and Paeslack, V., 1978 "Trampolinspringen — ein gefährlicher Sport?" Münch.Med.Wschr. 120: 985-988.

US Consumer Product Safety Commission. Bureau of Epidemiology. "Summary analysis of trampolines". 1973 July 19.

US Consumer Product Safety Commission. Fact Sheet 85, February 1976.

Vaughan, C. L., 1980 "A kinetic analysis of basic trampoline stunts". J. of Human Movement Studies 6: 236-251.

Whinnery, J. E. and Shaffstall, R. M., 1979 "G-induced loss of consciousness". Proceedings of the United States Air Force Multidisciplinary Workshop on pilot selection and flying physical standard for the 1980's. US Air Force School of Aerospace Medicine, Brooks Air Force Base, Texas 3-5 April: 284-290.

Zimmerman, H. M., 1955 "Accident experience with trampolines". Res.Q. 27: 452-455.